Journal of Information Systems Engineering and Management
2023, 8(3)
e-ISSN: 2468-4376
https://jisem-journal.com/ **Research Article**

Preparation and Characterization of Insulating Material from Rice Husk

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ARTICLE INFO

Received: 06 Aug 2023

Revised: 14 Sept 2023

Accepted: 25 Sept 2023

ABSTRACT

The rice husk is an agricultural waste that is obtained from the milling process of paddy and approximately 22% of the weight of paddy is rice husk. The aim of this study is to investigate a composite material based on rice husk with the composition of bentonite and exfoliated graphite. The husk is converted into ash which is known as rice husk ash (RHA). The ratio of RHA with other supporting materials forms a rice husk granule (RHG). The performance of the RHG sample was analyzed by the scanning electron microscope with energy dispersive X-ray spectroscopy (SEM-EDX), thermo-gravimetric analysis (TGA), and thermal conductivity analysis. Three samples of rice husk granules with different compositions are tested. The research indicates that increasing the RHA results in desirable insulation properties and lower thermal conductivity.

Keywords: Rice Husk, Insulating Materials, Rice Husk Granules, SEM- EDX.

Introduction

The rice husk, also called rice hull, is the coating on a seed or grain of rice. It is formed from hard materials, including silica and lignin, to protect the seed during the growing season. Each kg of milled white rice results in roughly 0.2 kg of rice husk as a by-product of rice production during milling [1]. Some important physical and thermal properties of rice husk are density of about 0.735 g cm^{-3}, a loose bulk density of 0.1 g cm^{-3}, and a packed bulk density close to 0.4 g cm^{-3}. Its calorific value ranges from approximately 13,827 to 15,084 kJ kg^{-1} [2]. The thermal conductivity of rice husk is comparable to insulation materials such as asbestos and mineral wool. Common products from rice husk are: solid fuel (i.e., loose form, briquettes, and pellets), carbonized rice husk produced after burning or it can be used as a feeding material to cattle.

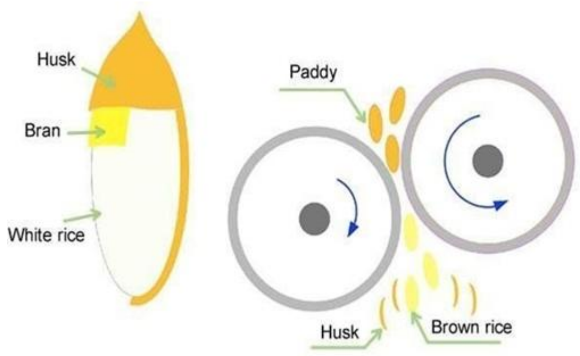

Fig 1: Formation of Rice Husk [3]

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Unique physical and chemical properties of RH, like high ash content, silica content, it can be effectively used in domestic and industrial processing. Rice husk in its loose form is mostly used for energy production. Rice husk contains about 30–50% of organic carbon and have high calorific value. It can be used to generate fuel, heat, or electricity through thermal, chemical, or bioprocesses. The energy conversion processes of rice husk are presented in a diagram in Figure 2

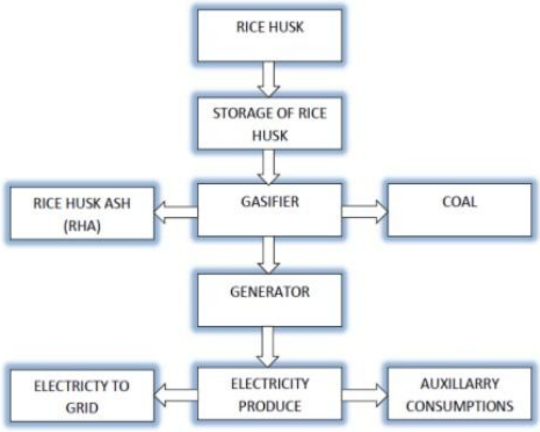

Fig 2: Energy Conversion Process from Rice Husk [4]

Many researchers have investigated composite materials made from rice husk. Dhand et. al [5] investigated the fabrication process and analyzed thermal properties of insulation board made from rice husk. Sri Haryati et al. (2017) investigated rice husk granules (RHG) with high silica content as a potential insulating material by varying the proportion of rice husk ash (RHA) with bentonite and exfoliated graphite, and reported that the sample with the highest silica content exhibited superior insulation performance, characterized by a higher onset temperature in TGA and lower thermal conductivity. Earlier, John R. Paules and William R. Curran (1991) [7] developed pelletized rice hull ash using bentonite clay and organic binders, demonstrating that such pellets could effectively insulate molten steel surfaces without generating dust or smoke, highlighting the thermal robustness of RHA-based materials. Rajendran Muthuraj et al. (2019) [8] explored biodegradable composites reinforced with agricultural by-products, including rice husk, and found that rice husk composites showed the lowest thermal conductivity (0.08 W/m·K) along with good mechanical strength and water resistance, making them promising for building insulation applications. Similarly, Basant Ashraf and Mostafa A. Radwan (2018) [9] reported that rice husk–epoxy composites possess thermal conductivity values significantly lower than conventional polyurethane foam, while also offering substantial cost benefits. In a different application, Md. Niamul Bari et al. (2022) [10] demonstrated the suitability of rice husk as a precursor for activated carbon production, achieving higher yield and improved properties at lower carbonization temperatures, thereby emphasizing the versatility of rice husk-derived materials. Furthermore, S. K. S. Hossain et al. (2018) [11] highlighted that RHA contains up to 85–95% amorphous silica and reviewed its extensive use in silicates, ceramics, catalysts, lightweight construction materials, and insulators, underscoring its potential as an alternative to conventional silica sources. Collectively, these studies confirm that rice husk and rice husk ash are promising, low-cost, and sustainable resources for developing advanced insulating and functional composite materials.

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Experimental Methodology

The preparation of rice husk–based granules is carried out through four main steps: raw material pretreatment, calcination, mixing, and testing. First, rice husk washing and drying are performed as a pretreatment process. The rice husk is washed using distilled water with the help of a magnetic stirrer to remove adhered soil, dust, and other soluble impurities (Step 1). Distilled water is used to avoid the presence of minerals and contaminants found in tap water that may influence the results. After washing, the husk is collected using a sieve and dried in a hot air oven (Type Scientific, Series 200) at 110 °C for 24 hours to remove moisture and volatile components (Step 2).

Next, the dried rice husk is calcined in a muffle furnace at 500 °C (Step 3) to convert it into rice husk ash (RHA). This calcination temperature is selected to ensure that the silica in the ash remains predominantly in the amorphous form, as crystalline silica is less reactive and undesirable for the present study. The obtained RHA is mixed with the supporting materials bentonite and exfoliated graphite, in different proportions (Step 4). Mixing is carried out using a planetary ball milling machine to achieve a homogeneous blend.

Fig 3: Steps to form RHG

Materials	Sample A (wt.%)	Sample B (wt.%)	Sample C(wt.%)
Rice Husk Ash (RHA)	85	88	90
Bentonite (B)	10	10	8.5
Exfoliated Graphite (EG)	5.0	2.0	1.5
Supporting Materials (S= B+EG)	15	12	10

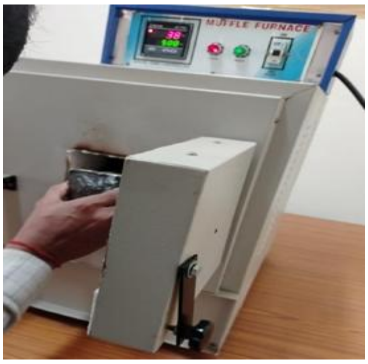
Table 1: Composition of samples

The mixture is then formed into granules and dried in an oven at temperatures ranging from 100 to 130 °C to produce rice husk granules (RHG).

Finally, the prepared samples (A, B, and C) with different compositions as shown in Table 1 are characterized to evaluate their properties. The microstructure and elemental composition are examined using scanning electron microscopy coupled with energy-dispersive X-ray spectroscopy (SEM–EDX). Thermogravimetric analysis (TGA) is performed to study the thermal stability, and thermal conductivity measurements are conducted to find the insulating performance of the samples

Step 1 (Magnetic Stirrer)

Step 2 (Vacuum oven)



Step 3 (Muffle Furnace)

Step 4 (Planetary Ball Mill)

Final Sample

Fig 4: Steps involving preparation of Samples

Characterization and Testing Procedure

The prepared samples (A, B, and C) are characterized using scanning electron microscopy with energy-dispersive X-ray spectroscopy (SEM–EDX), thermogravimetric analysis (TGA), and thermal conductivity measurements. SEM–EDX is employed to examine the surface morphology and elemental composition of the granules. The thermal stability of the samples is evaluated by TGA in accordance with ISO 11358 standards, where a small amount of sample (approximately 50 mg) is heated from ambient temperature up to 1000 °C at a controlled rate under nitrogen or air atmosphere. The continuous change in mass with temperature is recorded to identify moisture loss, decomposition of semi-volatile components, and residual ash content, thereby providing insight into the degradation behavior and upper usable temperature of the material. Thermal conductivity is

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measured using the transient hot-wire (THW) method following ASTM standards. In this method, a thin heating wire sensor is inserted into the sample, and a constant current is applied to generate heat. The resulting temperature rise, monitored through changes in the electrical resistance of the wire, is used to calculate the thermal conductivity of each sample. These combined analyses provide a comprehensive understanding of the microstructural features, thermal stability, and insulating performance of the developed rice husk granules.

Results and Discussions

SEM- EDX

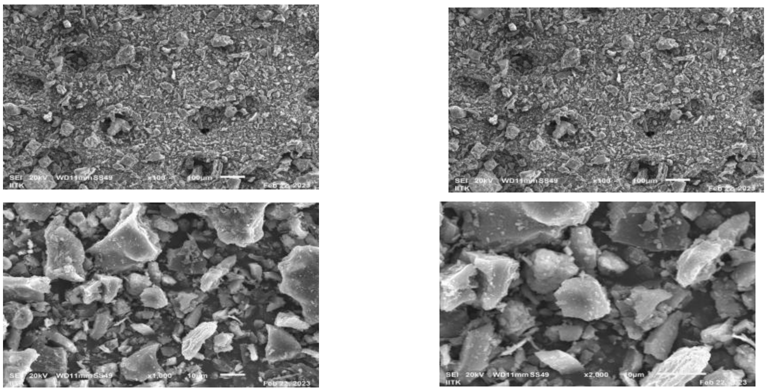

Fig 5: SEM EDX Images of Sample A in 100x, 500x, 1000x and 2000x

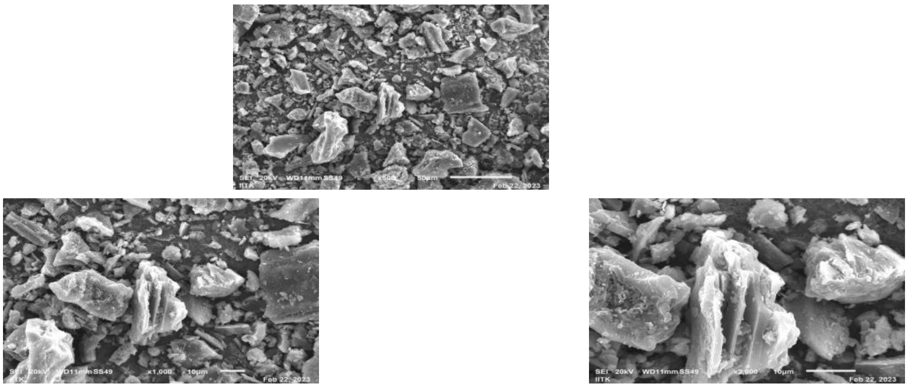

Fig 6: SEM EDX Images of Sample B in 100x, 500x, 1000x and 2000x

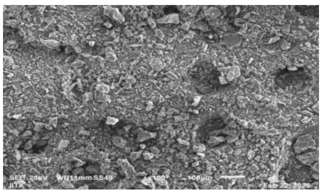

Fig 7: SEM EDX Images of Sample C in 100x, 500x, 1000x and 2000x

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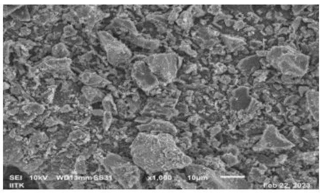

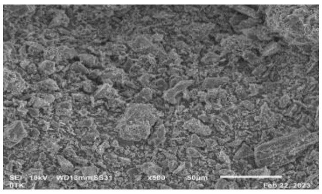

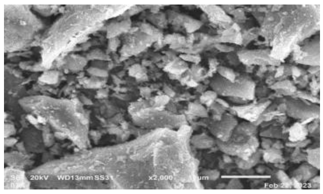

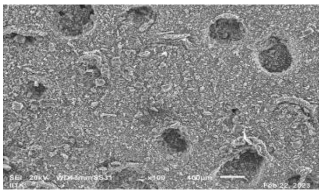

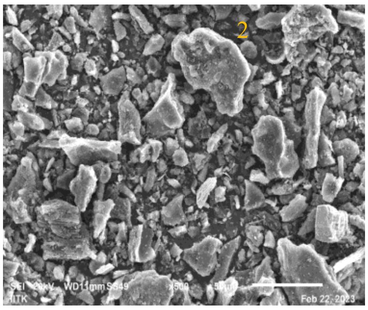

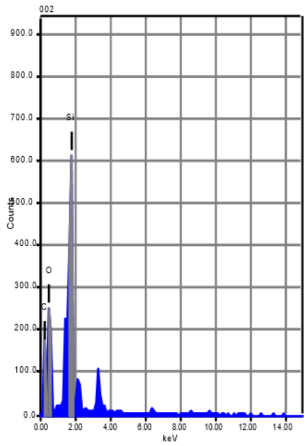

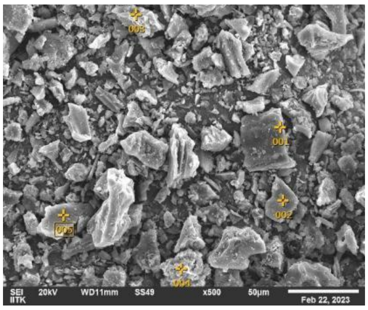

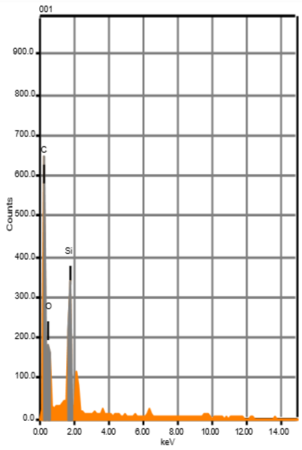

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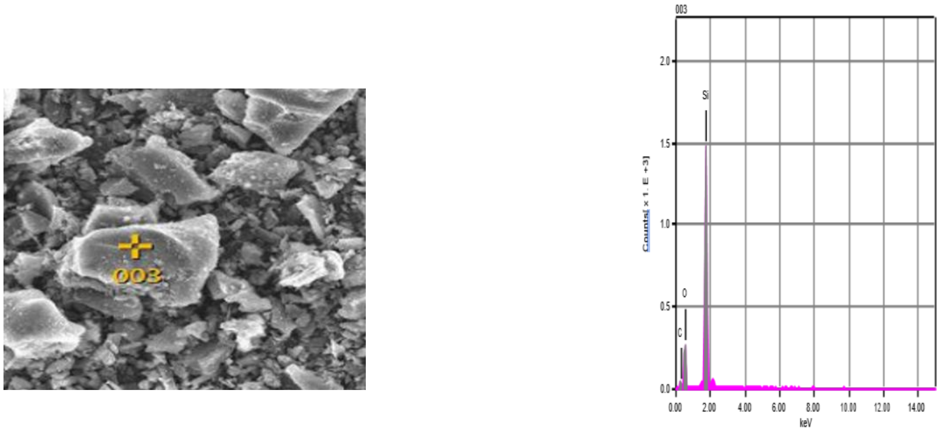

Fig 8: Components of Silica, Carbon and Oxygen in samples A, B and C, respectively.

The SEM images taken at 2000× magnification show that all three samples consist of irregular and angular particles with rough surfaces, which is typical of rice husk ash–based materials. The presence of agglomerated particles and small pores can be observed in all samples, indicating a porous structure that is favorable for thermal insulation. In sample A, the particles appear relatively coarse with uneven distribution, suggesting less uniform mixing of the constituents. Sample B shows the presence of plate-like and layered structures, which can be attributed to exfoliated graphite, along with better particle interlocking. In contrast, sample C exhibits comparatively finer particles and a more compact and homogeneous microstructure, indicating improved dispersion of RHA with the supporting materials. Overall, the SEM results suggest that increasing silica-rich RHA content leads to a denser and more uniform morphology, which is expected to contribute to better thermal insulation performance of the rice husk granules.

Thermogravimetric Analysis

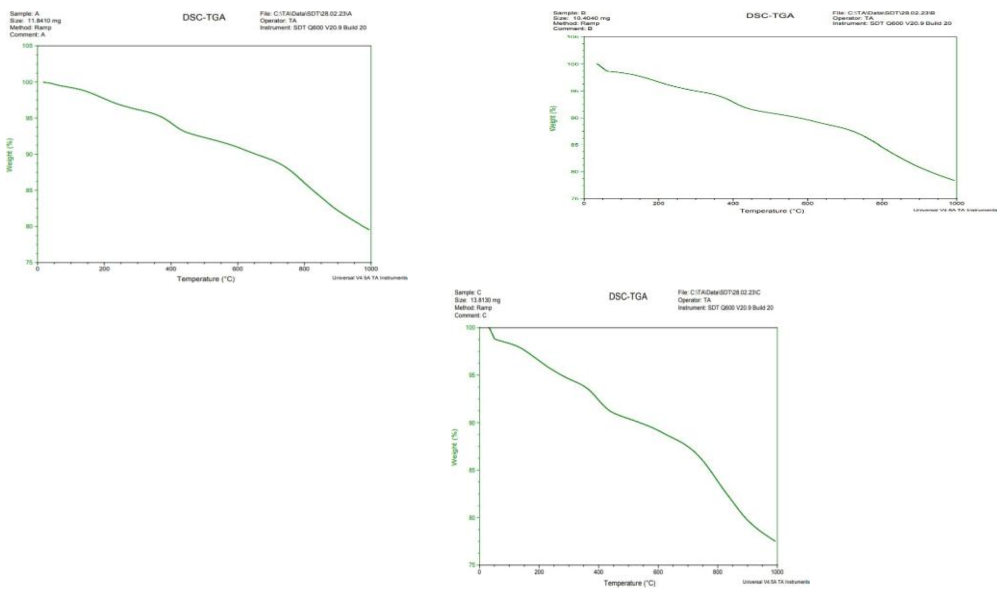

Fig 9: TGA Analysis of Sample A, B and C.

From the TGA results, it is observed that all three samples show a continuous decrease in weight as the temperature increases up to 1000 °C. Normally, a TGA curve becomes almost flat after a certain temperature, indicating that the material has reached thermal stability, known as the onset temperature. However, in the present study, none of the samples exhibit such a constant region within the tested temperature range. This means that the samples do not attain thermal stability up to 1000 °C and continue to lose mass throughout the heating process. Moreover, the TGA curves of samples A, B, and C are quite similar, suggesting that the difference in composition has only a minor effect on their thermal behavior. Therefore, it can be concluded that the prepared rice husk granules are not thermally stable up to 1000 °C and may reach stability only at temperatures higher than those considered in this work.

Thermal Conductivity

The thermal conductivity of all the samples is illustrated in table 2:

RHG samples	**Thermal conductivity** (W/m-K)
A	0.1985
B	0.1517
C	0.1119

Table 2: Thermal Conductivity of Samples

From the above table, it can be clearly seen that as the silica content increases along with the supporting materials, the thermal conductivity of the samples decreases, indicating improved insulating behavior.

Conclusions

In this study, rice husk, an abundantly available agricultural waste, was successfully utilized to develop rice husk ash–based granules with the addition of bentonite and exfoliated graphite. The experimental results show that the composition of the granules plays an important role in determining their thermal and microstructural properties. SEM–EDX analysis revealed irregular, porous, and well-distributed particles, confirming the formation of a composite structure suitable for insulation applications. The TGA results indicated continuous weight loss for all samples up to 1000 °C, suggesting that the materials do not attain thermal stability within this temperature range and may become stable only at higher temperatures. Thermal conductivity measurements demonstrated a clear decreasing trend with increasing silica (RHA) content, highlighting improved insulating behavior of the samples with higher RHA proportions.

Among the three compositions studied, the sample with the highest RHA content exhibited the lowest thermal conductivity, indicating its better potential as a thermal insulating material. Overall, the results confirm that rice husk ash, when combined with suitable supporting materials, can be converted into a low-cost and eco-friendly insulation material. This work not only provides a useful approach for value addition to agricultural waste but also contributes toward the development of sustainable materials for thermal insulation applications. Further studies may focus on improving thermal stability and exploring large-scale production for practical use.

Acknowledgement

The authors are grateful for the valuable support and contributions of the faculty and staff of IIT Kanpur for providing the necessary facilities and allowing us to conduct the experimental work in their laboratories. Their technical guidance and cooperation during the experiments are sincerely appreciated. The authors would also like to acknowledge the faculty and staff of REC Banda for their continuous encouragement and support in successfully completing this research work.

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Definitions/Abbreviations

RH	Rice Husk
RHA	Rice Husk Ash
RHG	Rice Husk Granules
TGA	Thermogravimetric Analysis
SEM	Scanning Electron Microscopy
EDX	Energy Dispersive X-Ray
Si	Silica
C	Carbon
O	Oxygen
ASTM	American Society for Testing Materials
THW	Transient Hot Wire
ISO	International Organization for Standardization