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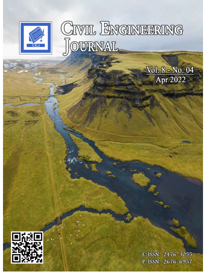

Characteristics of Combined Rice and Wheat Husk Ashes as a Partial Replacement for Cement in Mortar

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Abstract

The potential to recycle and utilize agricultural waste as a building material has been demonstrated in a variety of applications. The goal of this study was to assess the feasibility of partially substituting combined rice and wheat husk ashes (*CORWHA*) for cement in mortar. The two agricultural waste ashes, rice husk and wheat husk, were evaluated separately before being combined. Both husks were burned separately in an open room to reduce volume before being cremated for 2 hours at a regulated temperature of 600 °C to eliminate carbon and generate reactivity. The chemical and physical properties of the ashes were evaluated after grinding and sieving to determine their cementitious qualities before developing and testing 12 mix proportions of CORWHA and cement for mortar production. The mixing was done at three different percentages of cement replacement: 20, 30, and 40%. According to the findings, the maximum cement replacement yielding 5.98 MPa mortar strength is 30%, with a mixed proportion of 11% wheat husk ash (*WHA*) and 19% rice husk ash (*RHA*). It was also found that 95% of RHA is silica and 1.67% is alkaline, while 63% of WHA is silica and 12.16% is alkaline, which is good for preventing porosity and corrosion of reinforcement bars.

Keywords: Rice Husk; Wheat Husk; Agro-Waste Ashes; Cement Replacement.

1. Introduction

Agro-waste recycling has the potential to address both environmental protection and a construction material shortage. A recent study highlights the effort to save the environment through recycling waste rather than throwing it in open spaces [1]. Renewable resources have become a research focus under this notion because they are abundant and easy to get; they provide ecological benefits by being ecologically friendly; they are non-toxic to human health; they are lightweight; and they provide cost savings [2]. There have been a lot of studies that show that agricultural waste can be transformed into new products using natural and less expensive methods. These raw materials can also be used as a low-cost source of silica for industrial uses like therapeutic agents and glass manufacturing. [3]. The efforts shown by other scholars [4] to combat global warming, which is caused by CO_2 emissions, particularly during the production of Portland cement, include blending cement with agro-waste ashes to reduce the volume of cement production. Moreover, the prospect of developing local wheat husk as a lightweight aggregate and a lime-based binder was suggested in order to maintain environmental conservation and address the issue of uncontrolled wheat husks in Europe [5]. Additional research was conducted to determine the effect of partially substituting agricultural wastes, such as rice husk ash, for

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cement [6]. This study revealed that partially substituting agricultural waste decreases environmental consequences and results in ecologically friendly concrete and mortar. Furthermore, it was determined that rice husk ash and wheat husk ash both contain an acceptable amount of silica, which is crucial if these raw materials are to be considered for usage as supplemental cementitious materials in concrete [7].

Although the recycling of agricultural wastes into other products was meant to mitigate environmental degradation caused by improper agro-residue disposal [8], the practice has been hampered by a lack of understanding of the characteristics of agro-waste ashes and processing techniques. In Tanzania, agro-product wastes such as rice husks, wheat husks, maize combs, peanut shells, and wood dust are abundant. According to [9], the quantity of municipal solid waste generated in the country is expected to be more than 10,000 tons per day, with agricultural wastes such as rice husks and wheat husks accounting for a large share of this garbage. As a result, the availability of raw materials for cement replacement across the country is an undeniable issue because only 13% of waste products collected are used as an energy resource (to make fire, livestock fodder, and manure), while 60% of waste products are improperly disposed of, with some being burned in open places. Garbage burning significantly pollutes the environment and has a detrimental influence on human health [10]. Another study from Tanzania found that crop/food and animal product residues were the most often formed solid waste, accounting for 72.4 percent of total solid waste formation at the market [11].

As a developing country, Tanzania's economy is primarily based on agriculture. Agricultural waste, on the other hand, can be a major source of environmental pollution. By utilizing agricultural wastes for the large-scale production of new products, Tanzania has the potential to profit both economically and environmentally [12]. Wheat husk ash (WHA) and rice husk ash (RHA), for example, could be used as a partial replacement for Portland Cement [13]. In this regard, this study investigates the suitability of combining RHA and WHA for cement replacement in the production of mortar. Most of the previous investigations were carried out on concrete blended with either WHA or RHA as cementitious material individually, but the research work that explored the combined effect of both WHA and RHA is very limited. Furthermore, this study emphasizes the importance of sustainability, with the primary goal of investigating the use of RHA and WHA as alternatives for cement replacement, as these are the dominant agro-waste materials in our region. As a result, the research concentrates on the advantageous use of agro-waste materials for construction purposes.

2. Materials and Methods

2.1. Production of RHA and WHA

Rice husks are the hard protective coverings of rice grains that are separated from the grains during the milling process [14]. It is formed from hard materials, including silica and lignin, and is used to protect the seed (grain) during the growing season [15]. During milling of paddy, about 78% of the weight is received as rice, broken rice, and bran, while the remaining weight of paddy is received as a husk [16]. Rice husk is one of the important raw materials (after burning it into ash) in the process of producing cement replacement. The husk contains about 75% organic volatile matter [17], and the remaining 25% of the weight of the husk is converted into ash during the firing process, which is known as rice husk ash (RHA). In turn, the RHA contains around 85–90% amorphous silica. The RHA moisture content ranged from 8.68 to 10.44%, and the bulk density ranged from 86-114 kg/m^3 [18]. The wheat husk is a lignocellulosic waste produced during the separation of wheat grains from their covers, which is about 15–20% of them used as cattle food and fuel. The availability of wheat husk worldwide and in the Mbeya region shows that in 2017, world production of wheat was 772 million tons, with a forecast of 2019 production at 766 million tons [19]. The Mbeya region in southwest Tanzania is one of the country's major wheat-producing areas. Mbeya residents are estimated to produce roughly 20% of the region's wheat husks, which totals more than 1,678 tons per year. The Mbeya district is the region's leading wheat-producing area, accounting for 99% of all wheat produced in the region [20]. Figure 1 shows piles of rice husk and wheat husk produced in the Mbeya region, Tanzania.

a) Rice husk pile b) Wheat husk pile

Figure 1. Piles of rice husk and wheat husk produced in Mbeya region, Tanzania

2.2. Burning and Calcination of RHA and WHA

The rice husks used in this study were collected from the Mbeya region in the dumping area of a rice milling machine in Kabwe market while Wheat husks were collected from small - scale farmers in the Sumbawanga district of the Rukwa region. One day before burning, the collected husks were spread to a depth of 0.5m in different unshaded special burner rooms with dimensions of 2m x 2m. This uncontrollable burning process took more than six hours at the VETA Mbeya campus, after which the ashes were cooled separately at room temperature for twenty-four hours. The uncontrolled burned husk ashes had a black tint to them, indicating the presence of an excessive amount of carbon content, which agrees with the findings of previous research [2]. As a result, the RHA and WHA with blackness were further burned for 2 hours at 600°C in a special industrial furnace, as described in Figure 2.

(a) Burning of raw material

(b) Incinerating raw material

Figure 2. Husks burning process

The temperature of the furnace was increased at a rate of 100°C per hour for 6 hours until it reached the desired temperature of 600°C, after which it was kept steady for 2 hours under controlled conditions before being cooled for 12 hours. The mechanical laboratory at Mbeya University of Science and Technology (MUST) was used for the second burning process. The ashes were processed using a disc mill machine at a rate of 2 kg per hour before sieving in standard mesh.

2.3. Characterization of Materials

2.3.1. Chemical Composition of RHA, WHA, and OPC

The chemical composition of both ashes and cement samples were examined using X-ray fluorescence (XRF). Loss-On-Ignition (LOI) test was carried out as per procedure given in IS 1727: 1967 at Mbeya Cement Company Ltd chemistry laboratory. MUST laboratory examined the physical properties of these ashes. The purpose of chemical and physical testing on these materials is simply to check for the presence and levels of the main ingredients of chemicals used in cement manufacturing. Table 1 summarizes the XRF results, while Table 2 summarizes the physical properties of samples. As shown in Table 1, both RHA and WHA contain silica (SiO_2) and alkaline (K_2O) compounds that contribute to the reduction of concrete's porousness, hence preventing rust.

Table 1. Chemical Composition of RHA, WHA and cement

Compound	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	LOI
Cement 42.5N	14.89	3.83	3.06	60.71	0.81	2.38	0.11	0.37	13.3
RHA	94.27	1.13	1.89	0.72	0.33	0.05	0.16	1.67	0.75
WHA	69.64	3.15	2.55	2.79	1.54	0.35	0.20	12.16	7.12

Table 2. Physical properties of RHA, WHA and Cement

Materials	Specific gravity	Blaine (cm^2/g)
Cement	3.16	4350
RHA	2.05	7700
WHA	2.21	2380

2.3.2. Fine Aggregate Acidic Test

According to ASTM C778 - 17, and Fine aggregate consists of natural sand, crushed stone sand, or crushed gravel stone dust. It should be hard, durable chemically inert, clean, and free from organic matter, not containing any appreciable amount of clay balls or pellets and other harmful impurities such as alkaline, salt, mica, decayed vegetation, lumps [21, 22]. In addition, the sand was tested for organic and inorganic impurities. Another standard involved in sand confirmation is ASTM C109 [23]. Based on this reference, the researcher used the Mbeya Maji office's zonal water quality laboratory to analyze the sand collected from the Mbarali pit. The results are shown in Table 3.

Table 3. Sand chemical properties

Compound	Test results	Recommended	Comments
pH	7.03	6.5 to 7.5	Acceptable
Electrical conductivity (μS/m)	244	< 100,000	Acceptable
Chloride (mg/L Cl)	14.18	250 (WHO)	Acceptable
Sulphate (mg/L $S0_4^2$)	65	250 (WHO)	Acceptable
Salinity (ppt)	0.17	< = 0.5	Acceptable
Total dissolved solids (mg/L)	158	< 300 > 600	Excellent

2.3.3. Sieve Analysis

Sieve analysis of fine aggregates is one of the most important tests performed on-site. As a result of this, aggregates serve two primary functions in mixed design: as inert materials mixed with binding materials and as fillers in mortar and concrete for masonry and brick masonry. A sieve analysis experiment was carried out as per IS 383-1970 to assess the particle size of rice husk ash, wheat husk ash, and sand. The weight of the samples was 2,605g for accurate results, with the can weighing 287.7g. The weight of rice husk ash and wheat husk ash, on the other hand, was 100g for each sample, as measured using an electric balance at the MUST Civil Engineering laboratory. Each sieve's percentage of retained mass was calculated as per IS 383. Tables 4 and 5 show sieve analysis of fine aggregates and cementitious materials, respectively.

Table 4. Sieve analysis test of fine aggregate: test method: IS 383-1970

Sieve size (mm)	Mass of sample + can (g)	Mass of sample retained	% of Mass Retained	% Passing	Zone - 1	Zone - 2	Zone - 3	Zone - 4
37.5	287.7	0	0.0	100	100	100	100	100
20	287.7	0	0.0	100	100	100	100	100
14	295.3	7.6	0.3	100	100	100	100	100
10	292	4.3	0.2	100	100	100	100	100
5.0	341.4	53.7	2.1	97	90-100	90-100	90-100	95-100
2.36	493.1	205.4	7.9	90	60-95	75-100	85-100	95-100
1.18	819.8	532.1	20.4	69	30-70	55-90	75-100	90-100
0.6	1001.2	713.5	27.4	42	15-35	35-59	60-79	80-100
0.3	912	624.3	24.0	18	5-20	8-30	12-40	15-50
0.15	612.0	324.3	12.4	5	0-10	0-10	0-10	0 - 10
0.075	325.0	37.3	1.4	4				
Fineness Modulus (FM)				3.1	4.0-2.71	3.37-2.1	2.78-1.71	2.25-1.35

Initial dry mass of aggregate = 2,605g, Mass of can = 287.7g

Table 5. Sieve analysis test of cementitious materials

Sieve size	WHA	RHA	Cement
90 μm	99.10	100.00	98.20
75 μm	97.00	95.50	96.00
45μm	79.50	88.30	85.40

2.4. Specific Gravity of RHA and WHA

In the construction industry, specific gravity is used to determine the suitability of materials used in concrete and mortar production [24]. Cementitious materials' particles can sometimes include water or have pores that allow water to settle in, affecting the mixture design. A nominal mix, for example, is made with a cement with a specific gravity of 3.15, notwithstanding the fact that old stock cement may be altered by external moisture content. According to the results of this study's tests referenced in BS 1377: Part 2: 1990, Table 4, the specific gravity of RHA and WHA was 2.05 and 2.21, respectively. Tables 6 and 7 show specific gravity of solids (Gs) for WHA and AHA and cement, respectively.

Table 6. Specific gravity of solids (Gs) BS 1377: Part 2: 1990 for WHA and RHA

Sample Type	Unit	RHA		Unit	WHA	
Bottle No.		FR4	FS2		FR4	FS2
Mass of Bottle + Stopper	g	202.40	208.70	g	202.40	208.70
Mass of Bottle + Stopper + Solid	g	270.70	283.60	g	270.70	283.60
Mass of Bottle + Stopper + Solid + Water	g	541.20	549.60	g	541.20	549.60
Mass of Bottle + Stopper + Water	g	503.20	507.60	g	503.20	507.60
Gs for Solid		2.20	2.22		2.20	2.22
average of Gs		2.21			2.21	
Temperature of Water	°C	25.00		°C	25.00	
Correction factor for Gs		1.00	1.00		1.00	1.00

Table 7. Specific gravity of solids (Gs) BS 1377: Part 2: 1990 for Cement

Sample Type	Unit	Cement	
Bottle No.		FR4	FS2
Mass of Bottle +STOPPER	g	201.70	205.70
Mass of Bottle+ STOPPER +Solid	g	323.40	328.40
Mass of Bottle+ STOPPER +Solid +Water	g	524.30	528.60
Mass of Bottle+ STOPPER +Water	g	440.00	444.10
Gs of Solid		3.18	3.14
Average of Gs		3.16	
Temperature of water	°C	25	
Correction factor for Gs		1.00	1.00

2.5. Mix Proportions

The Combined Rice and Wheat Husk Ashes (*CORWHA*) were obtained by mixing these ashes in a ratio of 63% for RHA and 37% for WHA by weight. The ashes were divided into three groups, as shown in Table 8, to achieve this optimal level for partial replacement of cement in masonry mortar. The replacement of 20%, 30%, and 40% of cement with varying ratios of CORWHA is shown in the mix proportions that contain cement as a basic material to be replaced. Figure 3 shows the process of mixing raw materials to make CORWHA.

a) WHA b) WHA+RHA c) CORWHA

Figure 3. The process of mixing raw materials to make CORWHA

Table 8. Mix proportions for Cement, RHA, and WHA

Mix proportions for Cement, RHA, and WHA (% of Cement is constant per each level)					
Cement	100%	80%	80%	80%	80%
WHA	0%	7%	11%	15%	19%
RHA	0%	13%	9%	5%	1%
	100%	**100%**	**100%**	**100%**	**100%**
Cement	100%	70%	70%	70%	70%
WHA	0%	11%	17%	23%	29%
RHA	0%	19%	13%	7%	1%
	100%	**100%**	**100%**	**100%**	**100%**
Cement	100%	60%	60%	60%	60%
WHA	0%	15%	23%	31%	39%
RHA	0%	25%	17%	9%	1%
	100%	**100%**	**100%**	**100%**	**100%**

2.6. Preparation of Test Specimen

Ingredients for different mixes are prepared and measured in the ratio shown in Table 8 before mixing with a specific percentage of water. The specific mould that was prepared for the research was as follows: 50×50×50 mm for mortar cubes as per ASTM C109/C109M-20a and 50×50×10 mm slate mortar according to BS EN 998-2, but instead of using two masonry units, a special mould of the required size was prepared. The mortar was prepared and mixed using a masonry pan and two brick trowels with the help of a steel scraper, but precautions were taken to ensure uniform mixing of materials before being filled into the mould and shaken using a table vibrator for two minutes to remove voids in the mixtures. Immediately after casting, all samples were covered with a polythene membrane of 500-gauge size over the mould for 24 hours. After this specific time period in the first curing, the specimens were de-moulded and immediately placed in a water tank for further curing.

2.7. Tests

2.7.1. Standard Consistency

In IS: 269 (1976) and IS: 4031 (1968), the standard consistency or normal consistency of a cement paste is defined as the amount of water (in percentage by weight of dry cement) that permits the Vicat plunger to penetrate to a depth of 5 to 7 mm from the bottom of the Vicat mould. A certain minimum quantity of water is required to be mixed with cement to complete a chemical reaction between water and cement. And less water than this quantity would not complete the chemical reaction, thus resulting in a reduction in strength, while more water would increase the water-cement ratio and so would reduce its strength. Thus, the correct proportion of water to cement needs to be known to achieve proper strength while using cement in the structure [25]. Table 9 shows the Standard consistency. In this test, 400g of dry RHA and 400g of dry WHA were prepared whereby the Vicat apparatus was employed in performing the test at MUST Soil Laboratory as described below:

The process started by Weighing out 400gm of RHA and 400gm of WHA and place on the mixing plate. At this test the addition of water was as the following;

- For WHA the first amount of water was 120ml which was equal to 30% then 36ml which made the total amount of water be 156ml equals to be 39% of the amount of WHA weighed.
- For RHA the first amount of water was 120ml which was equal to 30% then 29ml which made the total amount of water to be 149ml equals to be 37% of the amount of RHA weighed.

Table 9. Standard Consistency

Materials	% Of water	Amount of water (ml)	Initial (Minutes)	Final (Minutes)	penetration (mm)
RHA	37	156	95	245	5
WHA	39	149	50	192	5

2.7.2. Setting Time

Initial setting time gives an idea about how fast cement can start losing its plasticity and the final setting time of cement gives an idea about how much cement takes to lose its full plasticity and gain some strength to resist pressure [26]. Setting time tests help in determining when the cement or binding materials used begin to lose their plasticity, which aids in the planning of the activity's working schedule. Table 10 shows the setting times of RHA, WHA and OPC. Figure 4 shows the flowchart for characterization of raw materials, including compressive strength testing.

Table 10. Setting times of RHA, WHA and OPC

Materials	Initial (Minutes)	Final (Minutes)
RHA	95	245
WHA	50	192
OPC	30	600

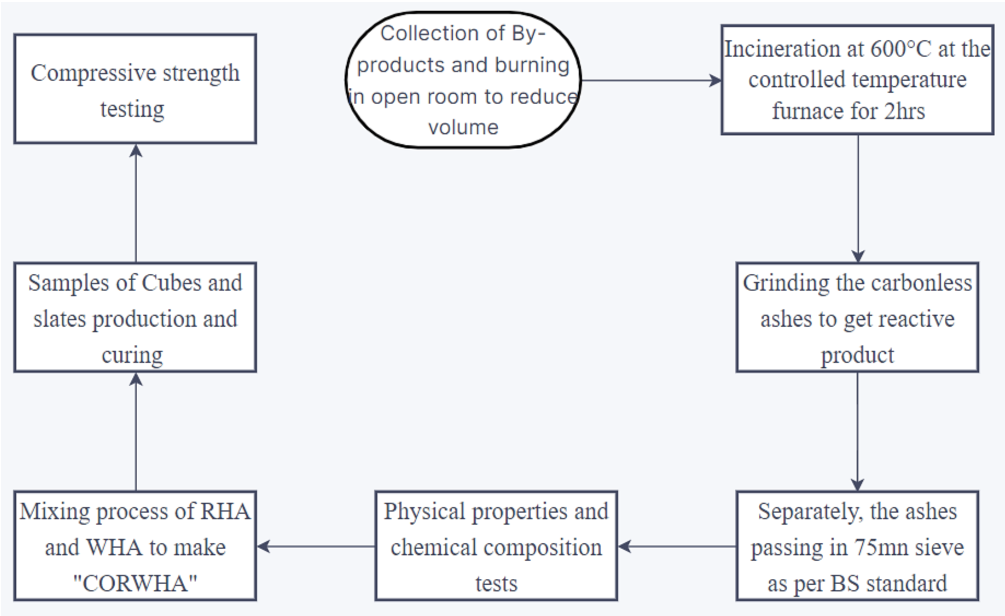

Figure 4. Flowchart for characterization of raw materials, including compressive strength testing

3. Results and Discussion

3.1. Results

3.1.1. Sieve Analysis for Cementitious Materials

Standard meshes of 90, 75, and 45 μm were employed to fine cementitious materials, with all samples passing through the 90 m sieve and retentions of 95.5, 96, and 97% at the 75 μm sieve. The final retained 45 μm sieve standard mesh size was 17, 20.5, and 15% by weight for rice husk ash, wheat husk ash, and cement, respectively. As reported by Bazzar et al. (2021), the fineness of the ash is the primary determinant of the mortar's compressive strength. It must consequently conform to the fineness requirement of the cement with which it will be mixed. The passing and retained percentage determined after the collection as per ASTM C184-1994 is shown in Figure 5.

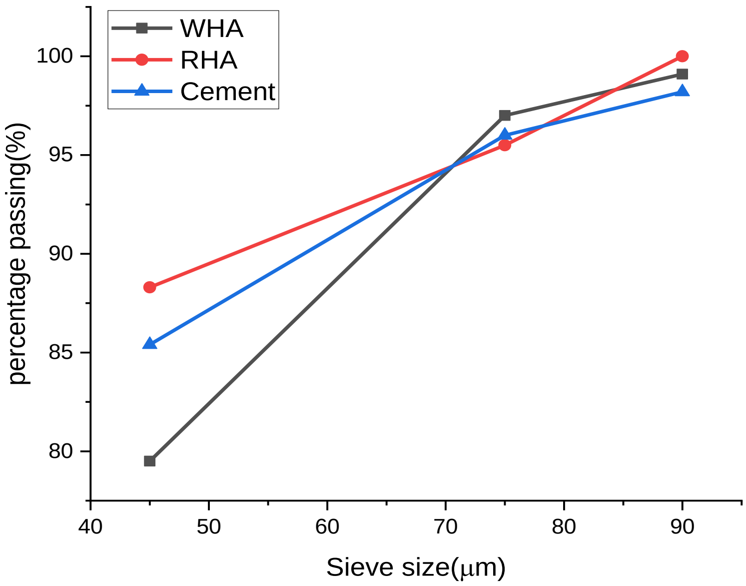

Figure 5. Grading curve for WHA, RHA and cement

3.1.2. Sieve Analysis (Grading Curve of Fine Aggregate)

From grading curve of fine aggregate shown in Figure 6, the percentage passing weight was compared with the permissible values given in the IS 383. The standard table in IS code shows the permissible values of percentage passing for different grading zones i.e., Zone I, Zone II, Zone III, and Zone IV. In this instance, based on the comparison to Table 4 IS:383, we determined that the fine aggregate from the Mbarali pit used in this research falls inside Grading Zone II.

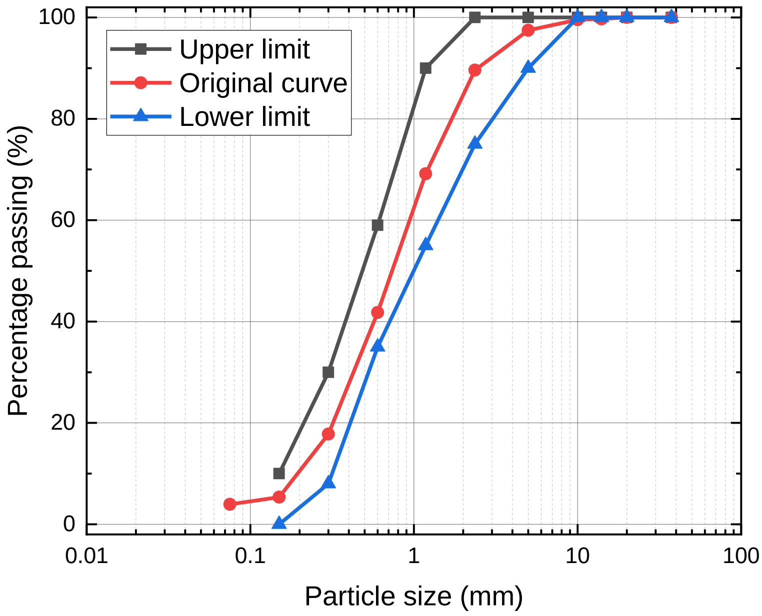

Figure 6. Sand grading curve

3.1.3. Compressive Strength

The compressive strength of CORWHA mortar was developed through testing of 144 mortar cubes (50 mm) and 48 slates of masonry joints (50×50×10 mm), which were produced at a ratio of 1:4 in each level of replacement percentage of 20, 30, and 40%. The cubes and slate samples were tested for compressive strength at the ages of 3, 14, 21, and 28 days. The mortar in this study was designed to have a compressive strength ranging from 5 to 15 MPa [27]. In Table 11 and Figure 7, the results of compressive strength are reported. It can be seen that the strength of mortars for various mix proportions increases with time.

Table 11. Mix proportion for RHA, WHA, and Cement with compressive strength per age

Age of cubes Mix proportion (% replacement)	Mortar Ratio	3days (N/mm²)	14days (N/mm²)	21days (N/mm²)	28days(N/mm²)
OPC 80%, WHA 7%, RHA 13%	1:4	2.29	2.96	5.10	6.13
OPC 80%, WHA 15%, RHA 5%	1:4	1.30	1.94	2.47	3.35
OPC 80%, WHA 11%, RHA 9%	1:4	1.74	3.00	3.46	4.80
OPC 80%, WHA 19%, RHA 1%	1:4	2.19	2.53	3.19	4.48
OPC 100%, WHA 0%, RHA 0%	1:4	3.22	4.70	8.21	11.34
OPC 70%, WHA 17%, RHA 13%	1:4	1.02	2.48	2.45	4.26
OPC 70%, WHA 11%, RHA 19%	1:4	1.90	4.03	4.70	5.98
OPC 70%, WHA 23%, RHA 7%	1:4	1.89	2.87	3.07	4.00
OPC 70%, WHA 29%, RHA 1%	1:4	1.45	2.67	2.95	3.57
OPC 100%, WHA 0%, RHA 0%	1:4	3.22	4.70	8.21	11.34
OPC 60%, WHA 39%, RHA 1%	1:4	0.27	0.67	0.56	1.49
OPC 60%, WHA 23%, RHA 17%	1:4	0.90	2.01	2.3067	2.47
OPC 60%, WHA 31%, RHA 9%	1:4	1.15	1.86	2.23	2.43
OPC 60%, WHA 15%, RHA 25%	1:4	1.23	2.00	2.40	2.92
OPC 100%, WHA 0%, RHA 0%	1:4	3.22	4.70	8.21	11.34

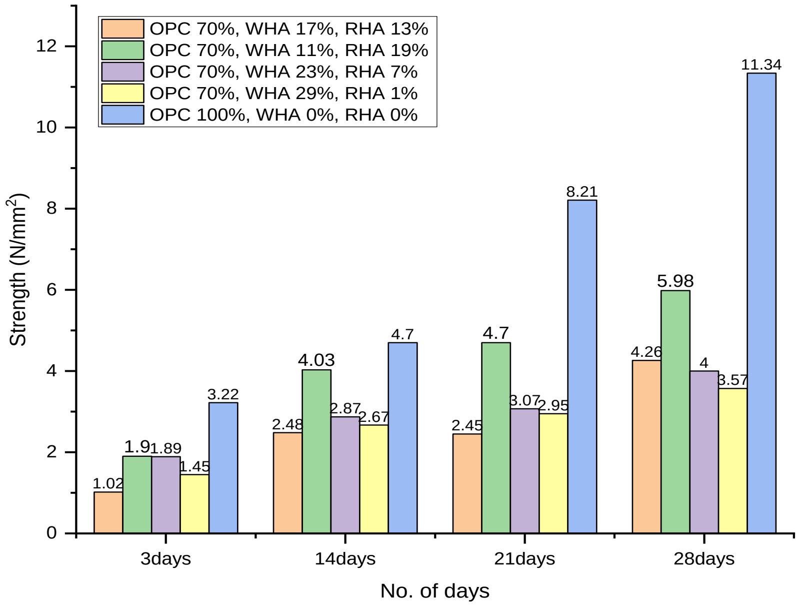

Figure 7. The graph of strength versus age of cubes corresponding to 30% cement replacement

3.2. Discussion

Figure 7 depicts the strength versus age of cubes for 30% cement replacement, while Table 11 shows the compressive strength of each group at 3 days, 14 days, 21 days, and 28 days. The optimal compressive strength for Group 1 (replacement of 20%) was 6.13 MPa from a mixture of RHA 13% and WHA 7%. The mix proportion of WHA at 11% and RHA at 19% yields a compressive strength of 5.98MPa, which appeared as the optimum strength in Group 2 (replacement of 30%), including the compressive strength of 7.01MPa produced by slates in the same group and replacement. The final group is the replacement of 40%, where the optimum compressive strength appeared at a mix proportion of WHA of 15% and RHA of 25%, yielding a compressive strength of 2.92 MPa. According to these findings, increasing the percentage of RHA in the mix proportion results in the best compressive strength, whereas increasing the percentage of WHA in the replacement lowers the compressive strength of mortar. The chemical composition analysis reveals that the high content of silica (SiO_2) and alkaline (K_2O) in both RHA and WHA in the mixture decreased compressive strength, which is very bad if compressive strength is the only property used to judge the suitability of replacement. However, when other properties and benefits are taken into account, the increase in alkaline and silica improves the final setting time of binding materials and forms the protective cover for reinforcement to protect rebars from corrosion. As a result, using less alkaline in cement contributes to reinforcement bar corrosion [28]. On the other hand, the reaction activity of silica with Portland Cement minerals results in a slight decrease in porosity and an improvement in the mechanical resistivity of cement pastes containing SiO_2 [29].

During the production of the testing specimens, tested parameters such as water to cement ratios, curing methods, and mortar testing age all had a significant impact on the compressive strength of the tested mixtures, as shown in Table 11. As with other types of mortars, increasing specimen age gradually improves mortar compressive strength, particularly at the 30% replacement level. On the other hand, increasing CORWHA replacement in cement, especially if the replacement is greater than 30%, reduces compressive strength, indicating that CORWHA's vulnerability at greater than 30% replacement necessitates further research.

Zareei et al. (2017) proposed ratios of rice husk ash (RHA) on concrete were presented using five mixture designs with proportions of 5, 10, 15, 20, and 25% RHA by weight. The ideal level of strength and durability attributes was indeed typically obtained with an increase of up to 20%, with a minor decrease in strength of about 4.5 percent after [30]. Aksoğan et al. (2016) conducted an experimental study of concrete made with ordinary Portland Cement and 10%, 20%, 30%, and 40% wheat straw ash replacing OPC. In this research, an optimum percentage of 10% WSA was recommended for use in concrete production [31]. Khan et al. (2020) investigated the utilization of micro-silica from rice husk ash for the creation of high-performance and sustainable cement mortar by substituting cement with 5%, 15%, and 25%, although the improvement was only shown at the 5% and 15% replacement levels [32]. In other studies [33, 34], wheat and rice by-product ashes were substituted in additional trials to see how they affected the properties of concrete mixes. The percentages of the husk ashes were 5%, 10%, 15%, and 20% of the weight of the cement, with the optimum obtained at 15%. In terms of replacement levels, the findings of the preceding research articles can be compared to current research. According to those studies, the maximum replacement does not reach 30% when compared to this study, and the majority of them were based on concrete mixes. However, only one study combined rice and wheat by-product ashes, and it only achieved the optimum of 15%.

4. Conclusions

The primary objective of this study was to determine the feasibility of substituting rice husk and wheat husk ashes for cement in the production of mortar. To obtain the minimum stipulated compressive strength of 5 MPa for mortar, various replacement percentages were specified to establish the optimal mix proportions. Based on the findings of this study's experiments, it is possible to conclude that:

- At 28 days, a compressive strength of 6.13 MPa was achieved by replacing 20% of the cement with 7% of WHA and 13% of RHA.
- At a 30% cement replacement, the suit mix was obtained by substituting 11% WHA and 19% RHA, resulting in a compressive strength of 5.98 MPa.
- At a 40% cement replacement, the suit mix was obtained by substituting 15% WHA and 25% RHA, resulting in a compressive strength of 2.92 MPa.
- The highest percentage of partial replacement of cement in mortar is 30%, with the mix proportions of WHA at 11% and RHA at 19%, yielding a compressive strength of 5.98 MPa, which is higher than the target strength of 5 MPa specified in this study.
- At the highest percentage of partial replacement of cement, the mix proportion of combined rice and wheat husk ashes (*CORWHA*) is 63% RHA and 37% WHA.

To achieve the best results, a CORWHA mix ratio of 63% RHA and 37% WHA is recommended, with a 30% cement substitution in mortar. However, additional research is needed to address the limitations of the results described, particularly when using more than 30% CORWHA in cement replacement and expanding its applications, such as in concrete and brick manufacturing, which were not the focus of this study. Future research will focus on evaluating the effect of CORWHA in the production of concrete as well as durability.

5. Declarations

5.1. Author Contributions

Conceptualization, D.N.M. and M.S.M.; methodology, D.N.M.; validation, D.N.M., M.S.M. and P.N.; formal analysis, D.N.M.; investigation, D.N.M.; resources, D.N.M.; writing—original draft preparation, D.N.M.; writing—review and editing, D.N.M. and P.N.; visualization, D.N.M. and P.N.; supervision, M.S.M. and P.N.; funding acquisition, D.N.M. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

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5.5. Conflicts of Interest

The authors declare no conflict of interest.

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