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# The Influence of Rice Husk Ash on Mechanical Properties of the Mortar and Concrete: A Critical Review

**Md Jahangir Alam[1*], Mithun Biswas[1], Mohammad Biplab Mia[1], Shahin Alam[2], Md Mosabber Hossain[1]**

[1]College of Civil and Transportation Engineering, Hohai University, Nanjing, China
[2]School of Civil Engineering, Chang'an University, Xi'an, China
Email: *jahangiralam504016@outlook.com, mithunbiswas.189046011ahut@gmail.com, biplab40103@gmail.com, srshahinalam440@gmail.com, akashnil202@gmail.com

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## Abstract

Increasing the population and infrastructure in both emerging and developed countries requires a considerable amount of cement, which significantly affects the environment. The primary materials of concrete ('cement') production emit a large quantity of $CO_2$ into the environment. Also, the cost of conventional building materials like cement gives motivation to find geopolymer waste materials for concrete. To reduce harmful effects on the environment and cost of traditional concrete substance, alternative waste materials like rice husk ash (RHA), ground granulated blast-furnace (GGBS), fly ash (FA), and metakaolin (MK) can be used due to their pozzolanic behavior. RHA waste material with a high silica concentration obtained from burning rice husks can possibly be used as a supplementary cementitious material (SCM) in the manufacturing of concrete, and its strong pozzolanic properties can contribute to the strength and impermeability of concrete. This review paper highlights a summary of the positive effect of using RHA as a partial substitute for cement in building construction, as well as its optimal inclusion of enhanced mechanical properties like compressive strength, flexural strength, and split tensile strength of mortar and concrete.

## Keywords

Cement, Rice Husk Ash, RHA Properties, Mechanical Properties, Carbon Dioxide Emission and Greenhouse Gas

## 1. Introduction

In the building industry, concrete and mortar are used widely and globally. They are two important materials throughout the history of humankind that have applications to strengthen structures. The building sector has a significant and obvious impact on global resources, energy consumption and $CO_2$ emissions. Due to the growth in population and structure in emerging and developed countries, the consumption of building materials and the quantity of manufacturing cement have increased rapidly [1] [2] [3] [4]. The process of making cement follows several steps, from the very early step of smashing the raw materials to the assembly of the cement bag. Cement production, especially the processing of clinkers, requires heating form that releases a lot of energy as well as considerable quantities of carbon dioxide ($CO_2$) and other greenhouse gases (GHGs) into the atmosphere [5]. Carbon dioxide emissions from the cement manufacturing sector are predicted to account for about 7% of worldwide $CO_2$ emissions, and total carbon emissions from the world's cement industry are expected to grow by4% by 2050 [1] [6]. To mitigate global warming and overall cost of concrete production, many researchers have intensively researched the utilization of waste materials from industries and agriculture such as waste paper sludge ash [7] [8], electric arc furnace dust [9] [10], waste foundry sand [11] and rice husk ash [12] [13], corn cob ash [14], rice straw ash [15], coal bottom ash [16] and sugarcane bagasse ash [17] as partial cement replacement in concrete and mortar.

Rice husk ash is an optimistic agricultural waste cementitious substance for mortar and concrete because of its pozzolanic properties and huge silica contents. Mehta got a patent in 1978 for the manufacturing of RHA that may be utilized as a pozzolan. To produce ash from rice husks, a process of slow combustion of the husks at a temperature of 500 to 700˚C is necessary [18]. RHA contains a lot of $SiO_2$, and the majority of it is in amorphous form. It is estimated that 1000 kg of rice grains generated 200 kg of rice husks and after burning the rice husks, approximately 20% or 40 kg became RHA [19]. The United States Department of Agriculture (USDA) predicts global rice production in 2023/2024 will reach 518.14 million metric tons, which is an increase of 4.45 million tons or 0.87% compared to last year [20], and it indicates the availability of RHA as a substitute for cement-like substances in mortar and concrete.

During the RHA production period, much less $CO_2$ is released than cement production because it's a carbon-neutral material and requires lower energy. On the other hand, the removal of rice hulls during rice refining is harmful to nature and pollutes the soil and the nearby region where the rice is thrown because the rice hulls are mostly indigestible to humans and don't have useful economic advantages [21]. Therefore, the commercial uses of rice husk ash in the construction industry as an alternative solution to disposal problem.

RHA can be utilized as an economic alternative for silica fume like SCM, which has qualities similar to microsilica. Therefore, to reduce the total production costs of concrete, it is more appropriate to use RHA as the most available, cheaper and less environmental pullulate [22]. According to previous experimental researches, the incorporation of RHA considerably enhanced the microstructure and mechanical characteristics of mortar and concrete composites. The following paper summarizes the physical and chemical characteristics of RHA in sections 2, 3 and 4 are the effect of RHA addition on the mechanical properties of mortar and concrete, which includes compressive strength, flexural strength and split tensile strength of mortar and concrete. Finally, a brief discussion of future prospects and limitations was also provided.

## 2. The Physical and Chemical Characteristics of Rice Husk Ash

Previous studies' RHA physical properties, such as specific gravity, the specific surface area, bulk density, particle size, and color, were thoroughly reviewed. **Table 1** presents the physical properties of RHA as used by different researchers.

As can be seen from **Table 1**, the average particle size of RHA varies from 3.80 μm to 40 μm [23] [24] [25], while the specific gravity varies between 2.00 to 2.82 [23] [24] [25] [26] [27]. **Table 2** shows the chemical characteristics of the RHA used in the prior study.

It can be noticed from **Table 2**, that the amount of silica is significant, and different chemical components like silica oxide, alumina oxide, and iron oxide are more than 92%, which indicates rice husk ash is pozzolanic materials in concrete [28] [29] [30].

**Table 1.** The physical characteristics of RHA.

| Sources | Specific gravity | Specific surface area ($m^2/kg$) | Bulk density ($kg/m^3$) | Particle size (μm) | Color |
|---|---|---|---|---|---|
| [23] | 2.00 | 183.3 | - | 3.80 - 5.6 | - |
| [24] | 2.11 | - | - | 11.5 - 18.3 | - |
| [25] | 2.35 | - | 236 | 10 - 40 | - |
| [26] | 2.82 | 460.0 | - | - | - |
| [27] | 2.14 | 462.0 | - | <45 | - |

**Table 2.** The chemical characteristics of RHA.

| Sources | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $Na_2O$ | $K_2O$ | $P_2O_5$ | LOI* |
|---|---|---|---|---|---|---|---|---|---|
| [24] | 88.32 | 0.46 | 0.67 | 0.67 | 0.44 | - | 2.91 | - | 5.81 |
| [28] | 92.08 | 0.11 | 0.05 | 0.78 | 0.49 | - | 3.50 | 1.35 | 1.83 |
| [29] | 92.95 | 0.31 | 0.26 | 0.53 | 0.55 | 0.08 | 2.06 | - | 1.97 |
| [23] | 86.49 | 0.01 | 0.91 | 0.50 | 0.13 | 0.05 | 2.70 | 0.69 | 8.83 |
| [30] | 90.55 | 0.82 | 0.46 | 1.56 | 0.98 | 0.58 | 1.33 | - | 2.62 |

*LOI: Loss on ignition.

# 3. The Effect of the Rice Husk Ash Addition on the Mechanical Properties of Concrete

## 3.1. Compressive Strength of Concrete

The compressive strength of concrete is the ability of a concrete substance or structure to sustain the vertically acting forces. A brittle material begins to break down when the compressive strength limit is reached [31]. According to previous research, an enhancement in the compressive strength of concrete was observed at different amounts of RHA replacement. In **Table 3**, several researchers investigated the impacts of RHA on the compressive strength of concrete at various rates of replacement, ranging from 0% to 30%.

**Table 3.** Compressive strength of concrete.

| Sources | Replacement levels (%) | Compressive strength (MPa) | | | |
|---|---|---|---|---|---|
| | | 7 days | 14 days | 28 days | 90 days |
| [32] | 0 | 25.5 | 28.4 | 31.7 | - |
| | 5 | 28.4 | 31.5 | 32.6 | - |
| | 10 | 30.5 | 32.4 | 35.2 | - |
| | 15 | 31.1 | 33.7 | 36.4 | - |
| | 20 | 32.8 | 34.5 | 37.5 | - |
| | 25 | 30.4 | 33.2 | 32.6 | - |
| | 30 | 23.7 | 25.1 | 30.5 | - |
| [28] | 0 | 40.2 | - | 53.9 | 60.9 |
| | 10 | 42.3 | - | 57.6 | 66.8 |
| | 20 | 43.6 | - | 59.2 | 68.7 |
| | 30 | 38.0 | - | 51.6 | 59.4 |
| [33] | 0 | 32.1 | 43.4 | 46.5 | - |
| | 10 | 34.2 | 44.7 | 49.8 | - |
| | 15 | 33.2 | 43.7 | 48.5 | - |
| | 20 | 31.7 | 42.8 | 47.3 | - |
| [34] | 0 | 28.00 | 31.00 | 39.00 | - |
| | 5 | 28.20 | 31.50 | 39.20 | - |
| | 10 | 29.90 | 32.90 | 40.50 | - |
| | 15 | 26.75 | 29.00 | 35.20 | |
| | 20 | 25.00 | 27.00 | 32.50 | - |
| [35] | 0 | 17.51 | 21.60 | 29.51 | - |
| | 5 | 16.88 | 17.44 | 27.68 | - |
| | 10 | 12.10 | 12.83 | 20.88 | - |
| | 15 | 11.24 | 12.55 | 18.70 | - |

In a previous study [32] **Figure 1(a)**, it was observed that including RHA resulted in a strength increase of 5% - 20% of cement replacement in comparison with the control mix along with other RHA mixes. However, in concrete, the percentage of RHA after 20% showed a decrease in strength because of the existence of an enormous or high amount of RHA to mix with the cement and separate during the process of hydration. The other experimental research [28] [33] [34] **Figures 1(b)-(d)** with a different mixture of RHA showed a similar positive influence in compressive strength within a certain amount, and excessive dosage indicates lower compressive strength. In another study [35], **Figure 1(e)** shows lower compressive strength after mixing RHA in concrete. In summary of different studies, RHA is an optimistic cementitious concrete material.

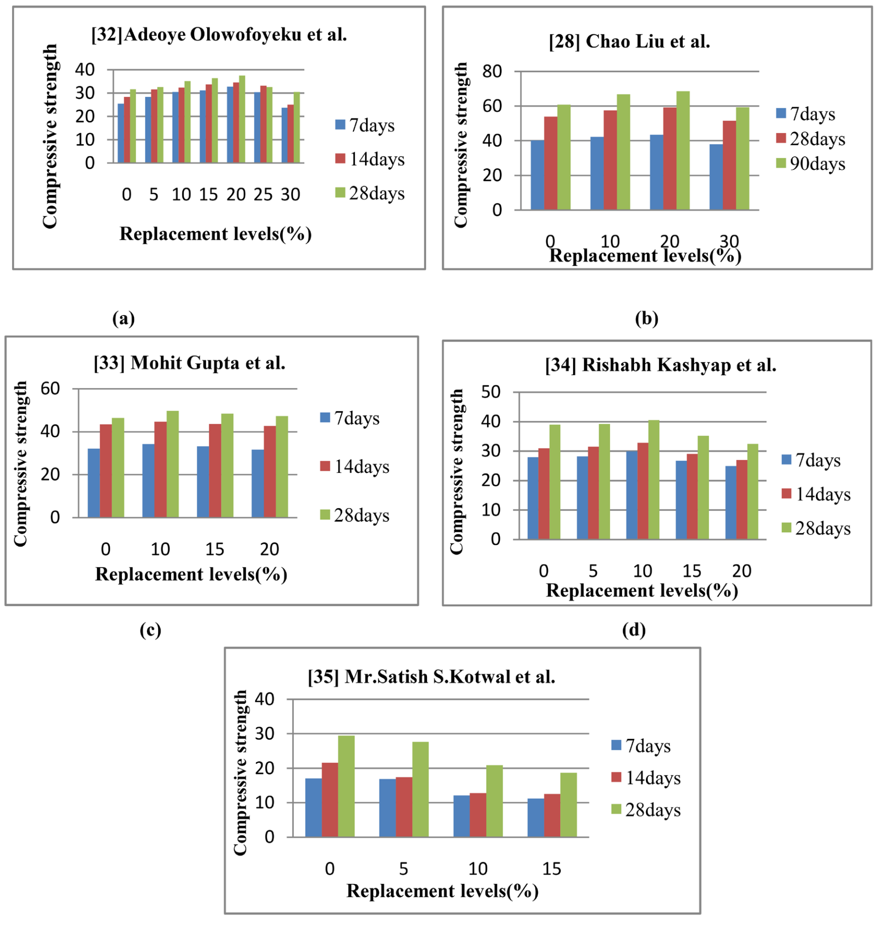



**Figure 1.** The Compressive strength of concrete (a, b) 30% RHA addition, (c, d) 20% RHA addition, (e) 15% RHA addition.

### 3.2. Flexural Strength of Concrete

The flexural strength of concrete using RHA as a substitute for cement depends on the amount of smaller particles included in the concrete mixture, because the particle size of RHA used in concrete is finer than the particle size of cement.

Because of improved particle packing and strong interfacial interaction with the cementitious matrix, the flexural strength of concrete improves as the proportion of smaller particles in RHA increases. As compared with conventional concrete, the mechanical property of concrete, especially the strength property, increased because of the presence of high silica in RHA incorporation concrete [36].

**Table 4** provides information about some researchers who studied the impact of RHA on the flexural strength of concrete with various replacement rates that vary from 0 to 25%. In one study [37], **Figure 2(a)**, the flexural strength of concrete was determined to be 4.6 MPa for the control concrete, which was reduced to 4.0 MPa for the concrete mix containing 15 % of RHA admixture after 3 days of curing. Similarly, at 7-day and 28-day curing periods, flexural strength gave positive influence by replacing 5% to 10% and it started to reduce the mix containing 15%. The flexural strength decreased due to extra non-hydraulic materials in the microstructure and low CH concentration, which was needed in the pozzolanic reaction. In the other experimental studies [26] [38] [39], **Figures 2(b)-(d)** have beneficial effects on the flexural strength of concrete with the addition of a certain amount of RHA, and after that, the results are smaller than the control mixture. To conclude, regarding various studies, RHA has a great impact as a cementitious material of concrete.

**Table 4.** Flexural strength of concrete.

| Sources | Replacement levels (%) | Flexural strength (MPa) | | | |
|---|---|---|---|---|---|
| | | 3 days | 7 days | 28 days | 56 days |
| [37] | 0 | 4.6 | 5.9 | 7.1 | - |
| | 5 | 4.5 | 6.7 | 6.9 | - |
| | 10 | 4.3 | 6.8 | 7.4 | - |
| | 15 | 4.0 | 5.2 | - | - |
| [38] | 0 | - | 3.9 | 4.9 | - |
| | 5 | - | 4.25 | 5.5 | - |
| | 10 | - | 3.5 | 4.72 | - |
| | 15 | - | 3.15 | 3.9 | - |
| | 20 | - | 2.5 | 3.15 | - |
| [26] | 0 | - | - | 4.5 | 5.1 |
| | 10 | - | - | 3.9 | 4.1 |
| | 15 | - | - | 4.7 | 5.6 |
| | 20 | - | - | 3.7 | 3.8 |
| [39] | 10 | - | - | 3.0 | - |
| | 20 | - | - | 2.5 | - |
| | 25 | - | - | 2.4 | - |

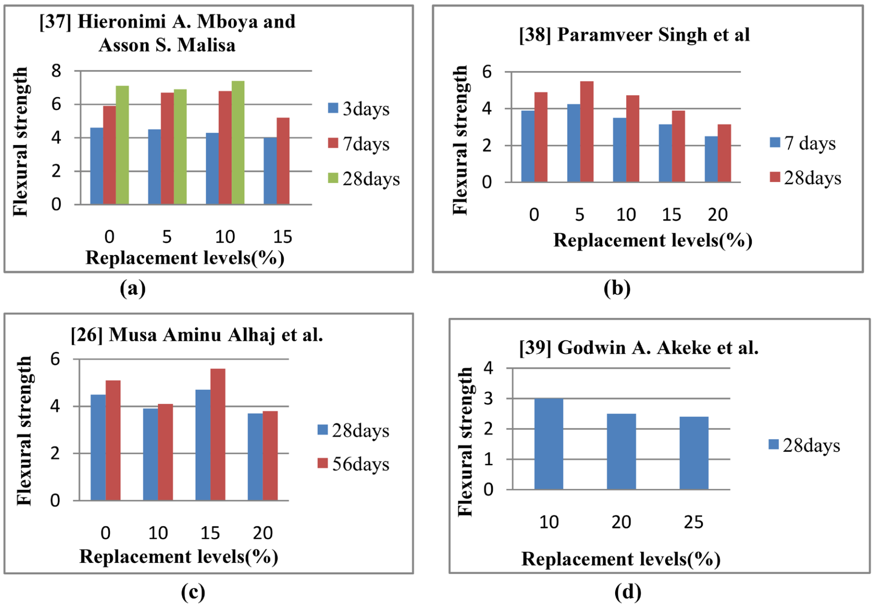



**Figure 2.** The Flexural strength of concrete (a) 15% RHA addition, (b, c) 20% RHA addition, (d) 25% RHA addition.

### 3.3. Split Tensile Strength of Concrete

The tensile strength of concrete is an essential property that has a great influence on the dimension of fractures that occur in construction due to the brittleness of concrete. In Table 5, some researchers checked the split tensile strength of concrete after 7 and 28 days of curing periods with varying amounts of RHA replacement, and it was reported that the tensile strength improved with the curing time.

**Table 5.** Split tensile strength of concrete.

| Sources | Replacement levels (%) | Split tensile strength (MPa) | |
|---|---|---|---|
| | | 7 days | 28 days |
| [40] | 0 | 2.22 | 3.128 |
| | 5 | 1.90 | 3.118 |
| | 7.5 | 2.092 | 3.316 |
| | 10 | 1.90 | 3.28 |
| | 12.5 | 1.89 | 3.075 |
| | 15 | 1.650 | 2.911 |
| [41] | 0 | 1.63 | 2.41 |
| | 10 | 2.10 | 2.55 |
| | 15 | 2.12 | 2.78 |
| | 20 | 2.15 | 2.83 |
| | 25 | 2.48 | 2.93 |

Continued

| | | | |
|---|---|---|---|
| [42] | 0 | 2.163 | 3.021 |
| | 5 | 2.360 | 3.178 |
| | 10 | 1.921 | 2.643 |
| | 15 | 1.814 | 2.517 |
| | 20 | 1.586 | 2.118 |
| | 25 | 1.443 | 2.041 |
| [43] | 0 | 1.182 | 1.526 |
| | 5 | 1.249 | 1.651 |
| | 10 | 1.289 | 1.677 |
| | 15 | 1.380 | 1.697 |
| | 20 | 0.950 | 0.961 |
| | 25 | 0.92 | 0.781 |

According to the test results [40] **Figure 3(a)**, the mixture with 7.5% RHA cement substitution had the highest splitting tensile strength after 28 days. It was also shown that when RHA concentration increases, the split tensile strength improves and replacement strength begins to decrease up to 7.5%. In another study [41] **Figure 3(b)**, the inclusion of RHA as a partial substitute for cement was investigated at 10%, 15%, 20% and 25%, and at 25% substitution the split tensile strength was increased the most compared to other replacement levels. Similarly, other experimental studies' results illustrated [42] [43] **Figure 3(c)** and **Figure 3(d)** influence the positive effect of split tensile strength of concrete with various replacements at 7 and 28 days periods of curing.

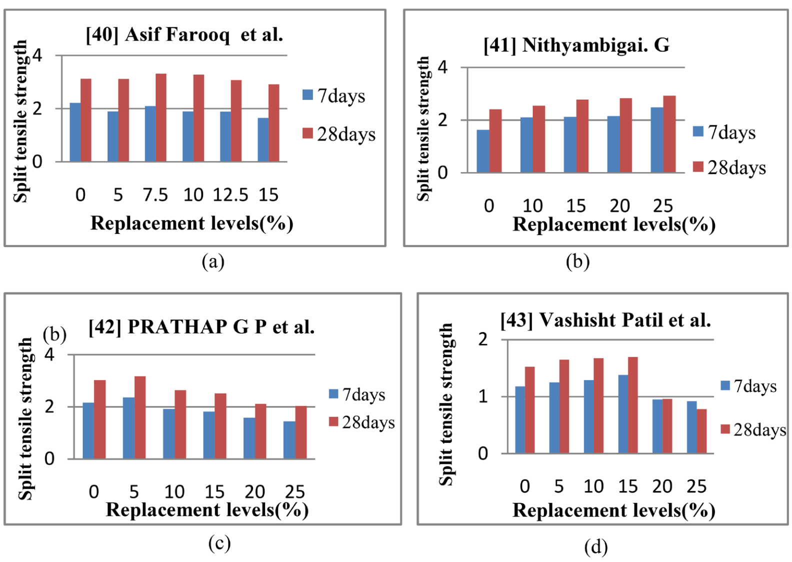



**Figure 3.** The Split tensile strength of concrete. (a) 15% RHA addition, (b, c, d) 25% RHA addition.

## 4. The Effect of the Rice Husk Ash Addition on the Mechanical Properties of Mortar

### 4.1. Compressive Strength of Mortar

The improvement of mortar compressive strength can be attributed to the correct proportion of $SiO_2$ (from RHA and cement) and $Ca(OH)_2$ (a by-product of the hydration reaction), which combine to generate a C-S-H reaction called pozzolanic that strengthens the microstructure [44]. In addition to concrete, plenty of investigations have been undertaken to determine the impact of adding RHA to mortar. **Table 6** indicates the cement replacement percentage is 0% to 25%.

**Table 6.** Compressive strength of mortar.

| Sources | Replacement levels (%) | Compressive strength (MPa) | | | |
|---|---|---|---|---|---|
| | | 7 days | 14 days | 28 days | 56 days |
| [45] | 0 | 32.808 | - | 40.228 | - |
| | 5 | 31.192 | - | 35.48 | - |
| | 10 | 33.972 | - | 52.768 | - |
| | 15 | 24.448 | - | 35.576 | - |
| | 20 | 20.184 | - | 13.128 | - |
| [46] | 0 | 16.50 | 21.00 | 24.00 | - |
| | 5 | 17.00 | 23.00 | 25.00 | - |
| | 10 | 14.50 | 21.00 | 23.00 | - |
| | 15 | 14.50 | 19.00 | 21.00 | - |
| [47] | 20 | 15.00 | 19.00 | 20.00 | - |
| | 25 | 15.00 | 17.50 | 19.00 | - |
| | 0 | 16.00 | - | 27.00 | 30.00 |
| | 5 | 17.00 | - | 28.00 | 32.00 |
| | 10 | 18.00 | - | 32.00 | 33.00 |
| | 15 | 17.50 | - | 26.00 | 29.00 |
| [48] | 0 | 28.13 | - | 43.08 | - |
| | 10 | 26.42 | - | 39.73 | - |
| | 20 | 28.13 | - | 50.06 | - |
| | 30 | 17.08 | - | 26.65 | - |

From the study [45] **Figure 4(a)**, the compressive strength results at 28 days was greater than at 7 days excluding mortar with 20% RHA. The compressive strength of 10% RHA replacement mortar at 7 and 28 days of age was 33.972 MPa and 52.768 MPa, accordingly, and particularly demonstrated that 10%

RHA had the best compressive strengths in comparison with other combined ratios, which include the reference OPC mix for 7 and 28 days with 32.808 MPa and 40.228 MPa, accordingly. From other experimental research studies [46] [47] [48], **Figures 4(b)-(d)** showed a similar positive influence on compressive strength with a 5% - 10% addition of RHA in cement mortar and also increase of curing period has a great impact on mechanical properties of mortar. However, with increasing cement replacement after 5% - 10%, RHA starts to decrease the compressive strength. Therefore, increasing the rate of replacement above the optimal amount would be more unlikely to improve concrete characteristics.

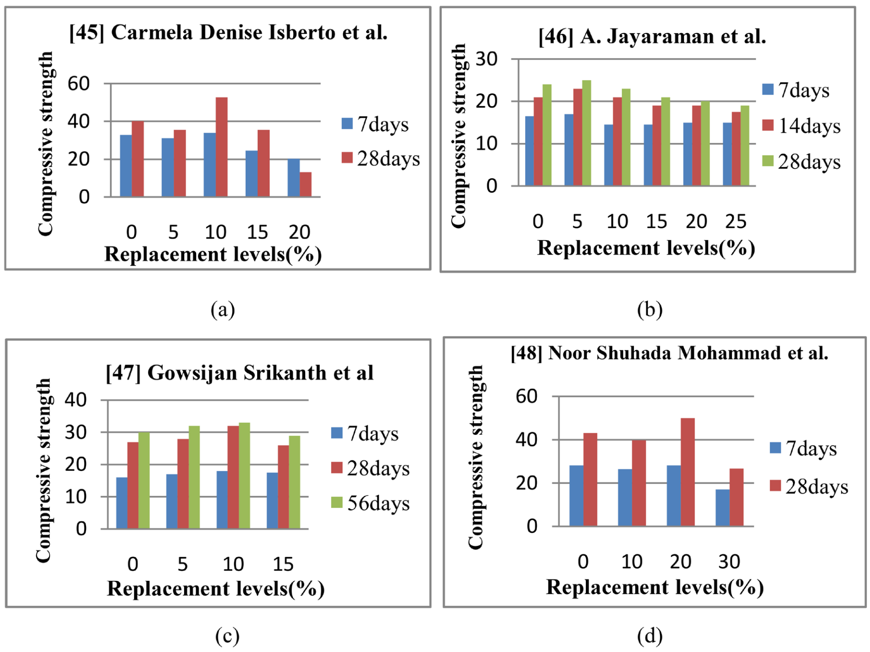



**Figure 4.** The Compressive strength of mortar (a) 20% RHA addition, (b) 25% RHA addition, (c) 15% RHA addition, (d) 30% RHA addition.

## 4.2. Flexural Strength of Mortar

The flexural strength observations from previous studies are shown in **Table 7**. The flexural strength of the mortar increased according to the rate of RHA inclusion [49] **Figure 5(a)** due to cement hydration and development of pozzolanic effect with a curing period of 14 days and 28 days until 20% of cement replacement. In addition, the same amount of RHA incorporation does not positively affect flexural strength within 7 days of curing. In other experimental studies [48] [50], **Figure 5(b)** and **Figure 5(c)** also observed a similar positive influence of flexural strength with 10% and 20% cement replacement. However, another research [51], **Figure 5(d)**, has examined only enhanced flexural strength with increasing the incorporation of RHA, and 18% of cement replacement gave the highest flexural strength, 11.50 MPa, respectively with 90 days of curing period.

**Table 7.** Flexural strength of mortar.

| Sources | Replacement levels (%) | Flexural strength (MPa) | | | |
|---|---|---|---|---|---|
| | | 7 days | 14 days | 28 days | 90 days |
| [49] | 0 | 3.90 | 4.30 | 4.70 | - |
| | 10 | 3.80 | 4.60 | 4.80 | - |
| | 20 | 3.70 | 4.50 | 4.82 | - |
| | 30 | 3.30 | 3.45 | 4.60 | - |
| | 40 | 2.60 | 2.40 | 4.10 | - |
| | 50 | 1.80 | 1.82 | 3.00 | - |
| | 60 | 1.00 | 1.40 | 1.90 | - |
| [50] | 0 | 5.30 | - | 6.32 | - |
| | 10 | 4.70 | - | 5.80 | - |
| | 20 | 4.80 | - | 6.80 | - |
| | 30 | 3.80 | - | 6.90 | - |
| [48] | 0 | 3.59 | - | 4.62 | - |
| | 10 | 3.90 | - | 5.29 | - |
| | 20 | 4.37 | - | 6.66 | - |
| | 30 | 2.58 | - | 4.55 | - |
| [51] | 0 | - | - | 9.50 | 10.70 |
| | 6 | - | - | 9.70 | 11.00 |
| | 12 | - | - | 9.90 | 11.40 |
| | 18 | - | - | 10.10 | 11.50 |

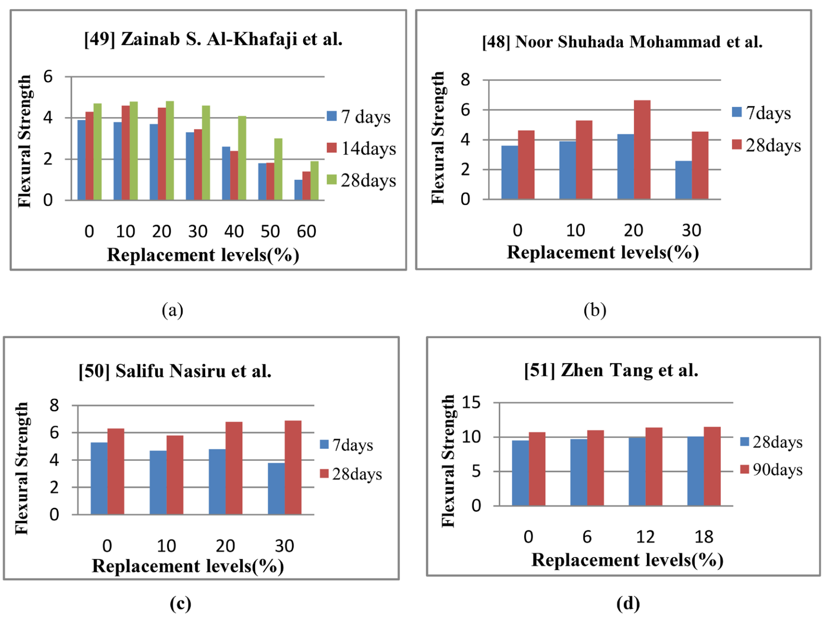


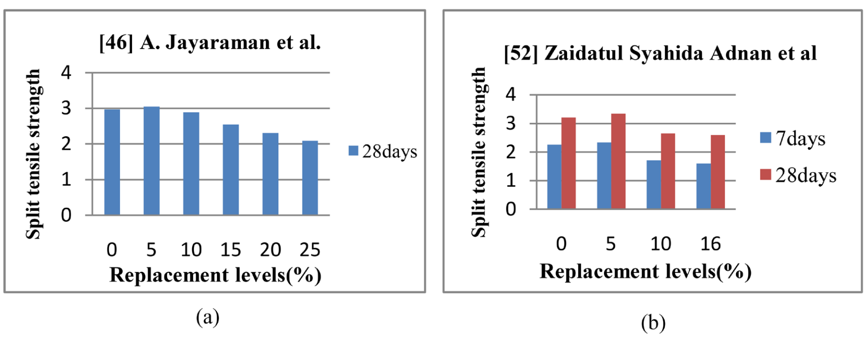

**Figure 5.** The Flexural strength of mortar (a) 60% RHA addition, (b, c) 30% RHA addition, (d) 18% RHA addition.

### 4.3. The Split Tensile Strength of Mortar

A small number of experimental research investigations have been done that deal with the split tensile strength of mortar incorporation of RHA. The addition of RHA to cement mortar increases or decreases the strength, as illustrated in **Table 8**. According to the study [46], **Figure 6(a)**, substituting 5% of cement with RHA after 28 days of curing gave an optimal splitting tensile strength of 3.05 MPa, as opposed to 2.97 MPa for the control mortar mixture. Tensile strength values declined with increasing substitution (usually above 20%), similar to compressive strength values.

**Table 8.** Split tensile strength of mortar.

| Sources | Replacement levels (%) | Split tensile strength (MPa) | |
|---|---|---|---|
| | | 7 days | 28days |
| [46] | 0 | - | 2.97 |
| | 5 | - | 3.05 |
| | 10 | - | 2.89 |
| | 15 | - | 2.54 |
| | 20 | - | 2.31 |
| | 25 | - | 2.09 |
| [52] | 0 | 2.26 | 3.21 |
| | 5 | 2.34 | 3.34 |
| | 10 | 1.71 | 2.65 |
| | 16 | 1.60 | 2.59 |




(a) (b)

**Figure 6.** The Split tensile strength of mortar (a) 25% RHA addition, (b) 16% RHA addition.

Based on the observation from the study [52] **Figure 6(b)**, it was found that only 5% inclusion of RHA as a partial substitution of cement in the mortar enhanced the tensile strength compared to the control sample along with different replacement amounts after 7 days and 28 days of the curing process.

## 5. Future Prospects and Limitations

Rice husk ash in concrete has some research limitations regarding service life of building structures, appropriate cement replacement amounts to achieve higher compressive and flexural strength, and economic stability. The difficulties are based on dependable information sources like previous experimental research, admixture compatibility, and environmental effect. Considering this, RHA has promising future prospects since it can enhance concrete's mechanical properties and sustainability. It should be investigated exhaustively because the overall cement replacement amount may be expected to increase by using RHA combined with other mineral admixtures. Addressing research gaps can result in integrated guidelines and improved performance. Despite the developments in manufacturing technology and increased availability, RHA has significant promise for sustainable high-performance and UHPC concrete applications.

## 6. Conclusion

The addition of rice husk ash as a partial substitute for mortar and concrete showed some positive results. According to previous studies, RHA has numerous physical and chemical characteristics that might make it an optimistic, ecological construction material. Discussion and various experimental results show better performance in comparison with the control mixes when considering compressive strength, flexural strength and tensile strength. Most research studies suggest that the capacity of concrete and mortar mixtures to become harder can be maintained through the addition of 10% - 15% RHA and after that, it starts decreasing. This demonstrates that favorable results can be obtained with a proper RHA addition level and reduce the construction cost compared to conventional concrete. The inclusion of RHA in concrete mitigates environmental pollution regarding cement production compared to OPC-based concrete and enhances the possibility of using green concrete construction. According to a detailed literature review, it is suggested that the prospect of adding RHA with different pozzolanic materials be investigated in various replacement amounts for different types of concrete, especially geopolymer, self-compacting, and high-performance and Ultra-high performance concrete.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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