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Experimental Study of Concrete Using Raw Rice Husk as Partial Replacement of Cement with Natural Fiber (Jute Fiber) as Reinforcing Material

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ABSTRACT

The release of GHG, radioactive metals and other chemicals is detrimental to the environmental impact of cement manufacturing. The use of natural pozzolan (raw rice husk) as a partial substitute of cement in concrete may not only serve to increase compressive strength but also be environmentally sustainable. This paper manages the idea of utilizing Rice Husk as a partial substitution of cement and non-metallic natural fibers (Jute fiber) in concrete to develop an FRC material to study the possible improvement in the 28-day strength and also to reduce the plastic shrinkage crack. Different compositions of 13mm jute fiber (0.1%, 0.2%, and 0.3%) and Rice Husk (5%, 10%, and 15%) were added to concrete with a water-cement ratio of 0.38 in this study. It depicts that the compressive strength improves by up to 2.03% relative to plain concrete after using both jute fibers and rice husk. Further addition of fiber and rice husk prompts a diminishing pattern in strength as the two substances increased, the compressive strength gets diminished, causing low workability of concrete. Moreover, Shrinkage tests were performed to assess the existence of shrinkage cracks; it indicates that when applying jute fiber, the shrinkage crack region decreases. The optimum content of jute fiber is 0.2% (13mm) and rice husk is 10% for the maximum increment of compressive strength. However, the incorporation of 0.3% jute fibers with 13 mm concrete length was found to be very effective in suppressing shrinkage cracks to near zero.

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1. Introduction

Concrete is produced with aggregates bonded by cementitious material and water. Each of these specific primary components has a distinct environmental impact which leads to various sustainability concerns. Along with the consumption of a massive quantity of aggregates and water, around two billion tons of cement are being used in concrete constructions per year. Portland cement is not an environmentally sustainable component in terms of energy consumption and greenhouse gasses (GHG) releases, which result in global warming. As global warming has arisen to be the most important environmental issue of our times and sustainable growth, cost effective and long-lasting concrete mixtures can be made with industrial and urban by products as a partial substitution of Portland cement, aggregates and drinking water. Alternative materials are incorporated to conserve natural resources and reduce waste disposal by incorporation of urban and industrial waste into concrete, in accordance with the circular economy principle [1]. Moreover, alternative materials provide an appropriate response to the increased costs of raw materials and natural resource use [2].

Day by day, it is becoming popular to strengthen the concrete with a little amount and random distribution of fiber. Fibers are utilized as supporting material since ancient times. within the past, the prospect of composite materials came utilizing horsehair and fiber-supported concrete was one of the subjects of concern. The accession of fibers to concrete impact its mechanical properties, which altogether rely on the sort and level of fiber. Ultimately, the act of fiber cementitious or concrete composites blended in with metallic or non-metallic fibers had been incredibly made in fields of elevated structure and frameworks to enhance extra prerequisites of high flexibility, execution and perseverance [3]. Between two sorts of fibers natural and artificial, natural fiber like jute fiber is more economical to be utilized. The jute fiber has respectably high explicit strength and stiffness. The properties of the fiber depend on factors like length, handling techniques embraced for the extraction of the fiber. Jute represents no danger to the climate since it neither transmits poisonous gases nor unsafe synthetics. Jute filaments are of smooth surface these are biodegradable and eco-accommodating. Moreover, the jute fibers are less extensible with high tensile strength [4]. On the other hand, rice husk is a biological remains that is delivered in large quantities including developing countries like Bangladesh. It's a common outgrowth of rice processing and the production of agro-based biomass. Rice husk is a cellulose-based fiber that contains a large amount of silica, about 20% [5–8]. It also consists of volatile matter, fixed carbon content and ash in a considerable amount [5,7,9,10]. Water absorption capacity of rice husk is ranges from 5% to 16% of its weight [5]. The addition of rice husk to sintered samples increased their porosity [11]. Rice husk reacts with calcium hydroxide in concrete to produce further hydration products. Calcium hydroxide ingestion reduces the reactivity of chemicals ingested from the water.

Therefore, using those two natural wastes (rice husk and jute fiber) for increasing compressive and tensile strength in concrete is economical and productive. The primary goal of this research is to determine the feasibility of using rice husk and jute fiber in concrete and to identify a proper method for minimizing environmental contamination by using these agricultural wastes.

2. Materials and methods

2.1. Cement

Ordinary Portland cement (OPC) with a strength class of 52.5 N was used in this research. This cement's initial setting time was 45 minutes, and its early strength was 20 MPa after two days. The specific gravity of OPC was found to be 3.12, and it contains 95-100% clinker and 0-5 % gypsum.

2.2. Aggregates

The fine aggregate used in this study was coarse sand, and the coarse aggregate was crushed stone chips (ASTM C33). Figure 1 and Table 1 demonstrate the physical properties of these aggregates.

(a) (b)

Fig. 1. (a) Coarse Aggregate, (b) Fine 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/m^3)	1585	1550

2.3. Rice husk (RH)

Rice husk ash has been commonly used as a pozzolanic additive to cement mixtures in the civil engineering field. In this research locally available raw rice husk has been used. The common chemical and physical ingredients of rice husk (RH) and rice husk ash (RHA) are displayed in Table 2. For this research, Rice husk (Fig. 2a) is used as partial replacement of 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%		-	-

2.4. Jute fiber (JF)

Jute fiber is mainly made up of cellulose, hemicellulose, and lignin. It is more resilient than cotton and other natural fibers. Jute fiber shows high tensile strength and low extensibility. It is also reinforcing and crack resisting material for concrete. Table 3 lists the properties of jute fiber.

(a) (b)

Fig. 2. (a) Rice Husk and (b) Jute Fiber (13 mm).

Table 3
Characteristics of the jute fiber used in the research (textile engineering study, 2012).

Length of fiber (mm)	**13**
Diameter of Fiber (mm)	0.05
Aspect Ratio (l/d)	260
Density (kg/m^3)	1395
Tensile Strength (MPa)	400
Color	Off-white to brown
Specific Gravity	1.5
Elongation at break %	1.7

2.5. Concrete mix proportion

The mix design was done in accordance with the American Concrete Institute's guidelines (ACI, 211.1-2009 [17]). Trail mixtures were prepared (slump value = 75-100 mm) to achieve a target strength of 35 MPa after 28 days [18]. Until mixing, all of the aggregate must be saturated and surface dry (SSD). A total number of 60 specimens were prepared for compressive strength test with additional 12 concrete slabs for plastic shrinkage test.

Table 4
Proportion of concrete mix used for experimental works.

Mixing Type		Water (kg/m^3)	Cement (kg/m^3)	CA (kg/m^3) [SSD]	FA (kg/m^3) [SSD]	Jute Fiber (kg/m^3)	Rice Husk (kg/m^3)
JRC0 (Plain concrete)		215	566	999	565	-	-
Jute Fiber and Rice Husk	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
	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

2.6. Concrete mixing and casting

A machine mixer was used to mix the concrete. A 50-liter volume was considered for each trial mixer. Adequate quantity of fine aggregates (FA), coarse aggregate (CA) and cement were taken and dry mixing applied for two minutes. Water was then applied to the mix. To achieve a uniform distribution in the concrete, fibers were spread by hand in the mixture for an extent of 4 minutes. Concrete workability was measured using a slump cone after it had been mixed. The concrete was poured into the cube, and it was tamped with a tamping rod. The new concrete was finished with a smooth steel trowel. These molds are removed after 24 hours, and test specimens are cured in water [19].

2.7. Compressive strength testing

Compressive strength test for cubic specimen serves as an indicator of all the properties of concrete. This test can also be used to assess whether the concrete work was properly done. The compressive strength of concrete ranges between 15 MPa and 30 MPa. in industrial and commercial structures (4400 psi). Concrete's compressive strength is determined by a variety of factors, including the water-cement ratio, strength of cement, quality of concrete material, quality control during manufacturing, and so on. Compressive strength is measured using either a cube or a cylinder. In this experiment cube has been used.

At first mold was taken volume of 150×150×150 mm. In the cubes, three layers of concrete were poured. Each layer was compacted with 32 tamping rod strokes, and the top surface was finished with a trowel after the last layer was compacted. The specimen was taken out of the mold after 24 hours with proper care. To determine the compressive strength after 7 days and 28 days of curing, three specimens were tested in every case.

Fig. 3. Testing at compressive testing machine.

2.8. Plastic shrinkage test

For plastic shrinkage test a concrete slab of mold size (500 × 250 × 75) mm (Fig. 4a) was prepared. Concrete slab is a typical primary component of present-day structures, comprising of a level, flat surface made of cast concrete. In this experiment simple slab without reinforcement were casted to find out the shrinkage behavior of concrete. Slabs were casted with the same mix design as cube. Firstly, plain concrete was casted and the shrinkage test result observed. Then other slabs were casted with jute fiber and rice husk which were mixed in various proportion with the mix design. Finally, shrinkage test results of other slabs were observed and compared with other results.

Wooden mold was made to cast slab. Inner surface of the mold was coated with thin grease (Fig. 4b) then mold was filled with casted concrete. Then we put the mold in the oven maintaining temperature about (40± 2) °C. Then picture was taken in one-hour interval to check the shrinkage cracks.

(a) (b) (c)

Fig. 4. (a) Wooden Mold (500 × 250 × 75) mm, (b) Concrete Slab (c) Oven Drying.

3. Result and discussion

3.1. Effect of jute fiber and rice husk on compressive strength

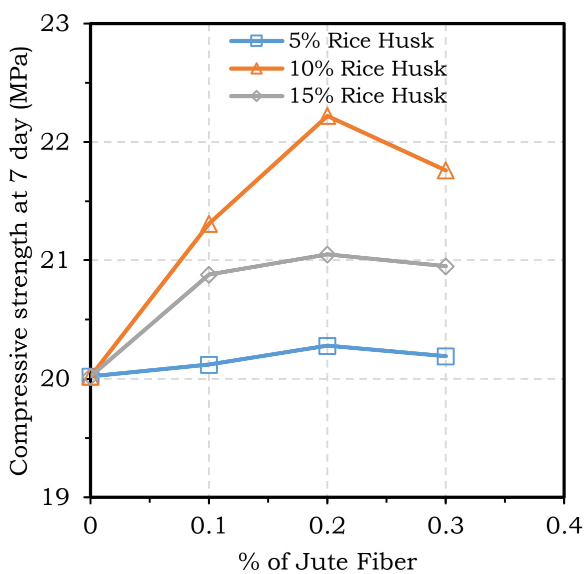
The concrete goal strength was set to 35 MPa in this analysis using ACI 211. (2009). The compressive strength of concrete made with the rice husk (Partial substitution of cement) and jute fiber are represented in figures 5 and 6. From Figure 5, it is seen that the addition of 10% rice husk with 0.2 % jute fiber (13mm) gives a significant improvement in compressive strength up to 1.10% in 7 days (Fig.5a). With this same combination of jute fiber (13mm) and rice husk, the compressive strength can be improved up to 2.03% at 28 days (Fig.5e). Because of the higher amount of reactive silica in rice husk that contributes in the pozzolanic reaction by producing calcium silicate hydrate which enhances the compressive strength. Further addition of rice husk tends to show a decreasing pattern of compressive strength due to the higher requirement of water which affects the workability of the mix as well as the hydration reaction. Bawankule *et al.* [20] found that the compressive strength reduction ranges from 7.11 % to 41.35 % for 2.5 to 15% replacement of cement by rice husk ash (RHA). Furthermore, Krishna *et al.* [14] also reported the reduction of compressive strength with an extent of 8.15% to 40.62% for 5% to 20% replacement of cement by RHA. Patil *et al.* [21] narrated that, 15% RHA in concrete is obtained as an indication of maximum increment of compressive strength. Use of 1% Coconut Fiber (CF) and 9% RHA in concrete as a replacement of cement shows a great increment of compressive strength at 7 days but at 28 days no increment was found [22].

Moreover, addition of distinct jute fibers in concrete, the crack expansion is bridled, and the brittle mode of failure is changed to a more ductile pattern (Figure 6). The more fibers in the mix, the more porosity in the matrix and interference with the concrete matrix's cohesiveness, resulting in the balling effect and a loss in compressive strength [23]**.** In this study, 10% replacement of cement with rice husk and 0.2% jute fiber as reinforcing material is found to be more effective not only for strength improvement but also for reducing failure pattern.

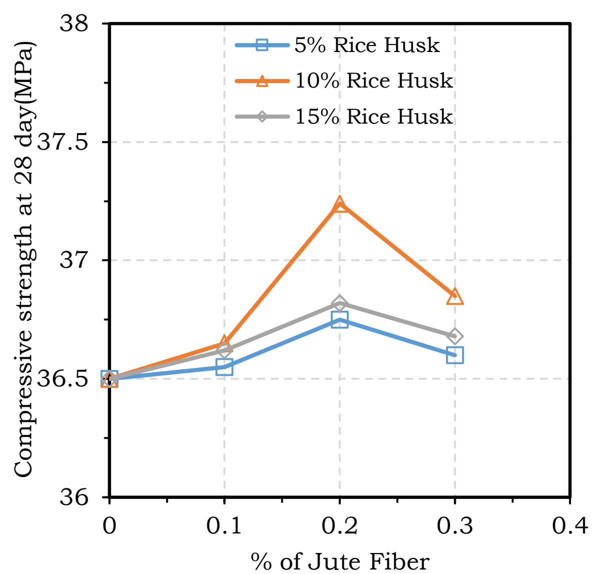
Table 5
Compressive strength and strength effectiveness.

	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.*



(a)



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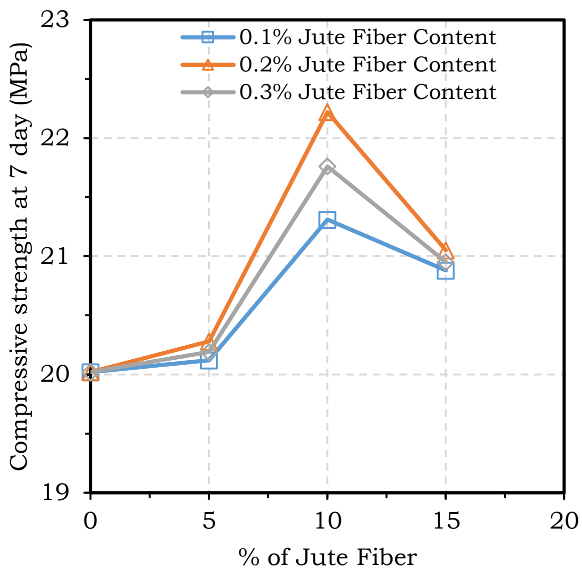

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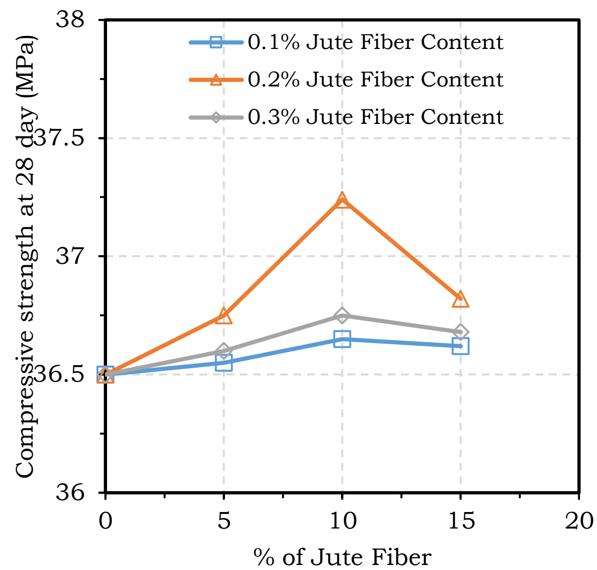
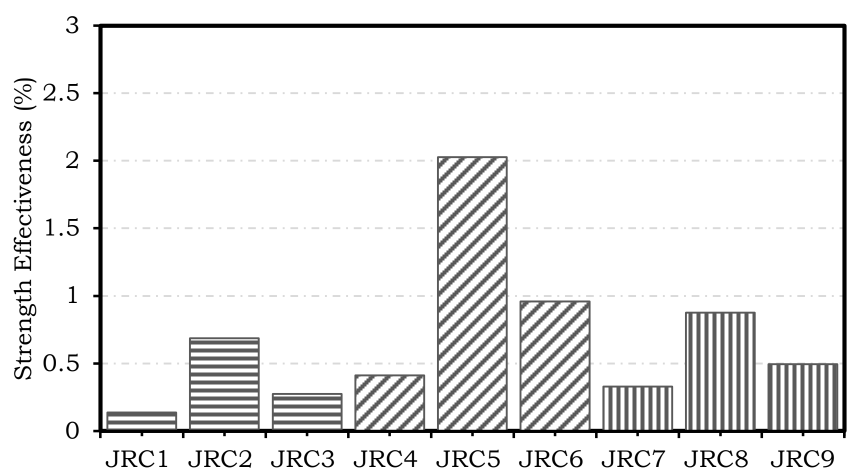


(d)



(e)

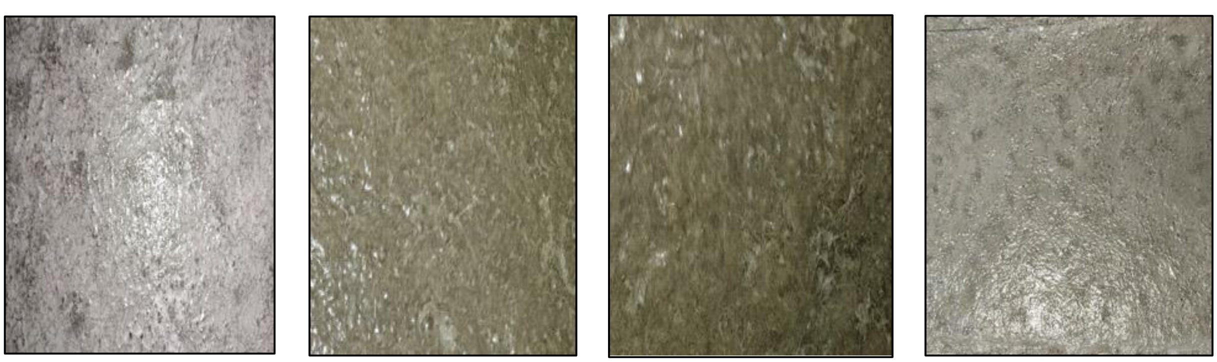
Fig. 5. Comparison of Compressive strength with (a) jute fiber (13 mm) for 7 days curing, (b) jute fiber (13 mm) for 28 days curing, (c) rice husk for 7 days curing, (d) rice husk for 28 days curing (e) Comparison of strength effectiveness.

3.2. Shrinkage test

Figure 7 depicts experimental findings of plastic shrinkage cracks. Since the optimum content of rice husk was found 10%, the shrinkage test was conducted for JRC4, JRC5 and JRC6. The compressive test results represent that the addition of jute fiber has a positive and momentous effect on shrinkage crack. Incorporation of jute fiber (0.1% -0.3%) with 13 mm length (Figure 7d), remarkable reduction of the shrinkage crack was found. The reason behind reducing shrinkage crack can be explained that with addition of jute fiber in concrete bridging mechanism between the pores is increased which subsequently reduce the shrinkage crack. Image analysis software was used to obtain the visible outline of the crack from the images. The pictures were then processed using the 'image j' software. The inspected results are demonstrated Table 6 and Figure 8. Addition of 0.3% jute fiber (by volume), the shrinkage crack is not noticeable. Furthermore, appearance period of first crack was noticed after 2 hours 34 minutes for plain concrete slab whereas jute fiber addition prolonged the appearance period of first crack about 5 times higher than plain concrete. Özgür Erena *et al.* [24] reported, for addition of 0.5% to 1.5% hooked steel fiber (by volume of concrete), the reduction of plastic shrinkage crack ranges between 19.67% to 73.95%.

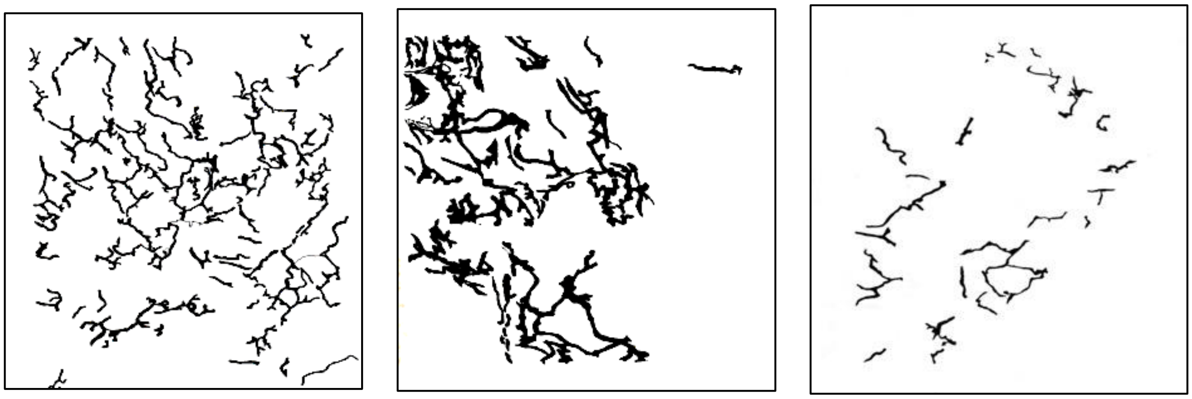
(a) (b)

Fig. 6. Specimen after Compression failure (a) Plain Concrete (b) JRC4 (JF 0.1% & RH 10%).



(a) (b) (c) (d)

Fig. 7. Plastic shrinkage crack formation in concrete slab (covered area: 48 in^2) (a) Plain Concrete (b) JRC4 (10% RH + 0.1% JF) (c) JRC5 (10% RH + 0.2% JF) (d) JRC6 (10% RH + 0.3% JF).



(a) Plain concrete (Crack area: 7.536 in^2) (b) JRC4 (Crack area: 3.264 in^2) (c) JRC5 (Crack area: 0.768 in^2)

Fig. 8. Image analysis for shrinkage crack (area covered 48 in^2).

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.

3.3. Cost analysis considering environmental sustainability

The environmental effect of cement manufacturing has been examined by several researchers. The cement kiln emits CO_2, NO_x, trace amounts of dust, chlorides, fluorides, sulfur dioxide, carbon monoxide, radioactive metals, and organic compounds [25,26]. Natural waste is increasingly being used in concrete work to achieve sustainability, hygiene, and protection. The inclusion of rice husks up to 15% (as a partial replacement of cement) and jute fiber up to 0.3% (as reinforcing material) in concrete provides a significant impact on cost reduction. Considering the cost of cement 450 Tk per bag of 50 Kg and rice husk 5 Tk/Kg for Bangladesh, the depletion of cost is found 2-7% for 5-15% addition of rice husk. Figure 9 shows a decrease in cost per bag of 50kg cement with the increase in rice husk content. The optimum condition is for 10% replacement of cement with rice husk. Considering compressive strength test results of concrete at 28 days along with environmental sustainability, 10% replacement of cement will save 4.7% cost of construction and will reduce the production and release of gasses like CO_2, NO_x, SO_x etc.

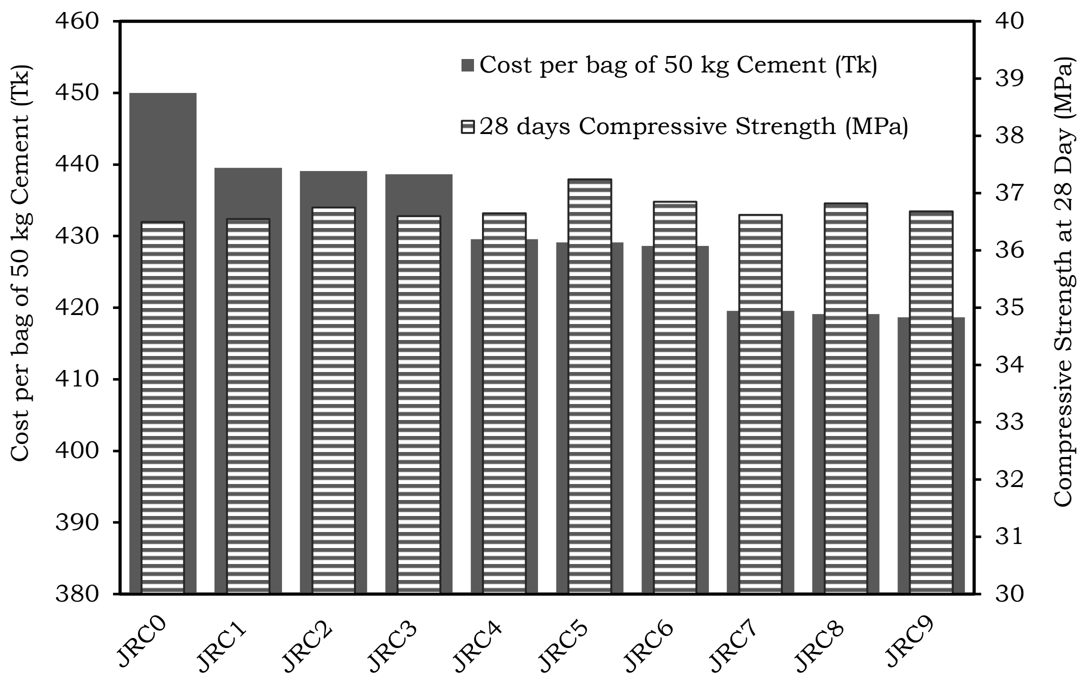


Fig. 9. Cost Analysis considering 1 bag of cement (50Kg).

4. Conclusions

The chemical composition of rice husk indicates that it could be used as pozzolanic material for the improvement of the compressive strength of concrete. However, the inclusion of jute fiber in concrete not only enhances the compressive strength but also diminishes the shrinkage cracks. Furthermore, the incorporation of natural wastes (rice husk) as a replacement material and natural fiber (jute fiber reinforcing material) can reduce the construction cost and production of greenhouse gas. After completion of the tests and analysis of the results regarding compressive strength and shrinkage crack of rice husk and jute fiber reinforced concrete, following are the conclusions that can be deduced:

- Addition of 0.1% to 0.3% jute fiber (13mm) and 5% to 15% rice husk the compressive strength increases from 0.14% to 2.03% with respect to plain concrete.
- The combination of 10% rice husk with 0.2 % jute fiber (13mm) gives a maximum improvement in compressive strength up to 1.10% in 7 days and 2.03% at 28 days.
- Concrete with larger percentages of jute fiber (>0.2%) and rice husk (>10%) has a small reduction in compressive strength. However, it is still comparable with plain concrete.
- Plastic shrinkage cracks were minimized by 56%–99% when 0.1%-0.3% jute fiber (13 mm) was applied to the concrete, relative to the control concrete.
- Incorporation of 0.3% jute fiber in concrete mix expurgates the shrinkage cracks.
- Furthermore, 15% rice husk as cement replacement results in a cost savings of up to 7%. However, considering compressive strength and shrinkage cracks 10% rice husk as cement substitution will be the most promising mix content with cost-saving up to 4.7%.

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