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An Experimental Study of Jute FIBRE Reinforced Concrete By Partial Replacement Cement With Rice Husk Ash

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Abstract
This research paper is all about the experimental utilization of jute fiber and rice husk ash as partial substitutes for cement in concrete formulations. Aim of this experimental study is to explore eco-friendly alternatives in construction materials. Jute fiber, known for its considerable tensile strength and environmental compatibility, and rice husk ash, rich in reactive silica, are proposed as reinforcements to enhance the mechanical properties of concrete, such as its compressive strength and resistance to shrinkage cracks. The investigation encompasses a detailed assessment of these materials' effects on concrete, focusing on optimizing the mix proportions to achieve desired strength and durability while also conducting a comprehensive analysis of the cost implications and environmental benefits. This experimental study not only underscores the potential of utilizing agricultural waste in mitigating the environmental impacts associated with construction materials but also highlights the economic advantages of adopting such sustainable alternatives in the construction industry.

***Keywords**: Jute Fibre Reinforced Concrete, Rice Husk Ash, Sustainable Construction, Compressive Strength, Shrinkage Cracks, Pozzolanic Material, Environmental Sustainability, Agricultural Waste Utilization, Concrete Cost Analysis*

INTRODUCTION:

Cementitious materials and water are utilized to tie totals in the creation of concrete. Various manageability issues emerge from the way that every one of these primary parts meaningfully affects the climate. Consistently, concrete activities drink north of two billion tons of cement, as well as utilizing huge measures of water and totals. With regards to energy use and the releases of ozone depleting substances (GHG), which add to an unnatural weather change, Portland cement is definitely not a reasonable part. Concrete blends might be made more financially savvy and dependable by partially subbing modern and urban byproducts for Portland cement, totals, and water. This is particularly urgent since that environmental change has arisen as the most squeezing ecological test confronting our age. In accordance with the round economy thought, concrete is reinforced utilizing reused materials to diminish the effect on landfills and save valuable normal assets [1]. The rising prices of unrefined components and the consumption of regular assets have provoked the improvement of reasonable options in contrast to these wares[2].

Adding a little quantity of fibre to concrete in a dispersed pattern is a growing trend. Since ancient times, fibres have been used as a kind of support. Composites made from horsehair and fiber-supported concrete were previously considered promising materials. Depending on the kind and density of fibre, the mechanical characteristics of concrete are affected by their addition. In the end, areas of high structure and frameworks have made great strides in meeting the additional demands of high flexibility, performance, and endurance by using fibre cementitious or concrete composites mixed with metallic or non-metallic fibres [3]. The use of natural fibres, such as jute fibre, is more cost-effective than that of artificial fibres. Both the explicit strength and the stiffness of the jute fibre are respectably high. Considerations such as length and the methods used to harvest the fibre have an impact on its characteristics. Jute does not contribute to global warming since it does not release harmful gases or manmade materials. The flat surface of jute filaments makes them biodegradable and environmentally friendly. Plus, jute fibres have a high tensile strength but aren't very extensible [4]. In contrast, poor nations like Bangladesh get huge amounts of rice husk, a biological byproduct. The processing of rice and the creation of biomass from agricultural sources often result in this byproduct. There is a significant quantity of silica, around 20%, in rice husk, a cellulose-based fibre [5-8]. In addition to ash, it contains a lot of volatile materials and fixed carbon content [5,7,9,10]. The rice husk can absorb water up to around 15% of its weight, according to research [5]. Sintered samples were shown to have an enhanced porosity when rice husk was added to them [11]. Additional hydration products are generated when concrete containing rice husk interacts with calcium hydroxide. The reactivity of compounds in water is reduced when calcium hydroxide is consumed.

So, it's cost-effective and productive to use the rice husk and jute fibre as natural reinforcements in concrete to increase its compressive and tensile strengths. This study aims to find out how to use jute fibre and rice husk in concrete and how to make it work so that these agricultural wastes don't pollute the environment.

MATERIALS AND METHODOLOGIES:

Cement

This study made use of 52.5 N Ordinary Portland cement (OPC). After two days, this cement had an early strength of 20 MPa and a setting time of 45 minutes. There is 0–5% gypsum and 95–100% clinker in OPC, which gives it a specific gravity of 3.12.

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Aggregates
In this research, coarse sand was used as the fine aggregate, whereas crushed stone chips (ASTM C33) were utilized as the coarse aggregate.

Table 1 Aggregate physical properties.

Physical Property	FA (Sand)	CA (Stone Chips)
Bulk Specific Gravity (OD Basis)	2.50	2.66
Absorption Capacity (%)	1.36	0.69
Fineness Modulus (FM)	2.61	-
Dry Rodded Unit Weight (kg/m3)	1585	1550

Rice husk (RH)
The civil engineering industry has long made use of rice husk ash in cement mixes as a pozzolanic ingredient. This study made use of raw rice husk that was readily accessible in the area. Table 2 displays the common physical and chemical components of rice husk (RH) and rice husk ash (RHA). The study use rice husk, as shown in Figure 2a, as a partial substitute for cement.

Table 2 Comparison of physical and chemical properties of RH and RHA.

Properties	RH	Reference	RHA	Reference
Color	Yellowish		Grey	-
Unit weight (kg/m^3)	83–125	Mansaray *et al*; 1998 [5]	-	-
Water Absorption	5-16%		104%	Subhash Chandra Paul *et al*; 2019 [12]
Bulk density(kg/m^3)	90-150	Bhupinder Singh; 2018 [13]	530-780	Krishnan *et. al;* 2016 [14], Satish *et al*, 2013 [15]
Silica	15-20%	Mansaray *et al*; 1998 [5], Ndazi *et al*; 2007[6], Hu *et al;* 2008 [7], Nair *et al*; 2008 [8], Bhupinder Singh; 2018 [13]	80-90%	Bhupinder Singh; 2018 [13], Muthadhi *et al*;2007 [16]
Volatile matter	60–65%	Mansaray *et al*; 1998 [5], Hu *et al;* 2008 [7], Kwong *et al*; 2007 [10]	-	-
Ash	17–23%		-	-
Fixed carbon	10–15%		5-7%%	Bhupinder Singh; 2018 [13]
Cellulose	40-50%	Chindaprasirt *et al*; 2007 [9], Bhupinder Singh; 2018 [13]	-	-
Lignin group	25-30%		-	-

Jute fiber
Cellulose, hemicellulose, and lignin are the three primary components of jute fibre. Compared to cotton and other organic fibres, it has more durability. Although it is not very extensible, jute fibre has a high tensile strength. It is also used as a material to reinforce concrete and make it more resistant to cracks.

Table 3 Characteristics of the jute fiber used in the research (textile engineering study, 2021).

Length of fiber (mm)	13
Diameter of Fiber (mm)	0.05
Aspect Ratio (l/d)	260
Density (kg/m3)	1395
Tensile Strength (MPa)	400
Color	Off-white to brown
Specific Gravity	1.5
Elongation at break %	1.7

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The length of the jute fiber is referenced as 13 millimeters (mm), which shows the size of the strands utilized in the examinations. This is a critical boundary since the length of the fiber can significantly impact the composite material's mechanical properties, including its capacity to disseminate focuses on and its collaboration with the cement network. The breadth of the fiber is given as 0.05 mm, a fine estimation that assumes a crucial part in the fiber's perspective proportion and its surface region in touch with the cement lattice, influencing the fiber-network bond strength. The angle proportion, determined as the length to breadth proportion (l/d), is noted as 260.

Concrete mix proportion
Following the standards set forth by the American Concrete Institute (ACI, 211.1-2009 [17]), the mixture was meticulously designed. In order to get the desired strength of 35 MPa after 28 days, trail mixes were made with a slump value ranging from 75 to 100 mm [18]. Each and every one of the aggregate's surfaces must be completely dry before mixing can begin. For the compressive strength test, sixty specimens were constructed, and twelve concrete slabs were reserved for the plastic shrinkage test.

Table 4 Proportion of concrete mix used for experimental works.

	Mixing Type	Water (kg/m3)	Cement (kg/m3)	CA (kg/m3) [SSD]	FA (kg/m3) [SSD]	Jute Fiber (kg/m3)	Rice Husk (kg/m3)
JRC0 (Plain concrete)		215	566	999	565	-	-
	JRC1 (JF 0.1% & RH 5%)	218	537.70	999	565	2.35	28.30
	JRC2 (JF 0.2% & RH 5%)	219	537.70	999	565	4.70	28.30
	JRC3 (JF 0.3% & RH 5%	223	537.70	999	565	7.04	28.30
Jute Fiber and Rice Husk	JRC4 (JF 0.1% & RH 10%)	219	509.40	999	565	2.35	56.60
	JRC5 (JF 0.2% & RH 10%)	220	509.40	999	565	4.70	56.60
	JRC6 (JF 0.3% & RH 10%)	224	509.40	999	565	7.04	56.60
	JRC6 (JF 0.1% & RH 15%)	220	481.10	999	565	2.35	84.90
	JRC7 (JF 0.2% & RH 15%)	221	481.10	999	565	4.70	84.90
	JRC8 (JF 0.3% & RH 15%)	225	481.10	999	565	7.04	84.90

Table 4 outlines the concrete mix proportions used in experimental works to investigate the effects of incorporating jute fiber (JF) and rice husk (RH) as partial replacements in concrete. The table presents a series of mix designs named from JRC0 to JRC8, varying in the amounts of water, cement, coarse aggregate (CA), fine aggregate (FA), jute fiber, and rice husk used per cubic meter of concrete. Each mix is designed to explore the impact of different concentrations of jute fiber and rice husk on the concrete's properties, particularly focusing on environmental sustainability and performance enhancement.

Concrete mixing and casting
In order to mix the concrete, a machine mixer was used. All trial mixers were assumed to have a 50-liter capacity. The proper amount of cement, fine aggregate (FA), and coarse aggregate (CA) were measured out, and then two minutes of dry mixing was administered. The mixture was then wetted. After four minutes of hand-mixing, the fibres were evenly distributed throughout the concrete. After mixing, the concrete was slump-tested to determine its workability. A tamping rod was used to compact the concrete after it was poured into the cube. A slick steel trowel was used to finish the freshly mixed concrete. The test specimens are cured in water after the moulds are removed after 24 hours [19].

Compressive strength testing
An indication of all the qualities of concrete is the compressive strength test for cubic specimens. You may also use this test to see whether the concrete work was done correctly. In commercial and industrial buildings, concrete's compressive strength is between fifteen and thirty million pounds per square inch (4400 psi). A number of variables, such as the water-cement ratio, cement strength, concrete material quality, manufacturing quality control, etc., influence the compressive strength of concrete. Cubes and cylinders are the two standard units of measurement for compressive strength. A cube has been used in this experiment.
The initial dimensions of the mould were 150×150×150 mm. Three coats of concrete were poured into the cubes. With 32 strokes of the tamping rod, we compacted each layer, and when the final layer was crushed, we completed the top surface with a trowel. After 24 hours, the specimen was carefully removed from the mould. Three specimens were evaluated after 7 days of curing and 28 days of curing to assess the compressive strength.

Plastic shrinkage test
Fig. 4a shows the dimensions of the concrete slab that was prepared for the plastic shrinkage test: 500 × 250 × 75 mm. In modern construction, a concrete slab—a flat, even surface composed of cast concrete—is a common main component. To

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determine how concrete behaves when compressed, this experiment formed a basic slab without reinforcing. Similar to the cube, slabs were cast using the mix design. The first step was to cast some plain concrete and then evaluate the shrinkage test result. Alternately, jute fibre and rice husk, blended according to the mix pattern, were cast onto additional slabs. The last step was to compare the outcomes of the shrinkage tests conducted on different slabs.

RESULTS AND DISCUSSIONS:

Impact of jute fiber and rice husk on compressive strength

For the purpose of this testing, the objective strength of the concrete was found to be 35 MPa, as specified by the American Concrete Institute (ACI) 211 (2009). The compressive characteristics of concrete that was generated by employing jute fibre and rice husk as a partial substitute for cement content are shown in both Figure 5 and Figure 6. Both figures are used to demonstrate the product. When 10% rice husk and 0.20 percent jute fibre (13 mm) are added to the mixture, the compressive strength improves by up to 1.10 percent in only seven days (Fig.5a). This is a significant improvement. After 28 days, it is feasible that the compressive strength might be enhanced by 2.03% by employing a similar blend of rice husk and 13mm jute fibre (Fig.5e). This would be something that would be doable. This is owing to the fact that the pozzolanic reaction results in the development of calcium silicate hydrate, which considerably enhances compressive strength. In addition to the fact that the rice husk has a bigger grouping of responsive silica, this is also the reason why this is the case. As the rice husk expands, the compressive strength of the combination diminishes. This is due to the fact that the mixture becomes less functional, and the hydration response becomes more impacted by the increasing water demand. This is because the combination loses some of its functionality, which is the reason behind this. According to the results of a research that was carried out by Bawankule and colleagues [20], the compressive strength of cement reduces from 7.11% to 41.35% when it is substituted with rice husk ash (RHA) at a ratio that ranges from 2.5 to 15%. Additionally, Krishna et al. [14] found that the compressive strength reduced by 8.15-40.62 percent when RHA was used in lieu of cement in quantities ranging from 5% to 20%. This was the case when the quantity of RHA utilised was between 5% and 20%. After a reduction in the proportion of RHA that was utilised, this was the situation. Concrete may obtain a large increase in compressive strength of up to 15% RHA, as stated by Patil et al. [21]. This is the greatest level of increase that can be reached by using concrete. When 1% Coconut Fibre (CF) and 9% RHA are used in lieu of cement in concrete, the compressive strength improves considerably after seven days; but, after 28 days, there is no way to see an increase [22]. This is because the cement has been replaced by the materials. The cement is no longer present in the concrete, which is the reason for this happening.

Incorporating separate jute fibres into concrete also modifies its failure mode from brittle to ductile, as seen in Figure 6. An increase in fibre content leads to a decrease in compressive strength and an increase in porosity in the matrix, both of which compromise the cohesiveness of the concrete matrix and cause the balling effect [23]. Results showed that both the strength and the failure pattern could be improved by 10% when cement was replaced with 10% rice husk and 0.2% jute fibre.

Table 5 Compressive strength and strength effectiveness.

	Fiber Content (%)	Rice Husk (%)	Compressive Strength at 7 days (MPa)	Compressive Strength at 28 days (MPa)	28 days Strength Effectiveness (%)	Replacement percentage of RHA*	Average Compressive Strength at 28 Days (MPa)*
JRC0	-	-	20.02	36.5	-	-	35.09
JRC1	0.1	5	20.12	36.55	0.14	1% CF+ 9% RHA	30.88
JRC2	0.2		20.28	36.75	0.68		
JRC3	0.3		20.19	36.60	0.27		
JRC4	0.1	10	21.31	36.65	0.41	2% CF+ 18% RHA	28.49
JRC5	0.2		22.22	37.24	2.03		
JRC6	0.3		21.76	36.85	0.96		
JRC7	0.1	15	20.88	36.62	0.33	3% CF + 27% RHA	5.98
JRC8	0.2		21.05	36.82	0.88		
JRC9	0.3		20.95	36.68	0.49		

* Tutur N et al;2020.

Shrinkage test

The results of the experiments on plastic shrinkage fractures are shown in Figure 7. The shrinkage test was carried out for JRC4, JRC5, and JRC6 because the optimal percentage of rice husk was determined to be 10%. According to the findings of the compressive test, adding jute fibre significantly reduces the likelihood of shrinkage cracks. Jute fibre, with a length of 13 mm and an incorporation percentage ranging from 0.1% to 0.3% (Figure 7d), significantly reduced the shrinkage crack. The use of jute fibre in concrete increases the bridging mechanism between the pores, which in turn reduces the shrinkage crack. This is the reason why the crack is reduced. We used image analysis tools to extract the crack's apparent shape from the photos. Next, the 'image j' programme was used to process the images. Table 6 and Figure 8 show the outcomes of the inspection. You won't even see the shrinkage crack when you add 0.3% jute fibre by volume. Adding jute fibres to plain concrete increased the apparent fracture appearance period by a factor of roughly five compared to plain concrete, which occurred after 2 hours and 34 minutes. According to Özgür Erena et al. [24], the amount of plastic shrinkage crack reduction measured in percentages varies from 19.67% to 73.95% when 0.5% to 1.5% hooked steel fibre is added to concrete, specifically by volume.

Table 6 Shrinkage test result.

Concrete type	**Measured crack (%)**	**Shrinkage crack reduction (%)**	**Hooked steel fiber Volume***	**Plastic shrinkage crack reduction (%) ***
Plain concrete	15.7	-	-	-
JRC4	6.8	56.7	0.5%	19.67
JRC5	1.6	89.8	1%	34.66
JRC6	0	100	1.5%	73.95

*Özgür Erena et al; 2010.

Cost analysis considering environmental sustainability
Several scholars have investigated the impact of cement production on the environment. Cement kiln emissions include carbon dioxide, nitrogen oxides, dust, sulphur dioxide, chlorides, fluorides, carbon monoxide, organic compounds, and radioactive metals [25,26]. To accomplish sustainability, cleanliness, and protection, natural waste is being employed more and more in concrete construction. One way to make concrete cheaper is to use rice husks as a partial cement substitute (up to 15%) and jute fibre as a reinforcing element (up to 0.3%). Adding 5–15% rice husk to a mixture costs 2-7% less than buying cement (450 Tk/50 kg) and rice bran (5 Tk/kg) in Bangladesh. The cost per bag of 50 kg cement decreases as the rice husk content increases (Figure 9). The ideal situation calls for using 10% rice husk instead of cement. In terms of environmental sustainability and the results of the concrete's compressive strength test at 28 days, using 10% less cement would minimise gas generation and release, which in turn will save 4.7% of the building cost.

CONCLUSION:
Based on its chemical makeup, rice husk has the potential to be used as a pozzolanic material to enhance the compressive strength of concrete. However, jute fibre improves compressive strength and reduces shrinkage cracks when added to concrete. Incorporating natural fibre (jute fibre reinforcement material) and natural waste (rice husk) as a substitute material may also save building costs and greenhouse gas emissions. The following inferences may be drawn from the results of the testing and analysis of the compressive strength and shrinkage crack of concrete reinforced with rice husk and jute fibre:
(i) The compressive strength of concrete is increased from 0.14% to 2.03% compared to ordinary concrete when 0.1–0.3% jute fibre (13mm) and 5–15% rice husk are added. (ii) The compressive strength may be increased by a maximum of 1.10% after 7 days and 2.03% after 28 days when 10% rice husk and 0.2% jute fibre (13mm) are combined. (iii) Adding more jute fibre (>0.2%) or rice husk (>10%) to concrete reduces its compressive strength somewhat. Nonetheless, it remains on par with standard concrete. (iv) Compared to the control concrete, concrete treated with 0.1%-0.3% jute fibre (13 mm) reduced plastic shrinkage cracks by 56% to 99%. (v) Shrinkage fractures are eliminated when 0.3 percent jute fibre is added to the concrete mixture. (vi) In addition, you may save up to 7% by using 15% rice husk instead of cement. The most cost-effective mix composition, taking compressive strength and shrinkage cracks into account, is 10% rice husk as cement replacement, which may result in a savings of up to 4.7%.

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