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Mechanical and Physical Performance Evaluation of Laboratory-Scale LDPE-Sand Composite Modified with Rice Husk, Rice Husk Ash, and Biochar

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Abstract. For a developing country like Nepal, the massive increase in amount of plastic waste and agricultural leftovers has created serious environmental issues. This study focuses on the development of plastic-sand composite bricks, using low-density polyethylene (LDPE) plastic as a binding material and sand as the aggregate. The control mix of plastic and sand only as well as the modified composites using rice husk, rice husk ash, and rice husk biochar were prepared as partial replacement of sand to study the change in material properties. Laboratory-scale samples having dimensions of 100 $\times$ 50 $\times$ 50 mm were fabricated using a mix ratio of 30:70 (plastic to sand) by weight, with 10% replacement of sand by agricultural derivatives for additive-based samples. The fabricated composite material was tested for their compressive strength, water absorption, and physical properties, and FTIR analysis. The highest average compressive strength of 19.34 MPa was shown by rice husk ash sample. Raw rice husk sample had the lowest average value of 15.56 MPa. The rice husk biochar sample showed moderate performance with strength of 17.07 MPa. FTIR analysis confirmed that bonding in the composite is mainly physical. This study shows that LDPE-Sand composites with suitable agricultural additives can work as sustainable construction materials and helps to promote effective waste utilization.

Keywords: FTIR, LDPE, Rice Husk Biochar, Sustainable construction, Waste utilization

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1. INTRODUCTION

For a developing country like Nepal, the massive increase in the amount of plastic waste causes a massive environmental challenge. Even if there exist different types of plastic in the market, Low-Density Polyethylene (LDPE) is the most common type of plastic that is used in day-to-day life. The LDPE type of plastic is used as shopping bags, containers, and as packaging. These types of plastics are thrown away after one-time use. These plastic stays in the environment for a long time. Which will cause both land and water pollution. Like plastic waste, agricultural products are also produced in large quantities in Nepal. Rice Husk is among one of those byproducts which are burned and discarded as waste instead of being used as a valuable resource. Clay bricks made from industry uses lots of natural clay and energy for production, which reduces natural resources and also emits greenhouse gases. In various countries, plastic brick is being fabricated in large quantity, and are being used as an alternative to clay bricks. These types of brick use plastic waste instead of clay. Which helps to conserve natural resources. Additionally, these types of composites absorb less water and lasts longer than normal clay bricks. Further, using the agricultural waste helps to improve sustainability. Among the materials, rice husk ash is largely used in various fields because of its high silica content, and rice husk biochar may prove to be useful due to carbon reinforcement.

There exists many studies and research, on plastic-sand bricks, but there exists limited research on comparing the use of different rice husk by-products in the same plastic-sand bricks, especially in a lab setting. This study aims to evaluate the performance of LDPE-Sand composite bricks modified with Rice husk byproducts. This study aims to focus on the comparative study of how these agricultural additives affect the physical, mechanical, and chemical properties of the final composites. The study has both engineering, and environmental benefits. Environmentally, this study encourages for the recycling of plastic waste and for the use of agricultural products for creating something meaningful instead of treating them as waste. From an engineering view point, this study supports for the development of low-cost and sustainable materials, which can be used as an alternative material for construction industry. The findings from this study can help with the utilization of such composites on non-load-bearing structures and for lightweight building elements like partition walls, and pavement blocks for roads.

Finally, comparing different agricultural residues provides a foundation for future studies and research, on materials made from waste.

A. WORKING PRINCIPLE

The working principle of the proposed composite brick sample lies in the behavior of thermoplastic binding of LDPE plastic. When Plastic(LDPE) is heated to its melting temperature at the range of approximately 110–140°C, LDPE pellets changes its form into a molten gel-like state. It acts like a binder material for bonding fine sand particles and additives. The mixture of the molten mix is poured into molds and compacted to eliminate air voids. Upon cooling to the room temperature, the LDPE solidifies in the solid form. The sand and additives gets bonded together with plastic in that solid state. The agricultural additives that are used in this study influence the composite structure in different ways. RH acts as a lightweight filler, RHA acts as silica-rich filler, and RHB acts as Carbon-rich filler. The final composite brick fabricated, is a plastic-bound composite material in which the aggregate and additives are physically locked within the solidified polymer matrix, rather than by any chemical reactions.

B. OBJECTIVE

The objectives of this project are divided into main and specific objectives.

1) MAIN OBJECTIVE. To evaluate the mechanical and physical properties of laboratory-scale LDPE-sand composite bricks, which are modified with rice husk and its derivatives.

2) SPECIFIC OBJECTIVE.

a. To fabricate LDPE-sand composite brick samples of laboratory scale.
b. To use rice husk, rice husk ash, and rice husk biochar as the materials for the partial replacement of sand.
c. To find the compressive strength of the prepared samples.
d. To find the physical and chemical characteristics of the composite.
e. To compare the performance of the modified sample with the control mix composite sample.

2. LITERATURE REVIEW

2.1. **WASTE PLASTIC AND PLASTIC-SAND COMPOSITE.** The accumulation of plastic products, which are being disposed in the natural environment has emerged as a significant global issue. The piled-up collection of plastic waste in landfills and natural ecosystems has been one of the major concern worldwide. And due to rapid increasing rates of such unmanaged plastic and their direct disposal to the environment, there is a need for sustainable waste management solutions. One of the solutions to tackle such problem is by using the waste plastics in construction materials. In the Construction materials, the waste plastics can especially be used as a binder in composite systems. Plastic-sand composites products have been studied as an alternative material to the conventional masonry materials that are available in the market, like clay bricks. For such composites, molten plastic binds aggregate to form durable composite products. Also, agricultural wastes or residue, such as rice husk (RH), rice husk ash (RHA), and rice husk biochar (RHB), are rapidly being studied as sustainable fillers. They are suitable for fillers due to their availability in mass quantity and due to them having beneficial material properties.
Globally, the plastic production has increased from around 100 million tons in 1990 to an estimated 370 million tons in 2020 [1]. This data shows how fast plastic has been produced and are being used. This rapid production and consumption of plastic at this speed shows the danger that plastic waste may pose to us in the future if this trend keep on increasing in the same manner. By 2035, accumulated plastic carbon waste will be equal to marine fish carbon [2]. This data tells us that the quantity of plastic carbon waste in a large amount is going to affect us in the upcoming years. Improper disposal of plastic waste causes pollution in all land, water, and air. Disposed plastics get piled up in natural ecosystems. Since plastics degrade very slowly they may release harmful substances during that time. Those harmful substances may cause health problem for people living near the disposal sites. In case of aquatic environments, plastic causes physical harm to aquatic plants and animals and is one of the major causes for micro plastic contamination in the food chain. Also, the uncontrolled and open burning of plastic waste releases toxic gases like carbon monoxide, which directly affects human health. To help tackle with these kinds of plastic waste problems, researchers have studied recycling and reuse methodologies. One of the best methods studied is to use plastic waste in construction materials. Previous studies conducted on plastic-sand composite have shown good durability, and low water absorption. Previous study on recycling and reuse, also tells us about the ability to use a large amount of waste plastic, helping with sustainable waste management.
The plastics that are used for construction purposes are broadly classified into two major Types. They are thermoplastics and thermosetting plastics. Thermoplastics plastic are the plastic which can be melted and shaped as desired. So they are used in studies where recycling needs to be done. They include PE, PP, PET, and PVC. Polyethylene-based plastics are used in the construction of composite materials because of their easy-to-handle properties. Low-density polyethylene (LDPE) was selected as the binder in this study due to various factors. Factors considered were its low melting temperature compared to other types of plastic, availability, and favorable mechanical properties. Compared to other plastic types, LDPE releases less harmful gases, which was also one of the major reasons behind the selecting of LDPE. LDPE plastic shows good flexibility and good bonding characteristics, allowing effective coating of aggregate particles. It's a suitable candidate for recycling-based construction applications because it is available easily, all over the world [3].

Plastic-sand composite bricks are made by mixing molten plastic (of various types) with sand to form a solid composite material. These kinds of composite brick have various advantages over conventional bricks, like low water absorption because of the hydrophobic nature of plastic, improved durability, and reduced environmental impact by the elimination of kiln firing. Mechanical performance of plastic-sand composites depends on the ratio between the plastic and the sand used, as well as the method of processing. Various studies have shown that using optimal ratios results in an increase in compressive strength. Chauhan et al. [4] studied high strength for a 1:2 ratio compared to 1:3 and 1:4 ratios, while Frank et al. [5] result reveals a compressive strength up to 38.14 MPa for a 30:70 mix. Various observations result shows us that optimal binder content can play a vital role in estimating composite performance. Despite their massive advantages, challenges like uniform mixing and perfect temperature control are the key factors for ensuring consistency in the quality.

2.2. **AGRICULTURAL WASTE AND RICE HUSK DERIVATIVES IN CONSTRUCTION MATERIALS.** To reduce the harm on environment, agricultural products and their derivatives are being studied. The materials made with mixture of agricultural products gives an alternative way of using the agricultural waste in something meaningful. Many agricultural products can be used as a cheap filler material in construction industry. Products like husk, sugarcane bagasse, and coconut shells are already being studied to enhance the property of construction materials. Using such agricultural byproducts helps reduce waste accumulation. Using such materials also contributes to the development of environmentally friendly construction materials. These materials are light in weight and have natural fibers in them, that make building materials light and tougher. However, their organic nature can sometimes affect the long-term durability and moisture absorption properties. Previous studies have shown that using agricultural materials like ash, in a certain proportion can help to increase the overall mechanical properties [6].

Among different agricultural products available, Rice husk and its derivatives are used most commonly. Husk are easily available and have high silica content. Having high amount of silica makes them suitable for construction applications. Rice husk is a lightweight and fibrous material. It reduces density in composite materials. Since husk has high porosity and organic composition, it may negatively affect strength and the moisture resistance. Its application in plastic-based composites still remains underexplored because of this specific reason.

Rice husk ash contains silica up to 90%. This makes it good at filling gaps. And high silica contains acts to improve particle packing and bonding, which can improve mechanical properties. Studies have demonstrated improved performance on the strength property with the controlled incorporation of RHA [7]. Rice husk biochar is a porous material which is rich in carbon. It is produced through pyrolysis. Its structure enhances interaction between composite materials. Previous Studies like [8] and [9] shows the potential to improve sustainability and performance. Although they have such massive potential, using them excessive may reduce their strength due to increased porosity.

2.3. **FTIR CHARACTERIZATION.** Fourier Transform Infrared Spectroscopy (FTIR) is used to identify functional groups as well as the chemical bonds present in materials. FTIR also helps to find the chemical composition of agricultural derivatives such as rice husk, ash, and rice husk biochar. FTIR analysis also helps to understand the bonding characteristics and interactions of materials within the composite systems [10]. The standard data range and the date range based on previous studies conducted on ash and biochar, helps to determine whether the biochar and ash prepared in laboratory is actually ash and biochar or not.

2.4. **SUMMARY OF PREVIOUS STUDIES AND RESEARCH GAP.** Based on previous studies, we know that the plastic-sand composites are materials that will be used worldwide, sooner or later. Especially for sustainable construction due to their strength and durability properties. Agricultural products such as rice husk and their derivatives like rice husk ash, and biochar have shown potential as additives in composite systems.

As shown in Table I, the ratio of 30:70 (plastic to sand) gives the highest strength compared to other tested ratios.

TABLE 1. Compressive strength and mix ratio of previous literatures

Author	**Mix Ratio**	**Strength Result (MPA)**
Frank et al. [5]	30:70	38.14
	60:40	33.2
	80:20	29.45
S S Chauhan et al. [4]	1:2 (33.3%:66.6%)	18.63–19.96
	1:3 (25%:75%)	12–13.3
	1:4 (20%:80%)	5.7–6.27
Suriyaa et al. [11]	1:2 (33.3%:66.6%)	9.17
	1:3 (25%:75%)	6.40
	1:4 (20%:80%)	3.50

In spite of all these advancements, there has only been little work done on comparative assessment of effects of RH, RHA, and RHB in the same LDPE-Sand composite brick system. The earlier studies mostly concentrate on one type of agricultural waste or changing the Plastic-Sand ratio without investigating any comparative behavior. Apart from this, the earlier works mainly focus on mechanical behavior, and not much attention is given to quality assessments and chemical characterization of LDPE-Sand composite. Also, the application of raw rice husk in plastic-based composite material has been comparatively less explored as compared to its processed form, like ash or biochar. Hence, the present study is aimed at a comparative investigation of the effects of RH, RHA, and RHB on physical, Mechanical, and chemical properties of LDPE-Sand composite brick.

3. Methodology

3.1. **MATERIALS.** The materials used in this study are shown in Fig. 2. Materials used includes LDPE plastic pellets, fine sand, raw rice husk (RH), rice husk ash (RHA), and rice husk biochar (RHB). LDPE plastic pellets were collected locally. And these pellets are used as the binder material due to their thermoplastic nature. Fine sand was used as the aggregate material. Rice husk was collected from a local rice mill in Bhaktapur, Nepal, while rice husk ash, and rice husk biochar were prepared under controlled laboratory conditions.

LDPE was selected because of its low melting temperature (110 °C). It also shows hydrophobic nature. And also have the ability to soften upon heating and solidify upon cooling. Which makes it a suitable binder for the composite [12].

Prior to use, sand was dried and sieved to remove impurities. It was then properly graded to achieve the particles having uniform shape and size. Rice husk and its byproducts were used as additional materials. They were used to study their effect on the final composite. Raw rice husk was washed, dried, and grounded to obtain fine powder of uniform size. Both ash and biochar were prepared with the help of muffle furnace. RHA was produced by controlled burning of rice husk. Where it was heated at 600 °C for 2 hours. RHB was produced through pyrolysis at 350 °C for 2 hours in a covered ceramic crucible inside the muffle furnace to provide a limited oxygen condition. No purge gas was used during the process. The covered crucible minimized the availability of oxygen and helped in biochar formation. Both RHA and RHB were used as partial replacements for sand in order to study their effect on plastic-sand bricks.

3.2. **MATERIAL CHARACTERIZATION.** Before the fabrication of the composite sample, the properties of fine aggregates were tested. Sieve analysis was carried out based on IS 383. It was done to investigate the particle size distribution of sand. And to determine its suitability as a filler material in the composite. For this purpose, a standard series of sieves ranging from 10mm to 0.15mm was used. And the percentage passing and percentage retained were measured at each sieve size. Based on the test results, a grading curve was prepared for the analysis of the gradation characteristics of sand. The sand was classified under Zone II grading. Which compiles with IS standard and indicates its suitability for construction and composite applications. The detailed

FIGURE 1. Different materials required for the fabrication process

results with compliance to IS 383 are presented in Table II, and the gradation curve is shown in Fig. 3.

TABLE 2. Gradation of sand

S.N.	Sieve Size (mm)	% Passing	IS Grading Zone II Limits (%)	Compliance with IS 383
1	10.0	100.00	100	OK
2	4.75	91.09	90–100	OK
3	2.36	79.44	75–100	OK
4	1.18	68.54	55–90	OK
5	0.60	55.48	15–59	OK
6	0.30	28.83	8–30	OK
7	0.15	8.61	0–10	OK
8	Pan	0.00	—	—

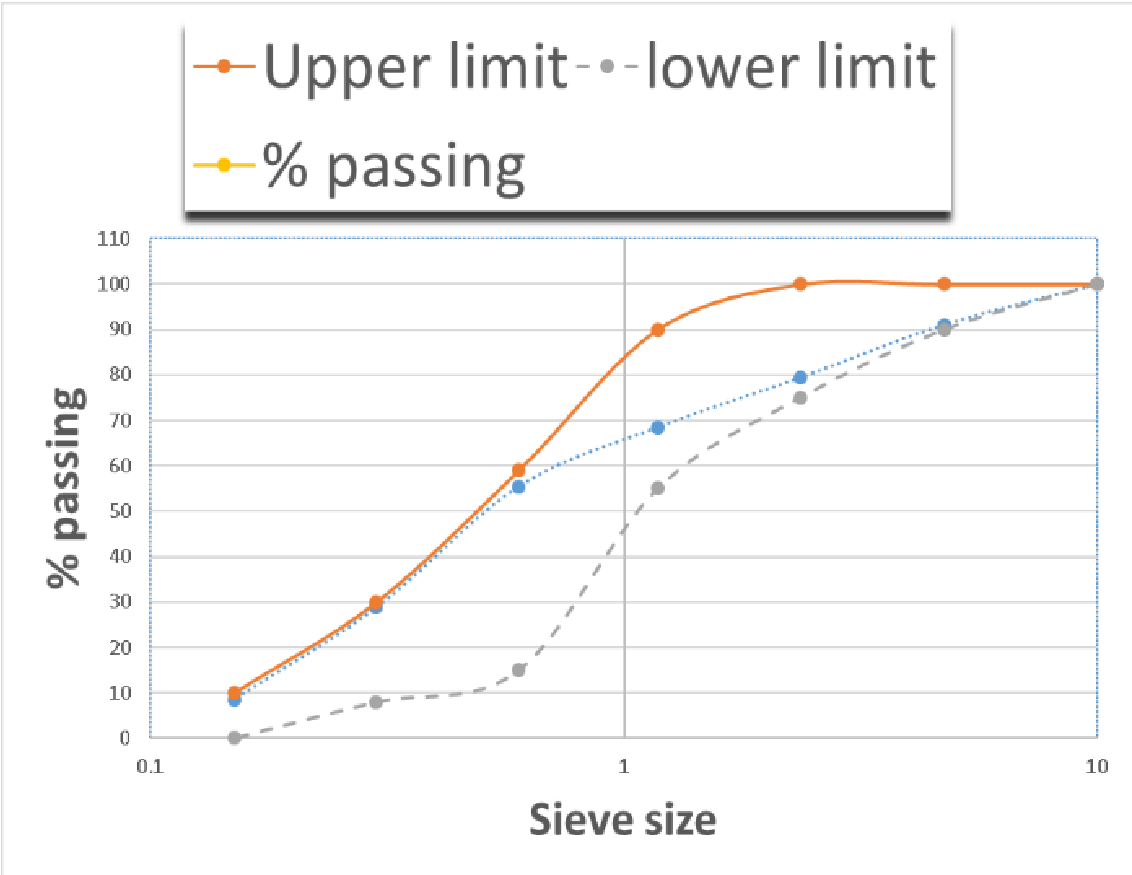

FIGURE 2. Gradation curve

Specific gravity of sand was measured by means of a pycnometer according to IS 2720 part 3. The aim of this test was to evaluate the density properties of the aggregate and to identify its suitability to make composites. The value of specific gravity obtained was compared to the reference value of fine aggregates. The specific gravity of the sand was calculated as 2.5. It falls within the range for fine aggregate. The results of sieve analysis and determination of specific gravity were analyzed to determine the suitability of fine aggregate for the fabrication of plastic-sand composite.

3.3. **MIX DESIGN AND COMPOSITE FABRICATION.** For the control sample, the mix proportion between plastic and sand was 30:70. On the other hand, for the modified samples, 10% of sand was replaced by agricultural derivatives. The mix proportions are shown in Table III.

Table 3. Mix proportion of control and additive samples

Sample	Plastic (%)	Sand (%)	Additive (%)
CTRL	30	70	0
RH	30	60	10
RHA	30	60	10
RHB	30	60	10

A 30:70 ratio provides maximum strength. This ratio is also supported by literature. 10% replacement of sand with agricultural derivatives helps in the comparison, without massive loss in strength. Single replacement level of 10%, ensures controlled experimentation.
The amount of plastic, sand, and additives that were needed was calculated depending on the mold dimension and respective mix proportion. In order to obtain four types of samples, control (CTRL), rice husk (RH), Rice husk ash (RHA), and rice husk biochar (RHB), the following amounts of materials had to be used and are shown in Table IV. Material quantity calculations were done considering losses. The losses were considered for mixing and molding process.

Table 4. Total materials required for the sample preparation

Material	Quantity (kg)
LDPE	2.048
Sand	3.324
RH	0.120
RHA	0.120
RHB	0.120

Before fabrication, plastic pellets were melted. They were melted in a steel container within the temperature range of 110–140°C. They were melted until a molten gel like state was achieved. Sand and additives were preheated and mixed with molten plastic, gradually, with constant stirring. The mixture was then poured into steel molds of dimensions 100mm × 50mm × 50mm and pressed manually in order to reduce air bubbles. After cooling the sample to room temperature, the samples were demolded and kept in a laboratory environment before testing. Figures 4 and 5 show the molds and samples, respectively.
During plastic melting and ash handling, safety precautions were applied. Experiments were conducted under adequate ventilation. And appropriate personal protective equipment was used. A face mask was used to reduce the chance of inhalation of fine particles and fumes. And a fire extinguisher was kept nearby as a preventive measure, while melting the plastic.

3.4. **EXPERIMENTAL TESTING.** The fabricated composite samples were tested through various test. Mechanical, physical, and qualitative tests were done to find their performance and suitability for construction purposes. The test carried out includes compressive strength test, water absorption test, visual observation test, scratch resistance test, and ringing test.

3.4.1. *COMPRESSIVE STRENGTH TEST.* The compressive strength test was carried out with reference to the IS 3495 (Part 1). The fabricated samples were placed on the compression testing machine. Load was applied evenly until failure occurred. The maximum load experienced by each sample was noted. Compressive strength was calculated using the formula.

$$F_c = \frac{P}{A}$$

Where:

FIGURE 3. Brick molds

$$F_c = \text{Compressive strength (MPa)}$$

$$P = \text{maximum applied load (N)}$$

and

$$A = \text{loaded area (mm}^2\text{)}$$

Fig. 6 shows the experimental setup used for the load calculation of the fabricated sample, as well as the data recorded by the machine on one of the samples.

3.4.2. *WATER ABSORPTION TEST.* Test for water absorption was done following the reference mentioned in IS 3495 (Part 2): 1992. This standard was formulated for burnt clay bricks. It was adopted in this present study because the fabricated samples were made in the shape of bricks. This procedure is a standard method used for evaluating water absorption behavior and moisture resistance. All the samples were sun dried before testing. The samples were cleaned and then weighed to determine their initial dry weight. These samples were allowed to soak in water at room temperature (Approximately 27°C) for 24 hours.

$$\text{Water Absorption (\%)} = \frac{W_s - W_d}{W_d} \times 100$$

as per IS 3495 (Part 2):1992

Where W_s is the Saturated weight of the sample and, W_d is the Dry weight of the sample. Fig. 7 shows the setup for water absorption.

Figure 4. Fabricated composite samples

3.4.3. *VISUAL EXAMINATION.* Visual examination of the fabricated composite samples was done to examine the nature, dimensions, surface characteristics, and its internal structure. Structures were broken in order to examine the distribution of sand and additives along with the plastic mixture. Fig. 8 shows the dimensions of the fabricated sample, showing that they were fabricated as per the required dimensions.

3.4.4. *SCRATCH TEST AND RINGING TEST.* Scratch and ringing tests were carried out as an initial qualitative field evaluation test to provide preliminary information regarding the surface hardness and internal integrity of the composite sample. These tests were used only as supplementary evaluation. These test were not intended for direct comparison with standardized mechanical tests such as the compressive strength test.

For the scratch test, a sharp steel object was used to scratch the sample, and the result of the scratch was examined visually. The sample with few scratches was considered to have higher resistance to abrasion. In ringing test, the samples were lightly struck against one another. The resulting sound of the collision was observed. The ringing sound was the indicator of well-bonded sample without any internal defect. And the dull sound suggested the possible presence of internal flaws or poor bonding.

3.4.5. *FTIR ANALYSIS AND DATA ANALYSIS.* Fourier transform infrared spectroscopy (FTIR) was used to study the chemical structure of the materials. The chemical properties of the final composites were checked with the properties of raw materials with help of this test. The FTIR was conducted at the Department of Chemistry, Amrit Campus, with the help of an FTIR spectrometer in the range of 4000–400 cm^{-1}. This study included the analysis of rice husk and its derivatives.

Figure 5. Test for compressive strength

Analysis of the final fabricated samples were studied as well for the comparative evaluation. Analysis of the obtained spectra was done through the interpretation of specific peaks. Special focus was given to O-H (hydroxyl), C=O (carbonyl), and Si-O-Si (silica) functional groups in order to evaluate the chemical characteristics of the materials and possible interaction with the composite system.

The experimental results obtained from compressive strength, water absorption, and other tests were compared to analyze the properties of different composites. Average compressive strength for all composite types was obtained by considering the data of three samples for each composite sample. Water absorption was obtained as the difference between the initial dry weight and the final wet weight of the samples.

The comparative study was conducted to investigate the effect of rice husk, rice husk ash, and rice husk biochar on the performance of LDPE-Sand composite bricks. The data were presented in the form of graphs, tables, and comparative plots that showed variation in the properties of various composites. The interpretation of the physical and the mechanical properties was done based on

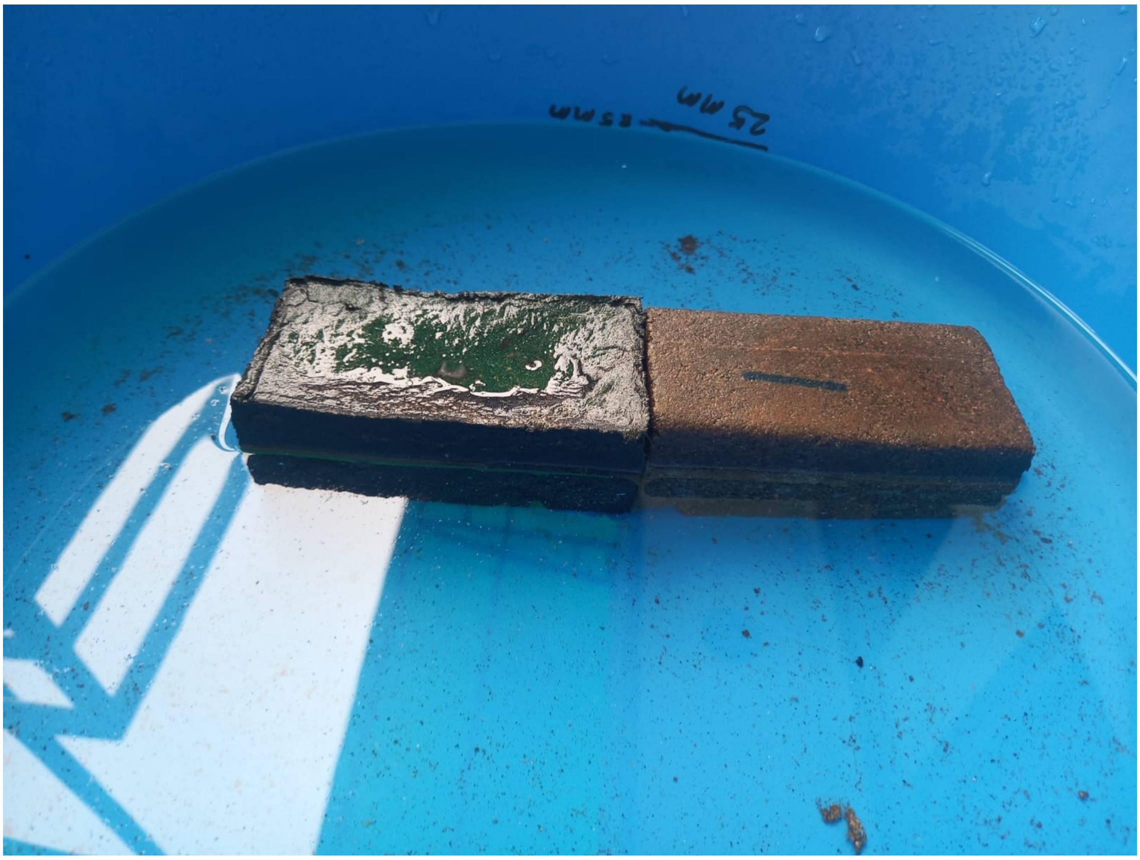

Figure 6. Water absorption

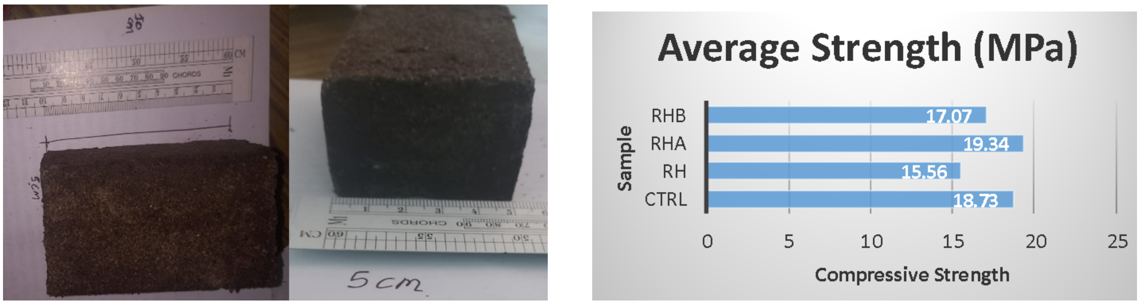

Figure 7. Dimension of the composite samples

the FTIR spectral data. Peak structure and functional group of the compound were studied for the analysis.

4. RESULT AND DISCUSSION

This section shows and discusses the experimental findings. The data recorded from the fabricated LDPE–sand composites are used as a mean to perform comparative evaluation. Performances of the control samples and the modified samples mixed with agricultural additives were tested through different tests. The results obtained are discussed in relation to their physical and chemical characteristics.

4.1. **VISUAL EXAMINATION AND PHYSICAL APPEARANCES.** Fabricated composite samples were checked visually after the cooling and demolding process to obtain their physical properties. All samples had the original mold dimensions of 100 mm × 50 mm × 50 mm, showing that the molten plastic has enough binding properties during the casting process.
The control samples, consisting of only LDPE and sand, showed a uniform dark grey appearance with a smooth outer surface. The RH-modified samples showed a comparatively rougher texture due to the fibrous nature of the rice husk particles. The RHA modified samples showed a dense and relatively smooth surface texture with the ash-like color on the surface, while the RHB samples appeared darker because of the nature of biochar, which is rich in carbon. No visible surface cracks or any major defects were seen in any of the samples. This result suggests that the assumed plastic melting temperature and hand compaction (manual) process were enough for producing good-quality laboratory-scale composite samples.

4.2. **RINGING AND SCRATCH TEST.** The scratch and ringing test was conducted as a qualitative field assessment to study the surface hardness and internal bonding of composite samples. During the scratch test, all samples showed good resistance to scratching. This indicates satisfactory surface hardness. In the ringing test, all samples produced clear sounds when struck against each other. Unlike clay bricks, which make a metallic sound when they collide, the composite sample didn't make any metallic sound due to the polymer absorbing the vibration. Even if they didn't produce the metallic sound, all samples made a clear sound, which proves the absence of internal voids or cracks. This result confirms that the molten LDPE tightly binds the sand particles and agricultural particles into one composite body.
It should be noted that the scratch and ringing test are only qualitative field assessments and were only used as a supplementary indicator of sample performance. Therefore, their result shouldn't be directly compared with the result of standard mechanical tests like compressive strength.

4.3. **WATER ABSORPTION BEHAVIOR.** Water absorption is one of the main tests of porosity and durability. Especially for materials that are made for construction use. Table V shows the measured weights and their water absorption percentage.

Table 5. Water absorption weight and percentages of the samples

Sample ID	Dry Weight (g)	Wet Weight (g)	Water absorption (%)
CTRL	400	410	2.50
RH	390	404	3.59
RHA	410	419	2.20
RHB	395	406	2.78

The control samples showed low water absorption (2.50%) due to the hydrophobic nature of LDPE, that restricts water penetration. The rice husk specimen showed the highest absorption, attributed to its porous and fibrous structure, which can act like pathway for moisture movement in the composite sample. The rice husk ash specimen demonstrated lower absorption (2.20%) due to fine particle size and high silica content of RHA, which reduced internal voids in the sample. The rice husk biochar sample showed moderate behavior (2.78%) due to its porous carbon structure.
These observations suggest that the type of agricultural additive significantly varies the moisture resistance. Out of all the tested agricultural additives, RHA showed the best performance. RHA showed the lowest water absorption. RHA result demonstrates enhanced durability for construction use, compared to existing plastic-sand composites.

4.4. **Compressive strength performance.** The compressive strength results obtained from UTM testing are summarized in Table VI.
Fig. 9 shows the average compressive strength of control, RH, RHA, and RHB samples, which were found to be 18.73MPa, 15.56MPa, 19.34MPa, and 17.07MPa, respectively.
Out of all samples prepared, the Samples modified with RHA attained the highest average compressive strength of 19.34MPa, with an increase of 3.3% compared to control sample. Additional

TABLE 6. Maximum load and compressive strength of the samples

Sample	Composition	Maximum load (KN)	Compressive strength (MPa)
CTRL	LDPE + Sand	95	19
CTRL	LDPE + Sand	94	18.8
CTRL	LDPE + Sand	92	18.4
RH	LDPE + Sand + RH	78.1	15.62
RH	LDPE + Sand + RH	77.4	15.48
RH	LDPE + Sand + RH	77.9	15.58
RHA	LDPE + Sand + RHA	99	19.80
RHA	LDPE + Sand + RHA	95	19
RHA	LDPE + Sand + RHA	96.1	19.22
RHB	LDPE + Sand + RHB	85	17
RHB	LDPE + Sand + RHB	84	16.8
RHB	LDPE + Sand + RHB	87	17.4

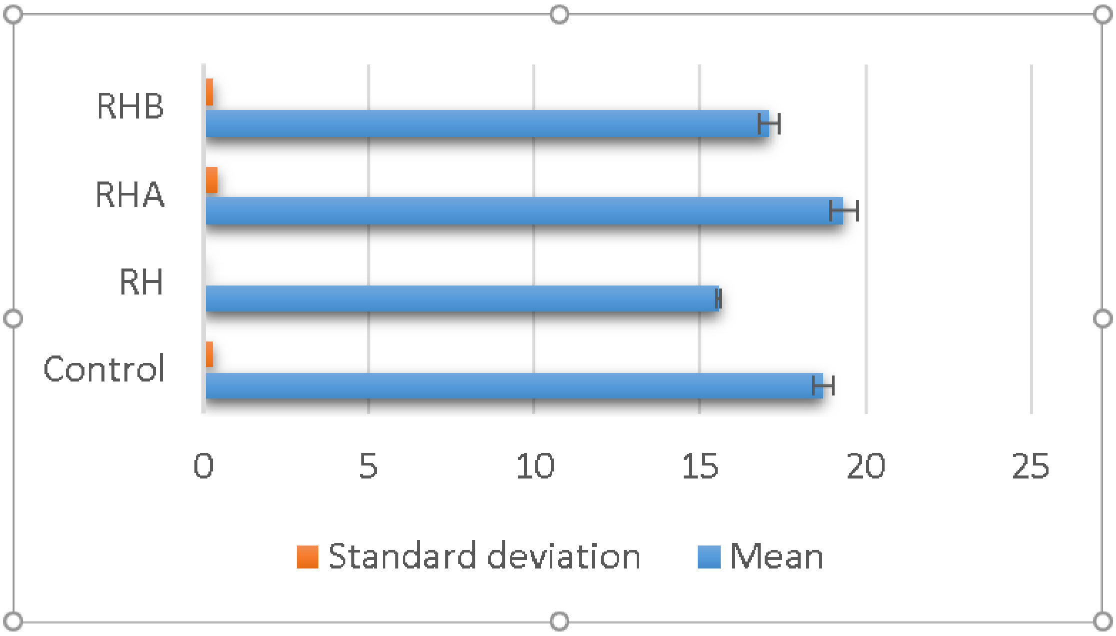

FIGURE 8. Average strength of composite samples

improvement in percentage may be due to the high silica content and fine particle size of RHA, which increases particle packing and reduces internal voids inside the composite. Fine ash particles likely acted as micro fillers. Which enhanced the transfer of stress between plastic and sand particles under compressive loading. Control sample showed an average compressive strength of 18.73 MPa, showing that the plastic-sand composites without any additives can also develop sustainable load-bearing capacity. The RH modified samples showed the lowest average compressive strength of 15.56 MPa. Which represent a decrease of 16.9 percent compared to control sample. This massive percentage reduction may be due to the porous and fibrous nature of rice husk. This reduction can cause internal voids and weaken the bonding between the additive and plastic. The RHB modified samples showed a moderate compressive strength of 17.07MPa. This strength was lower than the control but higher than the RH modified samples. The porous carbon structure

of biochar may have helped with partial reinforcement. And its internal porosity may also have limited the overall strength enhancement.
To study whether the observed differences in compressive strength among the composites were statistically significant, a one-way analysis of variance (ANOVA) was done. The ANOVA results are shown in Table VII. The F-value (96.35) was greater than the critical F-value (4.07), and the p-value (1.28×10^{-6}) was significantly lower than the significance level of 0.05.
As seen from the results, the variance in compressive strength between samples using different agricultural additives is statistically significant. According to findings of the ANOVA test, the additives used make a statistically significant difference in compressive strength ($p<0.05$).

Table 7. One-way ANOVA result for compressive strength

Source	**SS**	**df**	**MS**	**F**	**P-value**	**F crit**
Between	26.21	3	8.73	96.35	1.28E-06	4.07
Within	0.72	8	0.091			
Total	26.93	11				

Table VIII shows the average compressive strength along with their corresponding mean values and standard deviation.

Table 8. Average compressive strength

Sample	**Maximum strength (MPa)**	**Mean (MPa)**	**Standard Deviation (MPa)**
Control	19	18.73	0.31
RH	15.62	15.56	0.07
RHA	19.80	19.34	0.41
RHB	17.4	17.07	0.31

Fig.10 Shows the standard deviation, mean and error bar diagram. The minimum standard deviation (0.07) is of RH sample. The minimum standard deviation shows that the test result is close to each other and are highly consistent. The maximum standard deviation (0.41) belongs to RHA sample. That shows the test result value are less consistent than that of RH. Overall, the variation value is small in all samples. That small variation indicates the reliability and repeatability of test result.
According to the FTIR spectra of raw agricultural additive shown in Fig. 11, the rice husk spectrum showed a broad absorption band around 3400 cm^{-1}. Which corresponds to O-H stretching vibration caused due to cellulose and moisture. Peaks near 1640 cm^{-1} were related to lignocellulose components. And the absorption band around 1059 cm^{-1} showed the presence of silica-related Si-O-Si vibrations. The RHA spectrum showed a dominant Si-O-Si absorption peak near 1059 cm^{-1}. Which confirms the higher silica nature of ash. The RHB spectrum showed absorption bands related with aromatic carbon structures and oxygen-containing functional groups. Those groups are the characteristics of carbonized biomass materials.

Table 9. Major FTIR peaks and function group of composite sample

Sample	**Peak (cm^{-1})**	**Functional Group**	**Interpretation**
Plastic-Sand (CTRL)	2920	C–H stretching	Characteristic LDPE peak
Plastic-Sand RH	3450	O–H stretching	Cellulose/hydroxyl groups from rice husk
Plastic-Sand RHA	1020	Si–O–Si stretching	Silica from rice husk ash
Plastic-Sand RHB	1700	C=C vibration	Carbonaceous structure from biochar
All composite samples	2920	C–H stretching	Confirms the presence of the LDPE matrix

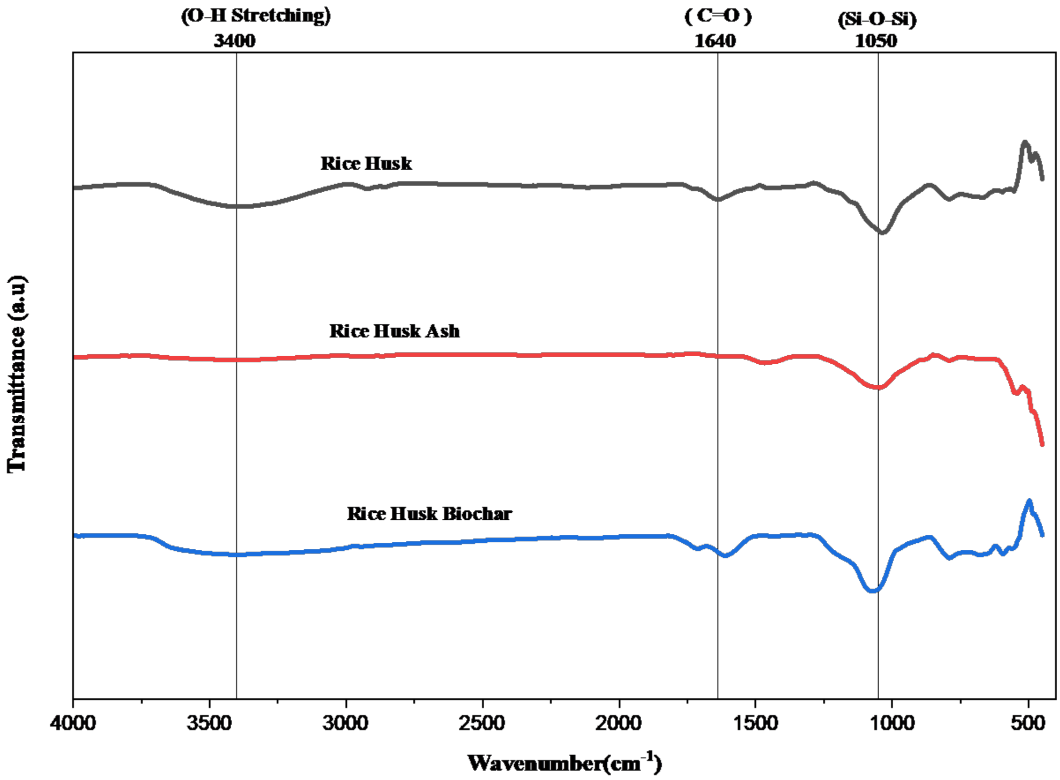

FIGURE 9. Standard Deviation, mean, and error diagram

The FTIR spectra of composite samples are presented in Fig. 12. And Table IX shows the peaks and their associated functional groups. All the composite samples showed absorption peak near 2920 cm^{-1}. Which corresponds to the C-H stretching vibration of polyethylene chains. The presence of those chains proved the presence of LDPE as the primary binder material. The RH modified composite showed an O-H absorption band around 3450 cm^{-1}. Which showed the presence of hydroxyl-containing compounds from rice husk. The RHA modified composites showed Si-O-Si absorption peak near 1020 cm^{-1}. Which confirmed the successful mix of rice husk ash in the composite matrix. Similarly, the RHB modified composite showed an absorption band around 1700 cm^{-1}. Which associated with aromatic carbon structures and oxygen-containing functional groups of biochar.

A comparison between the raw additives spectra and composite spectra showed that the characteristic peak of each agricultural additive remained even after the addition of plastic and sand. No significant new absorption peaks or major shift in peaks were observed after the composite fabrication. This suggests that no major chemical reaction occurred during the fabrication process.

Therefore, the interaction between materials used is considered to be physical rather than chemical in nature. The molten plastic primarily acts as a binding material which holds the sand and additives together. These findings confirm the successful addition of husk and its byproducts in the composite that was fabricated. The material addition was done while preserving their characteristic chemical features and support the observed mechanical and physical performance of the fabricated composite.

5. CONCLUSION

The purpose of this study was to study the effects of rice husk and its derivatives on the performance of LDPE-Sand composite brick. It was found that there was a significant effect of the choice of

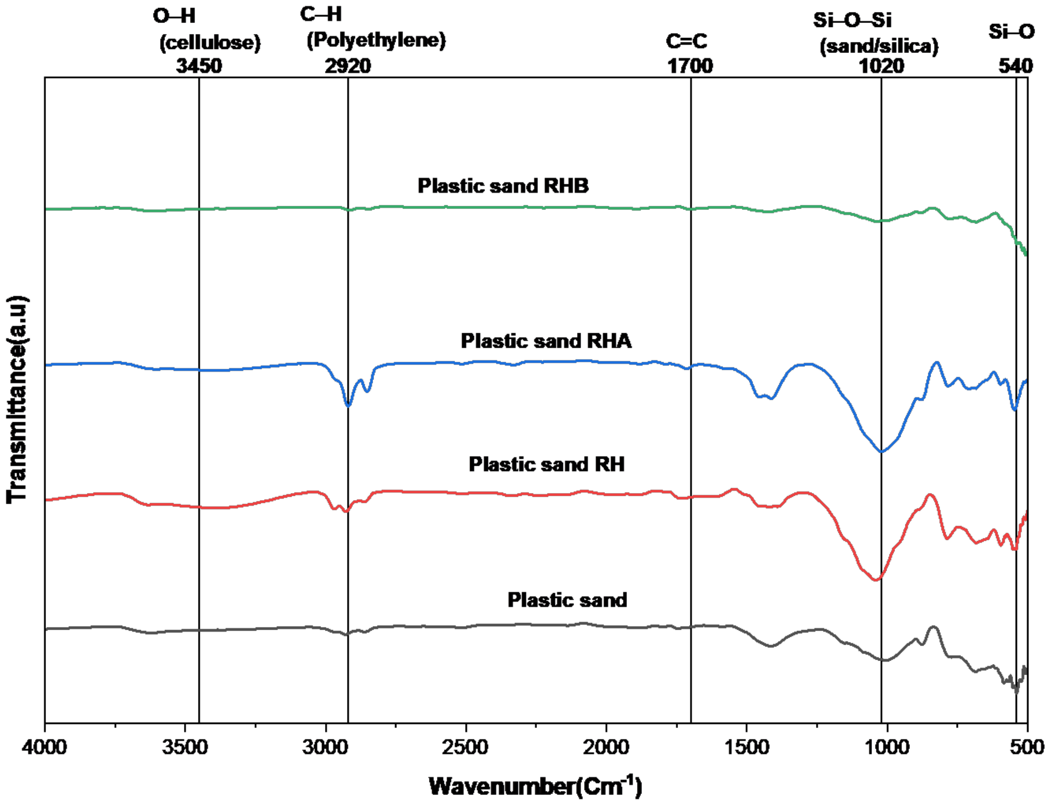

Figure 10. FTIR comparison of raw additives

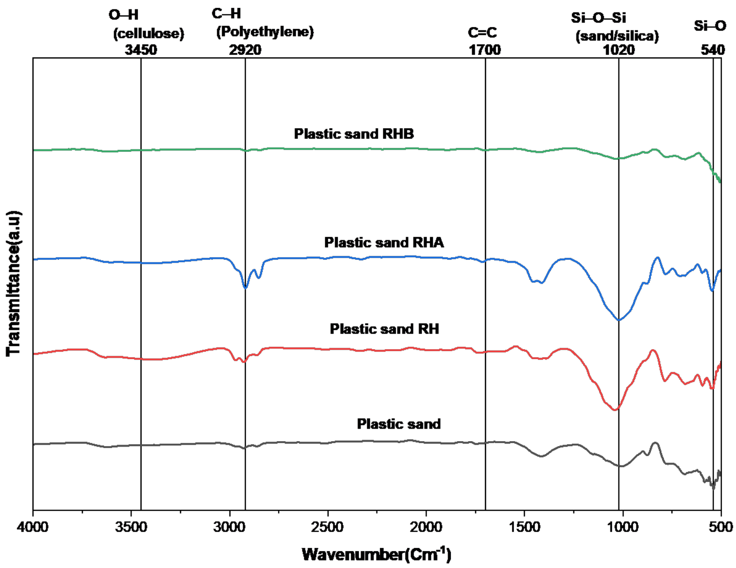

Figure 11. FTIR comparison of fabricated composite sample

different additives on the composite performance in terms of its mechanical and physical properties. RHA was found to be the best among the additives tested because it yielded the highest compressive strength and lowest water absorption value compared to others. The FTIR result proved the success of the addition of the additive and physical bonding.

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