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Research Article

Rice Husk Ash as a Partial Replacement of Cement in High Strength Concrete containing Fly Ash

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Abstract

Rice husk ash (RHA) is an agricultural waste product which is a pozzolanic material. It is blended with the cement for manufacturing concrete. It reduces the environmental impact of the cement industry. Blending of cement with supplementary cementitious materials like fly ash and rice husk ash makes concrete more durable. This paper studies effect of a partial replacement of cement with various ratios of rice husk ash (RHA) on physical and mechanical properties of concrete. Three mixtures were prepared with proportions of 4, 8, and 16% RHA by weight of cement in addition to 15% fly ash (FA) by weight of cement to be compared with a reference mixture with 100% Portland cement. Compressive strength test, tensile strength test, flexural strength test and rate of water absorption test were performed at different ages of curing. Test results have reflected that the compressive strength, tensile strength and flexural strength achieved with 16% replacement of cement with RHA maximum increase. Compressive strength increased with 16% RHA by 12.5% at 56 days age compared to compressive strength of control mix. Flexural strength increased with 16% RHA by 17.33% at 56 days age compared to flexural strength of control mix. There is significant development in mechanical properties compared to control mix. The mixture with 16% RHA showed the lowest ratios of water absorption by about 2.8% and 2% at 28 and 56 days of cuing, respectively.

Keywords: *High strength concrete, Rice husk ash, Compressive strength, Fly ash, Rate of water absorption*

1. Introduction

The use of pozzolanic materials like blast furnace slag, silica fume, metakaolin (MK), fly ash (FA) and rice husk ash (RHA) etc. can, not only improve the various properties of concrete, but also can contribute to economy in construction costs. The combination of metakaolin and rice husk ash provides a positive effect on mechanical properties. The samples incorporating the ternary blends of cement with 20–15% metakaolin and 5–10% rice husk ash showed better compressive strength than that of the normal sample without rice husk ash. These blends proved to be the optimum combination for achieving maximum effect [M.R. Shatat, 2016]. Rice husk is by- product taken from rice mill process, with approximately the ratio of 200 kg per one ton of rice, even in high temperature it reduces to 40 kg. Various ratios of rice husk ash (RHA) on concrete indicators through 5 mixture plans with proportions of 5, 10, 15, 20 and 25% RHA by weight of cement in addition to 10% micro- silica (MS) to be compared with a reference mixture with 100% Portland cement are studied.

Tests results indicated the positive relationship between 15% replacement of RHA with increase in compressive strengths by about 20%. The optimum level of strength and durability properties generally gain with addition up to 20%, beyond that is associated with slight decrease in strength parameters by about 4.5%. The same results obtained for water absorption ratios likely to be un favorable. Chloride ions penetration increased with increase in cement replacement by about 25% relative to the initial values (about less than one fifth) [S.A. Zareei et al, 2017]. RHA and lime were blended and used to replace conventional cement at different percentages to form RHA-Lime concrete. Results from strength test showed that RHA-Lime concrete exhibited higher early strength in comparison to the control. However, the early strength development was impaired by lime leaching. RHA-Lime cement mixes were found suitable for use in structural concrete and can replace conventional cement up to 25%. The inclusion of lime enhanced pozzolanic reaction, hence the strength properties of RHA-Concrete. RHA-Lime mixes can therefore serve a viable alternative to conventional cement in concrete P.A. [P.A. Adesina, F.A. Olutoge, 2019]. Concrete specimens were tested with different percentages of RHA as replacement of cement content

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and with different w/c ratio. Compressive strength, flexural strength, tensile strength and slump test were carried out to evaluate the appropriateness of using RHA in concrete. The replacement of cement by RHA in structural concrete represents a good alternative in as economical as strength consideration of concrete, even without any kind of processing and found environmental benefits related to the disposal of waste. Review of researches shows that RHA-used concrete can resist chloride penetration more than normal ordinary Portland cement concrete [A. Siddika et al, 2018]. Concrete cylinders (100mm - 200 mm) were prepared with 0–25% RHA with water-to-binder ratios of 0.50 at a constant mix-ratio of1:1.5:3 and cured in water. Test results revealed that the mean particle size of RHA decreases with increasing grinding time. The compressive strength (f 'c) of brick aggregate concrete (BAC) due to filler effect are 58.56–94.62% less compared to the pozzolanic effect of RHA for the 10%–25% replacement of cement. Meanwhile, the 15% RHA showed the maximum f 'c of BAC due to pozzolanic effect of RHA. The tensile strength (fsp) and flexural strength (fr) of BAC due to pozzolanic effect are 60%–150% and 25%–150% higher than that of filler effect of RHA for the 10%–25% replacement of cement respectively. The modulus of elasticity (Ec) and Poisson's ratio ν) of BAC due to pozzolanic effect are 2%–29% and 27%–43% greater than that of filler effect of RHA for the 10%–25% replacement of cement respectively [Md. Abu Noaman et al, 2019]. The chemical and morphological nature of RHA and silica fume (SF) are investigated. Both can be used to improve strength and durability properties of concrete. Particle size distribution, loss on ignition (LOI), X-ray diffraction analysis, scanning electron microscopic were conducted. The effect of replacement of cement 5%, 10% and 15% by weight with SF and RHA on compressive strength and workability has also been investigated for 32 MPa grade concrete blended with 30% Fly ash. The results show that concrete mixed with RHA had better strength than a similar mix with Silica Fume. RHA required additional amount of superplasticizer to improve the workability of concrete. In order to reduce the carbon footprint associated with cement industry, this paper gives satisfactory results to use RHA in sustainable construction [A.B. Srinivasreddy et al, 2013]. The optimum percentage of replacement of RHA was obtained as 10% by weight of cement for natural RHA replaced concrete and 15% for Ground RHA replaced concrete and corresponding improvement in strength as 4.3% and 11.4% respectively as compared to control concrete. Chloride penetration resistance characteristics of natural and ground RHA concretes are 19% and 52% respectively as compared to control concrete [V. Ponmalar, R.A. Abraham, 2015]. The effect of different contents of Rice Husk Ash (RHA) added to concrete containing super plasticizer and with and without plastic fibers on its compressive strength has been studied. Samples with 3%, 5%, 7%, 10%, 12% and 15% content of RHA replacing the cement have been tested. The results have been compared with those for the control sample and viability of adding RHA to concrete has been studied. It was observed that up to 10% of cement can be replaced with RHA mixed with plastic fibers with nearly equivalent compressive strength. Further replacement of cement up to 15% will result in concrete of fair compressive strength [R.K. Sharma, 2014]. Addition of RHA is effective in improving the strengths of recycled aggregate geopolymer concrete (RAGCs), particularly when the SiO_2/Al_2O_3 ratio is increased to 4.17. The 28-day compressive strengths of RAGCs containing RHAs ranged from 36.0 to 38.1 MPa due to the improved microstructure and denser matrix and were comparable to those of RAGCs made with nano-SiO2 (ns). However, the inclusion of SiO_2-rich materials had an adverse effect on the post-fire residual strength of geopolymer concretes made from recycled aggregates due primarily to the reduced porosity [P. Nuaklong et al, 2020]. The rice husk ash is served as replacement for cement ingredient such as 5%, 10% and 15% along with 10%, 20%, 30% and 40% of fine aggregates replaced with coal bottom ash in concrete. Total 180 concrete samples were prepared with mix proportion of 1:2:4 at 0.50 water/cement ratio and theses specimens were cured at 28 days. The slump test, compressive strength, split tensile strength and water absorption of concrete including different proportions of rice husk ash as replacement for cement and fine aggregates replaced with coal bottom ash separate and combine were performed. The outcome was detected that the workability and water absorption is dropped as the dosages of rice husk ash and coal bottom ash increases in concrete. The compressive and split tensile strength is enhanced by 9.10% and 7.73% while the utilizing of 5% RHA along with 30% of fine aggregate replaced with coal bottom ash in concrete at 28 days consistently [N. Bheel et al, 2021].

2. Work Objective

The main objective of this research is to study the effect of rice husk ash and fly ash on physical and mechanical properties for high strength concrete.

3. Experimental Work

3.1. Materials

The different materials used in this investigation are:-

Cement: Ordinary Portland (CEM-I) cement with grade 42.5 N confirmed Egyptian Standard Specifications (ESS) requirements (4756-1/2007).

Fine Aggregate: Medium well-graded sand of fineness modulus 2.85 was used for concrete complies an Egyptian Standard Specifications (ESS) requirement (ECP.1109/2002).

Coarse aggregate: Crushed dolomite was used as coarse aggregate. Maximum nominal size of coarse aggregate was 20 mm.

Water: Fresh tap water was used for both mixing and curing purposes.

Plasticizer: Sikament- 163M **(ASTM C-494 Type A& F)** was used to improve the workability of concrete.

Fly Ash: FA meets the general requirements of ASTM C618 Class F. table (1) presents the chemical composition and physical characteristics of fly ash, these tests were performed at National Research Center for Housing and Buildings Cairo, Egypt.

Table 1 The chemical composition and physical characteristics of fly ash

Parameters	values
SiO_2	87.2%
Fe_2O_3	0.16%
Al_2O_3	0.15%
Cao	0.55%
MgO	0.35%
SO_3	0.24%
C	5.91%
L.O.I.	5.44%
Fineness passing 45 micron	96%
Mineralogy	Non crystalline
Shape	Irregular

temperature of below 800 °C. A Los Angeles abrasion machine was used for grinding of RHA in order to improve fineness of RHA; grinding balls (14 steel balls each of 48 mm diameter) were used with grinding duration of 60, 90 and 150 min respectively. The rotational speed of the machine was kept 30–33 rpm and finally collects the ash which was paned through 200No. BS sieve. The obtained ash is a grey color and the specific gravity of RHA is 2.32. table (2) presents the properties of RHA, these tests were performed at National Research Center for Housing and Buildings Cairo, Egypt.

Table 2 Properties of Rice husk ash

Oxides	Content%
SiO_2	51.45
Fe_2O_3	5.19
Al_2O_3	27.26
Cao	7.73
MgO	5.16
SO_3	0.5
K2O	2.5
L.O.I.	0.19
Physical Properties	
Fineness (Blain)	4020 cm^2/g
Specific gravity	2.32

3.2. Concrete Mixes

The concrete mixture was weighed and mixed in mechanical mixer for 2 min. The concrete mixture was cast in steel molds for different tests and manually compacted. Test specimens were demolded after 24 hours and were cured. Four binder mixtures were prepared involve a control mix with 100% Portland cement and without RHA, and the others with rice husk ash in concentrations of 4, 8 and 16% (labeled in the table RHA 4, RHA 8, ...respectively), 15% fly ash by weight of cement and w/c ratio of 40%. Plasticizer was added with 1.5% by weight of cement. Materials required per cubic meter of high strength concrete are shown in Table (3).

Table 3 Mix design (Kg/m^3).

Mix	Control	RHA 4%	RHA 8%	RHA 16%
W/C	0.4	0.4	0.4	0.4
Cement	450	432	414	378
FA/cement ratio (%)	15	15	15	15
RHA	0	18	36	72
Water	180	180	180	180
Coarse aggregate	1072	1072	1072	1072
Fine aggregate	596	596	596	596
Plasticizer Sikament-163M	6.75	6.75	6.75	6.75

RHA: rice husk ash, FA: fly ash

3.3. Testing

3.3.1. Fresh Concrete

3.3.1.1. Slump Test & Compaction Factor

Workability is one of the physical parameters of concrete which affects the strength and durability as well as the cost of labour and appearance of the finished product. Concrete is said to be workable when it is easily placed and compacted homogeneously without bleeding or segregation. The workability of concrete is measured by compaction factor test and slump test.

3.3.2. Hardened Concrete

3.3.2.1. Compressive Strength Test

The compression test was conducted of the prepared concrete. The cube specimens with dimensions of 15*15*15 cm were cast. All specimens were provided with sufficient time for hardening (24 hours) and cured with four cases of curing methods. For each age, three (3) specimens were prepared. After the specified period (7, 28 and 56 days) all the specimens were tested for its maximum load in the compression testing machine. The cubes were tested on hydraulic machine 1500 kN capacity [ISO 4012].

3.3.2.2. Flexural Strength Test

Flexural strength test was carried out on prisms with dimensions 10*10*50 cm on flexure testing machine under four points loading. For each age, three (3) specimens were prepared. The strength was analyzed for 7, 28 and 56 days. The flexural strength is calculated from the formula as given below [ISO 1920,4013]: -

Flexural strength $=PL/d_1d_2^2$

Where, P the maximum applied load to the specimen (N), d_1 the width of the specimen (mm), d_2 the depth of specimen (mm).

3.3.2.3 Split Tensile Strength

The cylinder specimens with dimensions of 15*30 cm were tested on compression testing machine of capacity 1500KN. The bearing surface of machine was cleaned and other sand or other materials were removed from the surface of the specimen. For each age, three (3) specimens were prepared. The strength was analyzed for 7, 28 and 56 days. The load applied was increased continuously. The tensile strength is calculated from the formula as given below [BS-1881 Testing Concrete]: -

Tensile strength$=2P/\pi DL$

Where, P the maximum applied load to the specimen (N), D diameter of cylinder, L length of cylinder.

3.3.2.4. The Rate of Water Absorption

The cube specimens with dimensions of 10*10*10 cm were cured at age of 28 and 56 days with four cases of curing methods then concrete samples were dried in an oven at a temperature of 100 to 110 °C for not less than 24 hours. After removing each specimen from the oven, samples were cooled in dry air and the mass were determined. Samples were immersed in water at approximately 21°C for not less than 48 hours after final drying, cooling and determination of mass. Samples were removed from water and excess water was toweled and then weighed .The rate of water absorption is calculated from the formula as given below [ASTM C642]: -

Absorption after immersion%= [(B-A)/A] *100

Where
A The mass of oven-dried sample in air
B The mass of surface-dry sample in air after immersion

4. Results & Discussion

4.1. Fresh Concrete

4.1.1. Slump Test & Compaction Factor

Slump test and compaction factor were done to evaluate workability for different percentages of RHA. The results are shown in figures (1, 2). It was noticed that slump value and compaction factor value decrease with increase of percentage of RHA. The water demand increased as the percentage of RHA increased. The increasing demand for water may be due to fine particle or larger surface area or its irregular shape.

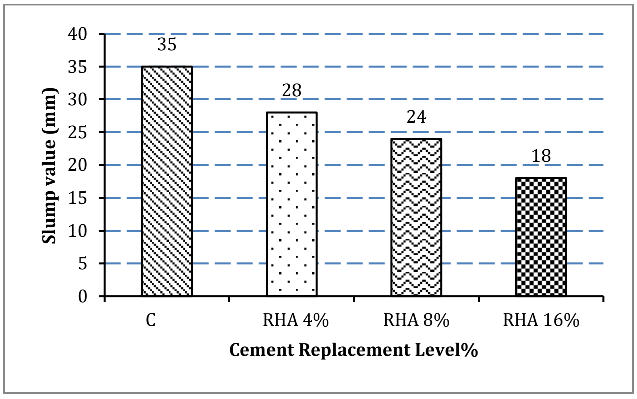

Fig. 1 Slump value for different percentages of RHA

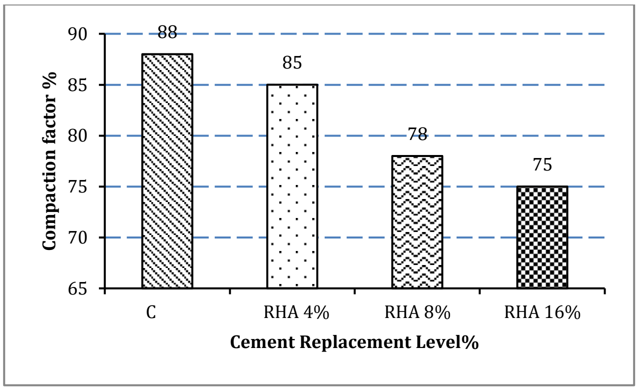

Fig. 2 Compaction factor value for different percentages of RHA

4.2. Hardened Concrete

4.2.1. Compressive Strength Test

The effect of RHA on compressive strength of concrete samples was investigated. At age of 7, 28, 56 days, compressive strength increased for different percentages of RHA compared to compressive strength of control mix as shown in table (4). At age of 56 days, compressive strength of 16% RHA had maximum increase, it is increased by 12.5% of compressive strength of control mix as shown in figure (3). It can deduce that RHA improved compressive strength compared to compressive strength of control mix. This is because rice husk ash contains 51.45% weight percent of amorphous silica SiO_2. Rice husk ash has unique pozzolanic property which means that SiO_2 reacts with Ca $(OH)_2$ that forms from the hydration of calcium silicates in cement to yield calcium silicate hydrate, which is responsible for the strength in cement-based materials.

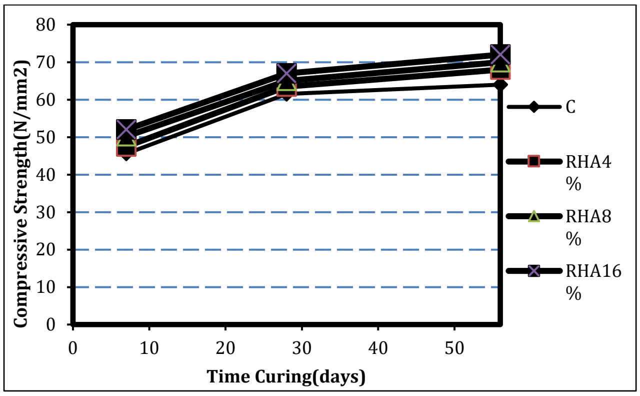

Fig.3 Compressive strength for different percentages of RHA

Table 4 Compressive strength (N/mm²) for different percentages of RHA

Mix	Compressive Strength (N/mm²)		
	Age(days)		
	7 days	28 days	56 days
C	45.6	61.5	64
RHA 4%	47.5	63.5	68
RHA 8%	50.2	65	70
RHA 16%	52	67	72

4.2.1.2. Flexural Strength Test

The results of the flexural strength are represented in table (5). And the graphical representation is shown in figure (4). At age of 7, 28, 56 days, flexural strength increased for different percentages of RHA compared to flexural strength of control mix. At age of 56 days, flexural strength of 16% RHA had maximum increase; it is increased by 17.33% of flexural strength of control mix. It can deduce that partial replacement of cement by RHA could enhance flexural strength compared to flexural strength of control mix.

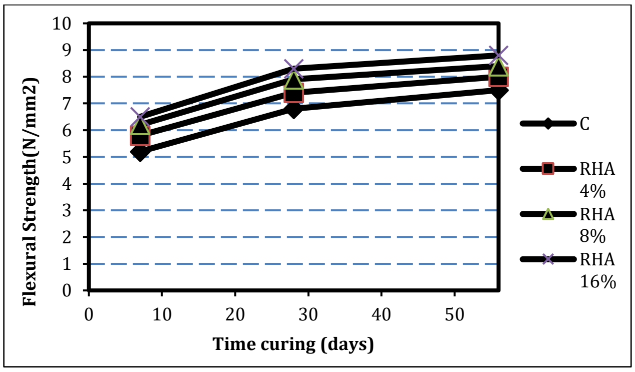

Fig.4 Flexural strength for different percentages of RHA

Table 5 Flexural strength (N/mm²) for different percentages of RHA

Mix	Flexural Strength (N/mm²)		
	Age(days)		
	7 days	28 days	56 days
C	5.2	6.8	7.5
RHA 4%	5.8	7.4	8
RHA 8%	6.2	7.9	8.4
RHA 16%	6.5	8.3	8.8

4.2.1.3. Split Tensile Strength

The influence of partial replacement of cement by RHA on the splitting tensile strength of concrete samples was investigated. At age of 7, 28, 56 days, splitting tensile strength increased for different percentages of RHA compared to splitting tensile strength of control mix as shown in figure (5). At age of 56 days, splitting tensile strength of 16% RHA had maximum increase; it is increased by 16.67% of splitting tensile strength of control mix as shown in table (6). Using RHA as partial replacement of cement contributes to improvement splitting tensile strength compared to splitting tensile strength of control mix.

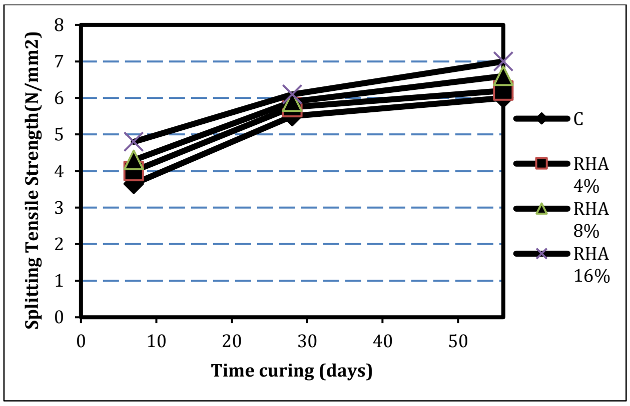

Fig.5 Splitting tensile strength for different percentages of RHA

Table 6 Splitting tensile strength (N/mm²) for different percentages of RHA

Mix	Splitting tensile strength (N/mm²)		
	Age(days)		
	7 days	28 days	56 days
C	3.65	5.5	6
RHA 4%	4	5.75	6.2
RHA 8%	4.3	5.9	6.6
RHA 16%	4.8	6.1	7

4.2.1.4. The Rate of Water Absorption

The results of rate of water absorption are represented in table 7. And the graphical representation is shown in figure (6). At age of 7, 28, 56 days, rate of water absorption decreased for different percentages of RHA compared to rate of water absorption of control mix. The mixtures with 16% RHA showed the lowest ratios of water absorption by about 2.8% at 28days and 2%

at 56 days of cuing, respectively. This is may be due to fineness of particles of RHA which act as filler for voids.

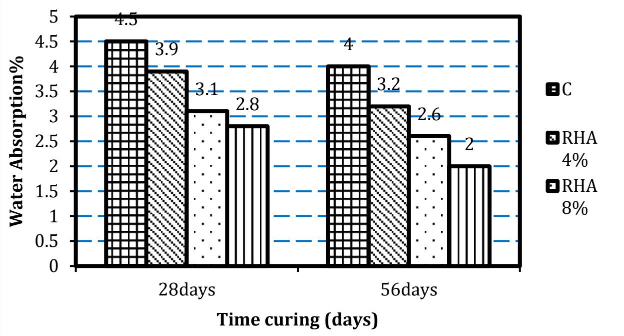

Fig.6 Rate of water absorption for different percentages of RHA

Table 7 Rate of water absorption for different percentages of RHA

Mix	Rate of water absorption%	
	Age(days)	
	28 days	56 days
C	4.5	4
RHA 4%	3.9	3.2
RHA 8%	3.1	2.6
RHA 16%	2.8	2

Conclusions

From the experimental study it can be concluded that:

1. The mixture with 16% RHA showed the lowest ratios of water absorption by about 2.8% and 2% at 28 and 56 days of cuing, respectively.
2. RHA improved compressive strength compared to compressive strength of control mix. Compressive strength increased with 16% RHA by 12.5% at 56 days age compared to compressive strength of control mix.
3. Flexural strength increased for different percentages of RHA compared to flexural strength of control mix. At age of 56 days, flexural strength of 16% RHA had maximum increase; it is increased by 17.33% of flexural strength of control mix.
4. Splitting tensile strength increased for different percentages of RHA compared to splitting tensile strength of control mix. At age of 56 days, splitting tensile strength of 16% RHA had maximum increase; it is increased by 16.67% of splitting tensile strength of control mix.
5. Different percentages of RHA affected on workability. Slump value and compaction factor value decreased with increase of percentage of RHA. The increasing demand for water may be due to fine particle or larger surface area or its irregular shape.

The results showed that RHA can enhance the mechanical and physical properties of concrete.

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