An overview of Utilization of Rice Husk Ash for Sustainable Concrete Manufacturing

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Abstract: The concrete is one of the most important material due to growing construction industry. Due to green building and sustainability requirement and scarcity of natural products, the researchers are investigating the innovative solutions to replace the cement partially with the economical methods. Rice Husk Ash (RHA) which shows an important role during the hydration process of cement which results as: (1) amount of silica in RHA effects the incineration method, time and grinding time; (2) only RHA produced to be as amorphous, generally achieved at burning temperature of between 600-700 ^{o}C; and (3) by applying proper incineration technique RHA can be a partially cement replacement in concrete because of pozzolanic properties of RHA.

Keywords: Mechanism of RHA, Sustainable Concrete, Chemical Composition of RHA, RHA Concrete Mechanical Properties

نظرة عامة على استخدام أرز قشر الرماد لتصنيع الخرسانة المستدام

الملخص: الخرسانة هي واحدة من أهم المواد بسبب صناعة البناء المتنامية. نظرًا لمتطلبات البناء الأخضر والاستدامة وندرة المنتجات الطبيعية ، يبحث الباحثون في الحلول المبتكرة لاستبدال الأسمنت جزئيًا بالطرق الاقتصادية. رماد قشر الأرز (RHA) الذي يظهر دورًا مهمًا أثناء عملية ترطيب الأسمنت والذي ينتج عنه: (1) كمية السيليكا في RHA تؤثر على طريقة الحرق والوقت ووقت الطحن ؛ (2) يتم إنتاج RHA فقط ليكون غير متبلور ، ويتم تحقيقه بشكل عام عند درجة حرارة الاحتراق بين 600-700 درجة مئوية ؛ و (3) بتطبيق تقنية الحرق المناسبة يمكن أن يكون RHA بديلاً جزئيًا للأسمنت في الخرسانة بسبب الخصائص البوزولانية لـRHA.

1.Introduction

The extensively use of concrete is now a days common material for construction [1]. The advancement in concrete technology are introducing new material for sustainability [2]. The concrete can be manufactured in any shape and using economical solution [3, 4]. The concrete production based on the common materials as cement, fine and coarse aggregates [5]. The concrete is one of the largest contributed construction material in the world [6], It is estimated by different researchers that the construction industry is annually utilizing 9 billion tons aggregates with 1.5 billion tons cement [7]. It is assumed that the cement is most important material then to water and is been used as binding material in huge amount annually [8, 9]. It is approximated that the annually production of greenhouse gas is about 1.35 billion tons from only cement or around 7% of overall gas emissions for environment [10, 11, 12]. Carbon dioxide gas emitted from three main sources during the production of cement [13]. Furthermore, it is reported that approximately, 1.6 ton of natural resources needed to make only 1 ton of cement [14].

The supplementary cementitious material concept is introduced to minimize this problem. The fly ash (FA), RHA, wood ash, bagasse and olive oil ash are agricultural and industrial waste ash which possess pozzolanic properties [15, 16]. Concrete is produced using cementitious material which is started to lower the cost and the rate of production of cement, overcome the adverse effects of OPC and utilize the industrial and agriculture waste materials which were providing injurious to atmosphere [17]. The various concrete properties and mortar such as resistance to cracks, strength, durability, workability and permeability is improved with use of cementitious material. Further, the adding industrial waste resulted in the producing concrete high-performance [17]. These products can be potential to increase concrete performance because of their reaction with pozzolanic and micro filler [18]. Different concrete mixes are improved with the replacement of different pozzolanic admixtures, which increase various concrete properties as microstructure and results in the reduction of calcium hydroxide concentration through a pozzolanic reaction [19].

This paper is arranged in sections in which section two defines origin of RHA and the different temperature effect on the structural RHA characteristics. Section three and four describes the physical and chemical RHA characteristics. Section five presents reaction RHA mechanism. Section 6 summarizes on fresh concrete at various level of Rice Husk Ash. Section seven summarizes RHA utilization as cement ingredient for various concrete types such as ultra high performance concrete (UHPC), high and normal strength concrete. Additionally, it is considered that realistic mathematical expression obtained by using all the possible testing results of RHA in the mixes to provide ease for obtaining the hardened concrete properties without performing any tests. The review on various RHA concrete characteristics as modulus of elasticity and absorption water in section 8, 9 and 10. A roadmap to use RHA and recommended further research regarding the usage of RHA are presented. Recent breakthroughs in low-cost materials developed using waste products that can be used to develop carbon captured concrete is also shows that RHA is one of the cement replacement constituent material [122, 123].

2.Origin of RHA

The agricultural waste such as rice husk material which comprises about 20% rice mass. It includes 15-20% of silica, 50% cellulose, 25-30% lignin [20]. There are most important three biomasses come from rice, bran, straw and shell [21]. Rice Husk (RH) is cover of white seed having large silica [21]. Incineration process of rice husk produced from open air incineration on the ground (about 1970s) to ignition applying liquidized layers technique (around 1990s) [22]. Silica content in the ash is found to be increases with higher the burning temperature [23]. It may also improve the fresh state characteristics of concrete such as workability, slow done the hydration process, increase strength at longer ages and reduce permeability [24]. Furthermore, the use of RHA reduces the cement requirement in the civil construction engineering work, decreases charges for production of concrete and minimize negative impact on environment which produced due to CO_2 emissions through the cement production [25, 26]. It is approximated that 200 kg Rice Husk produce from 1 ton of rice grain and about 40 kg Rice Husk or 20 percent RHA when rice husk is burnt at specific temperature [27]. As per food and agriculture organization (FAO) of UN (2018), the annual world rice production for 2017 was estimated by 759.6 million tons (503.9 million tones, milled basis) [28], and rice husk contribute around 20% of it [29]. The disposal of rice husk has been very challenging universally because of huge amount of residual ash resulting from improper burning [30]. As RHA have pozzolanic nature, so utility of this waste may provide safe environment easy disposal of RHA. Due to its potential ability to enhance the concrete properties through their pozzolanic and filling ability RHA will be recommended to use it in concrete [31].

The chemical composition of RH is depending on different factors such as climate, geographical conditions and variances in the paddy type [29]. The samples of RHA and RH are shown in Fig. 1.

Fig. 1. a) Rice Husk [32], b) Burnt RHA [33] and c) burning of husk at about 700°C for 6 hours and wet grinding for 80 minutes [34]

2.1. Combustion of Rice Husk

Rice Husk Ash is a ash obtained by incineration of RH either controlled or open field incineration in which burning time and temperature is controlled. On the field incineration method produces weak quality RHA. Furthermore, open field burning of RH always leads to the production of silica ash, which differs from gray color to black depending on unburned carbon content and inorganic impurities [34]. By uncontrolled incineration less than 500°C temp- the burning of rice husk is not completed and consequences of this the specific content of unburnt carbon is left in developing ash [35], excessive amount of carbon which negatively affect concrete performance and also form crystalline silica that is of minimal reactivity [36]. Dolage et al. [37] described that when carbon content is more than 30% was expected to minimize the RHA pozzolanic reactivity, rice husk ash quality is adjusted by ignition treatment to produce amorphous silica that is important for concrete structure [38]. Ignition rice husk using adjusted incineration below 800 °C temperature will return silica in ash [39, 40].

In addition, the pozzolanic reactivity is linked to area of ash's particles [41]. Mehta and Nair et al. [42, 43] also said ash is produced at burning temp of 550 to 800 °C and variation appears from amorphous to crystalline shape at about 800 to 900 °C temperature. Other researchers revealed that duration is important factor for burning the rice husk to make suitable ash [44, 45]. Nair et al. [43] described that lower temp- long period or higher temp- short duration will result in the production of amorphous ash. Therefore, it is mandatory to confirm that silica inside rice husk ash is amorphous form which is produced via adjusted burning process.

Different researchers worked to determine the burning temp- effects on specific surface area and structure of the RHA as checked from Mercury Intrusion Porosimetry, Scanning Electron Microscopy (SEM), X-Ray Diffraction, and Back-scattered Electron Image (BSE), values are mentioned in Table 1. [46, 47, 48]

Table 1. Burning Temperature Effect on the Structure of Rice Husk Ash [25, 36, 49, 50]

Temperature	Structure of RHA	Specific Surface Area (m^2/g)
Till 500 °C	Particles are spherical, globular form or with porous shape	0.5 – 2.1
500 – 600 °C	Particles are partially non-crystalline and crystalline	76 – 122
600 – 700 °C	Particles are amorphous, and diameter of pores is maximum	100 – 150 at low temperature
700 – 800 °C	Partly crystalline	6 – 10
800 – 900 °C	Crystalline	< 5
900 -1000 °C	The development of coral formed crystals increased, gradually finer & melted significantly.	-

3.Chemical Properties

The chemical characteristics of RHA to ensure that when it replaced with cement in concrete using it behaves properly. Hardened concrete rest on many factors such as chemical composition of material, water-cement ratio, cement content, type of cement, , quality of filler material and control of quality for the period of production of concrete etc. Based on an assessment of the chemical compositions shown in Table 2. The CaO content of ordinary Portland cement and RHA is within range of about 59 to 66% and 0.08 to 1.58%. Therefore the OPC have higher amount of calcium oxide as compared with mineral admixtures. Note that the proportion of SiO_2 in RHA is 67.30-95.04 %, the reaction of RHA is assessed by SiO_2 content in RHA. It is concluded that silica is the compound that may responsible for the strength development in RHA concrete [43]. If RHA is used during the production of concrete, which have the ability to participate the strength process. It is noted that the sum of SiO_2 + Fe_2O_3 + Al_2O_3 go beyond 70% for all the RHA cases and summarized that the RHA has similar composition as fly ash of Class F (ASTM C 618) with great pozzolanic reactivity [51, 52, 53, 54].

Table 2. RHA and Ordinary Portland Cement Chemical Characteristics

Elements		**OPC**	**RHA**
Calcium oxide	CaO	58.51-66.28	0.08-1.58
Silica dioxide	SiO_2	19.80-23.50	67.30-95.04
Ferric oxide	Fe_2O_3	2.50-11.38	0.16-2.86
Sulphur trioxide	SO_3	1.40-3.30	0.01-1.21
Graphite	-	-	4.77
Aluminum oxide	Al_2O_3	4.51-6.90	0.15-4.90
Magnesium oxide	MgO	0.22-3.13	0.21-1.81
Phosphorous pentoxide	P_2O_5	0.05-0.26	0.25-60
Potassium oxide	K_2O	0.22-1.10	0-3.68
Manganese trioxide	Mn_2O_3	0.17	-
Natrium oxide	Na_2O	0.10-2.72	0.05-3.56
Titanium dioxide	TiO_2	-	0.01-0.15
Manganese oxide	MnO_2	-	0.14-0.16
Chloride	Cl	0.06	-
LOI	-	0.51-5.68	0.51-18.25
References		[27, 29, 55-66]	[20, 29, 56, 57, 59-77]

4.Physical properties

The comparison of OPC and RHA mentioned in Table 3 [78, 79, 80]. The color of RHA is grey, black or dark grey. Color variations have directly linked with the completeness of the incineration process as well as unburned carbon and silica content in ash [35, 82, 83].

Table 3. Physical RHA characteristics and OPC

Physical properties	**OPC**	**RHA**
Color	Grey	Grey, Black dark grey
Particle size	22.5	7 – 42
Shape of Particle	-	Not regular
Sp Gravity	2.9 – 3.15	2 – 2.4
Fineness passing 45 microns	93%	70 – 99%
Loose Bulk density (g/cm^3)	1.16	0.40
Compacted Bulk density (g/cm^3)	1.56	0.49
Specific surface area Blaine (m^2/kg)	309 – 373	376 - 1620
Soundness (mm)	1 – 9	-
References	[24, 27, 35, 37, 42, 58-60, 67, 84-90]	[22, 24, 27, 35, 37, 42, 59, 64, 65, 67, 70, 85, 87, 90-95]

5.Reaction Mechanisms of RHA

A pozzolanic reaction starts only when aluminous/siliceous components of RHA react with $Ca(OH)_2$ (calcium hydroxide) in the presence of moisture to form compounds having good adhesive properties. OPC is made up of four principal mineralogical phases symbolically represented by C_3S, C_2S, C_4AF and C_3A. During the hydration process of cement's components (C_3S and C_2S) the CSH (gel) and CH (lime) are produced [96].

For C_3S:

$$2(3CaO.SiO_2) + 6H_2O \longrightarrow \text{Primary } 3CaO.2SiO_2.3H_2O + 3Ca(OH)_2 \quad (1)$$

For C_2S:

$$2(2CaO.SiO_2) + 4H_2O \longrightarrow \text{primary} 3CaO.2SiO_2.3H_2O + Ca(OH)_2 \quad (2)$$

The $3CaO.2SiO_2.3H_2O$, (C-S-H) is known as gel, is the main strengthening ingredients that produced during the hydration of C_3S and C_2S component as can be seen in equations (1) and (2). C-S-H is a glue that binds the filling particles together and provides concrete its strength, while $Ca(OH)_2$ causes small contribution to the strength development [97]. Furthermore, the Pozzolanic activity of RHA be governed by silica content, silica in amorphous or crystalline phase, surface area and size of the particles [98]. The Reactions that occur during the production of RHA concrete are; first the Silicon incinerated in the presence of oxygen produce silica [27].

$$Si + O_2 \longrightarrow SiO_2$$

The secondary reaction starts only when this silica gets in touch with $Ca(OH)_2$ which released during the hydration of cement, resulting in the production of calcium silicate hydrate.

$$SiO_2 + Ca\,(OH)_2 + H_2O \longrightarrow Secondary\ CaO.SiO_2.H_2O$$

This reaction decreases the Ca $(OH)_2$ content in the concrete. The weak calcium hydroxide does not participate to strength [27]. The pozzolanic reaction, fills the pores in concrete making the microstructure of the concrete denser and improves the interfacial bond among filler and binder materials and thus the durability, strength and transport properties of the concrete are enhanced [99].

where:

$2CaO.2SiO_2$	=	C_2S, Dicalcium silicate
$3CaO.2SiO_2$	=	C_3S, Tricalcium silicate
$3CaO.2SiO_2.3H_2O$	=	(C-S-H gel), Calcium silicate hydrate

6.Fresh Properties of Concrete

6.1. Compaction Factor (C.F)

The compaction factor results for the different concretes having RHA as cement replacement are shown in Table 4. The workability of concrete usually evaluates the behavior of concrete in the fresh form from mixing up to the compaction. The terms transportability, mix-ability, mould ability and compact-ability mutually indicate the workability of concrete. Various researchers had performed different tests to examined the workability of concrete and also studied the effects of RHA on fresh properties of concrete [6]. Kishore, Bhishma [27] in their studies concluded that the bulk density decreases as the amount RHA increases. Therefore, value of compaction factor is minimum at higher amount of replacement. Krishna, Sandeep [80] in their studies about use of RHA as cement replacement, revealed that the compaction factor reduces as the amount of RHA increases. Abhijith, Anjali [100] also assessed the influence of RHA on the properties of concrete prepared at various %age replacement of RHA with cement. The results demonstrated that the C.F values get reduced with the increasing of rice husk ash ratios. Authors reported that the compacting factor values decreased from 0.91- 0.79 as the percentage replacement of RHA increased from 0% - 25%. Kachwala, Pamnani [101] in their studies reported the same as the previous authors that the compacting factor values become reduced with the increasing of rice husk ash content. Further they described that the its values decreased from 0.92 - 0.88 with 5% - 25% RHA content. They concluded that presence of RHA causes to decrease the workability of concrete. Hence higher amount of water or super-plasticizing admixture is needed to get more workability.

Obilade [102] have evaluated the properties of RHAC. The results demonstrated that the bulk density of concrete get decreased at higher replacement levels of RHA. This might be recognized to the increase in air voids in the concrete specimens as the amount of rice husk ash increases.

Table 4. Compaction factor of Rice Husk Ash concrete

RHA %	Compaction Factor					
0	0.87	0.87	0.882	0.91	0.92	0.91
5	0.86	0.83	0.866	0.85	0.91	0.91
10	0.82	0.81	0.782	0.84	0.90	0.90
15	0.80	0.80	0.661	0.83	0.89	0.90
20	-	-	0.601	0.82	0.88	0.89
25	-	-	-	0.79	0.88	0.88
Mix Proportions	1:0.83:2.53	1:0.78:2.36	1:1.64:3.41	1:1.34:3.16	M20	1:2:4
w/b	0.36	0.35	0.55	0.50	-	-
References	[27]		[80]	[16]	[101]	[102]

6.2. Workability

The RHA effect on workability is shown in Table 5 [79, 18, 103]. Gaesan, Rajagopal [35] have examined the RHA as cement replacement. In their study 5-35% RHA is substituted by cement weight. Authors concluded that slum increases up to 10% RHA replacement further the percentage of RHA increases, the workability reduces.

Padhi, Patra [86] experimented the influence of RHA on the concrete workability. The results showed that the presence of RHA reduced the workability of the concrete. This decrease in slump values increased as RHA amount increased. Madandoust, Ranjbar [24] have analyzed the effects of RHA as cement replacement (5%, 10%, 15%, 20% and 25%) on concrete properties. Authors revealed that the slump value of concrete decreases with the replacement of RHA by cement. Abhijith, Anjali [100] explored the influence of RHA as cement replacement on workability 0%, 5%, 10%, 15%, 20%, and 25% RHA replaced with cement. Results showed that the slump value decreased from control mix to 25% addition of RHA. Krishna, Sandeep [80] have carried out research on RHA concrete.in their study they substituted up to 20% of cement by RHA. The authors described that the addition of RHA in concrete caused to a decrease in workability, which rest on the RHA amount. Further they revealed that this reduce in slump value is due to the absorption of water by admixture particles.

Kishore, Bhishma [27] experimented on the effects of RHA replacement by cement on concrete workability. It was observed that the concrete workability decreases by 27% when the amount of RHA increases. Aleem, Istehsan-ur-Rahim [31] carried the experimental work on the properties of concrete containing RHA as partial replacement of cement. The RHA replaced with cement at the rate of 5 - 15%. They performed the slump test to check the concrete workability, results showed that the slump value of concrete is 72 mm at 20% replacement and the normal concrete workability is 76 mm.

Table 5. Slump of RHA Concrete

RHA %	Slump (mm)

0	98	73	65	112	65	40	35	76
5	106	70	60	98	55	37	32	80
10	115	64	55	95	32	35	29	75
15	91	58	55	92	14	32	27	72
20	81	54	56	86	6	-	-	-
25	74	50	50	82	-	-	-	-
30	64	46	45	-	-	-	-	-
35	41	42	-	-	-	-	-	-
40	-	-	-	-	-	-	-	-
Mix Proportions	1:1.50:3.00	1:1.51:2.93	1:2.13:2.40	1:1.34:3.16	1:1.64:3.41	M40 1:0.83:2.53	M50 1:0.78:2.36	-
W/b	0.53	0.45	0.53	0.50	0.55	0.36	0.35	-
References	[35]	[86]	[24]	[100]	[80]	[27]		[31]

6.3. Density

Mass per unit volume of concrete is known as density. It is a main factor in the evaluation of porosity, determination of strength and durability [81]. The influence of different percentage of RHA are shown in Table 6. Padhi, Patra [86] performed the experiment on the Risk Husk Ash concrete. They substituted up to 35% cement by RHA. The results demonstrated that the density of control mix is 2420 kg/m^3 which reduces to 2190 kg/m^3 with the 35% RHA replacement. Madandoust, Ranjbar [24] examined the effect of different percentage of replacement of cement by RHA on density of concrete. The concrete made with several content of RHA (0-30%) as cement replacement. The authors reported that there is no significant variation in density is observed when compared with normal concrete.

Further investigation by Kachwala, Pamnani [101] described that the bulk density of concrete decreased when amount of RHA increased. Obilade [102] Made concrete containing up to 25% of RHA. They revealed that the density of normal concrete mix is 2430 kg/m^3 which decreases to 2280 kg/m^3 with 25% of RHA.

Table 6. RHA Concrete Density

RHA (%)	**Density (kg/m3)**			
Mix Proportions	1:1.5:2.9	1:2.1:2.4	M20	1:2:4
Water to cement ratio	0.45	0.53	-	-
0	2418	2346	2430	2430
5	2410	2345	2330	2330
10	2390	2345	2300	2300
15	2370	2346	2300	2300
20	2320	2342	2280	2290
25	2280	2342	2270	2280
30	2140	2345	-	-
35	2190	-	-	-
References	[86]	[24]	[101]	[102]

7.Concrete Mix proportion

7.1. Normal Strength Concrete (20-45 MPa) Using RHA

Paramveer et al. [84] investigated on RHA concrete. In their study the RHA used to substitute the cement by weight at the rate of 5-20%. The results showed that Compressive strength increased by 2.1% at 5% replacement as compared with referral mix for M40 concrete grade and then decreased with the increment of RHA percentage.

Akeke et al. [104] have evaluated the influence of RHA as cement replacement on the strength of concrete. The RHA was replaced by cement at the rate of 10%, 20% and 25%. Authors concluded that 25% replacement gave the maximum compressive strength. Anwara et al. [105] directed the investigational work on RHA concrete. 10-20% RHA used as cement replacement. The test results demonstrated that the compressive strength of the concrete decreased by the influence of RHA. Kishore et al. [27] have investigated to study the influence of RHA on the concrete strength for M40 and M50 concrete grade. In their study the RHA replaced with cement (on the mass basis) at the rate of 0%, 5%, 10% and 15% [80]. In their work 0 to 20% RHA has been introduced as cement replacement, result showed that the 28-days strength increased from 27MPa to 29.3MPa with addition of 10% RHA. It is also detected that the compressive strength increased gradually, up to nearly 10% replacement and then reduced. Siddika et al. [91] experimented the influence of RHA as cement replacement on the hardened properties of concrete. 0%, 10% and 15% RHA is used as a replacement of cement. W/B was kept 0.4, 0.5 and 0.6. From their investigation, concluded that compressive strength of the concrete decreases by the influence of RHA.

7.2. High Strength Concrete (45-85 MPa) Using Rice Husk Ash

Padhi et al. [86] researched the individual effect of RHA replacement on the strength of concrete. The cement was changed by RHA at rate of 0% (control mix), 5%, 10%, 15%, 20%, 25%, 30% and 35% (by weight) in concrete. The authors concluded the same as previous authors that the percentage of RHA increases the strength of the concrete decreases. Bhushan et al. [92] evaluated the best replacement of RHA for M20 concrete. Results showed that the compression strength of the concrete mix increases with the replacement of RHA up to 10% afterward the gradually reduce in strength is noted. Kirti et al. [32] substituted up to 20% of RHA by cement weight. The test results described that the maximum 28 days compressive strength observed at 5% RHA.

Gaesan et al. [35] have worked to examined the optimum replacement of RHA as cement replacement for M25 concrete grade. The cement was substituted by RHA at rate of 0% (control mix), 5%, 10%, 15%, 20%, 25%, 30% and 35% (by weight) in concrete. The test results demonstrated that the 20% replacement is an optimum replacement for M25 mix and at 30% RHA, the strength of RHAC with 30% RHA replacement attained values more than to the referral concrete specimens. Tashima et al. [88] have experimented the effect of utilization of RHA as cement replacement on the concrete strength. in their study up to 15% RHA is substituted by cement weight. The results demonstrated that the optimum strength was attained at 5% replacement. Madandoust et al. [24] assessed the impact of different proportion of RHA by cement on compressive strength of concrete. The RHA was replaced by cement at the rate of 5%, 10%, 15%, 20%, 25% and 30%, results demonstrated that at early age testing, the compressive strength of referral mix is higher than other concrete mixes having different percentage of RHA.

Abhijith et al. [100] examined suitability of RHA replacement on the concrete strength. The cement is replaced by RHA at rate of 0% (control mix), 5%, 10%, 15%, 20% and 25% (by weight) in concrete. The experimental results described that the maximum compressive strength attained at 20% replacement and the compressive strength at 25% replacement is more than the referral mix. Abalaka et al. [30] assessed the hardened RHA characteristics concrete prepared with different replacement of RHA at different water cement ratios of 0.35 and 0.3. A partial replacement of 5%, 10%, 15% and 20% RHA by cement were studied. The Experimental results describes the maximum 28days compressive strength observed at 5% replacement is 55.5MPa and 59.9 MPa at water to binder ratios 0.35 and 0.3 respectively. Therefore, 5% RHA seems to be the optimal limit. Zareei et al. [106] made concretes containing up to 25% RHA. The results demonstrated that although the best percentage of replacement is 20%, the concrete with 25% RHA has a more compressive strength to the referral one.

Sensale et al. [87] researched the hardened of concrete in which the RHA was replaced 10-20% by weight of cement and three different water-cement ratios (0.32, 0.40, 0.50), were used. Based on results, 10% RHA is observed as optimum percentage replacement at both waters to binding ratios of 0.5 and 0.4. and 20% RHA is observed as optimum replacement at 0.32 water to binding material ratio. Zhang et al. [81] demonstrated that the concrete strength at 10% RHA content is greater than the referral concrete mix. Suman et al. [23] investigated to examine the optimum replacement of RHA for M20 concrete grade mix. A partial replacement of 5%, 10%, 15% and 20% by cement were studied. Authors reported that 15% is an optimum replacement for M20 concrete grade. Giaccio et al. [89] assessed the properties of concrete at 10% replacement of RHA by cement and four different water to binder ratios (0.28, 0.32, 0.4, 0.5), were used. The authors reported the same as previous authors, in that 10% RHA content contributed the maximum compressive strength.

Nirubha et al. [93] concentrated to produce an economic concrete by substituting the cement with RHA at the rate of 10% - 20%. The authors expected that the optimum utilization of RHA for M60 concrete grade is as 10%. Bawankule et al. [1] made concretes containing up to 15% of RHA. Authors reported the same as previous authors that the compressive strength of the concrete decreases by the influence of RHA. Ephraim et al. [107] investigated to assess the compressive strength of RHA concrete. 0- 25% RHA is used as cement replacement.

The results demonstrated that the compressive strength of the concrete at 28days of curing is 38.4 MPa, 36.5 MPa and 33.0 MPa with 10%, 20% and 25% replacement respectively. The strength of the referral concrete mix is 37 MPa. The authors concluded that 10% replacement gave the maximum compressive strength.

Rambabu et al. [108] investigated to analyze the optimum replacement of RHA for M35 concrete grade mix. A partial replacement of 5%, 6%, 7%, 8%, 9% and 10% RHA by cement were studied. The authors suggested that the 6% is an optimum replacement for M35 concrete grade. Bangwar et al. [109] examined the individual effect of RHA replacement on the strength of concrete. In their research 0%, 2.5%, 5%, 7.5% 10%, 12.5% and 15% of RHA has been used as cement Replacement. Mahmud et al. [110] conducted research to produce M80 grade concrete in which RHA is replaced with 15% of weight of cement. The compressive strength with 10% Rice Husk Ash content is greater with all the mixes. The authors suggested that it is efficient to use 10% RHA for Mega structures. Kumar et al. [111] employed up to 30% cement by RHA at variuos w/c ratios. The author suggested same as previous authors that the %age replacement of cement by RHA enhance will result in the decreases of concrete strength.

Obilade [102] examined the individual effect of RHA on concrete strength. This study cement is replaced with 5%-25% RHA. From the test results the compressive strengths of concrete reduces with RHA content. Sundararaman et al. [112] explored the use of various %age of replacement RHA by cement in concrete. In their study RHA replaced in the with 25%, 20%, 15%, 10% and 5% with weight of cement and 10% silica fume for M20 concrete. Authors reported similar as other authors, in which 10% RHA content contributed with highest compressive strength, beyond 10% replacement reduce in strength is observed. Naveen et al. [113] have assessed the effect of RHA as cement substitute of concrete compressive strength. RHA was partially replaced at different percentage (20%, 15%, 10%, 5% 0%) by cement weight.

The authors expected that the optimum utilization of RHA for M30 and M60 concrete grade is as 10%. Investigation results performed by various researchers are given in Table 7.

7.3. UHPC using Rice Hush Ash

Van Breugel, K. and Y. Guang. [118] examined produce UHPC using RHA. It was specified that RHA contributes highly to long term development of UHPC compressive strength after 28 days [114, 115, 116, 117]. It was reported that the compressive strength of UHPC enhanced to 12 % and 18% at 28 and 91 days respectively, as the percentage RHA replacement to 20%. Van Tuan et al. [119] examined the flexibility to produce UHPC using RHA. Results described that the UHPC compressive strength containing RHA, could achieve more than 150 MPa with normal curing method. Additionally, this achievement was even greater than samples with silica fume (SF). Furthermore, investigation conducted by ößler, C., D.-D. Bui and H.-M. Ludwig., [120], revealed that the sample containing 10% of SF and 10% RHA substituted with cement showed better compressive strength than control sample. The RHA with higher average particle size attains lesser compressive strength than the minimum mean particle size. Nguyen [121] have suggested the mean particle size of RHA to be used in UHPC vary between 3.6µm-9µm which will be combined with cement. However, Van Tuan, N., et al. [119] studied that the packing density of UHPC with particle sizes of RHA ranging from 3.6µm-5.6µm at 20% replacement of OPC give the best results in comparison to the UHPC containing SF. Nguyen V [121]

Table 7. Different Replacement levels of RHA for Hardened Properties of Concrete

`RHA (%)	Mix proportion	w/b ratio	SP (%)	Compressive strength (MPa)		28-day splitting tensile strength (MPa)	28-day flexural strength (MPa)	References
				28 days	90 days			
0	M40 1:1.82:2.77	0.4	0.5	47.4	-	3.2	4.9	[84]
5			0.5	48.5	-	3.3	5.5	
10			1.0	46.8	-	2.7	4.7	
15			1.0	40.5	-	2.6	3.9	
20			1.0	33.8	-	2.2	3.1	
0	1:2.41:2.44	0.6	-	31.1	33.4	3.1	4.8	[105]
10			-	24.6	30.6	2.8	4.4	
20			-	20.5	27.0	3.4	4.4	
0	M40 1:0.83:2.53	0.36	-	50.8	51.7	4.2	4.9	[27]
5			-	48.2	49.1	4.0	4.4	
10			-	44.7	47.0	4.0	4.3	
15			-	43.1	45.0	4.0	4.1	
0	M50 1:0.78:2.36	0.35	-	59.4	62.5	4.2	5.3	
5			-	56.4	58.3	4.6	4.9	
10			-	53.4	56.4	4.2	4.7	
15			-	50.5	52.5	4.2	4.7	
0	1:1.6:2.61	0.4	-	35.6	-	4.8	5.2	[91]
10			-	35.0	-	4.5	4.9	
15			-	31.0	-	4.2	3.9	
0	1:1.65:3.40	0.5	-	31.7	-	4.7	5.1	
10			-	30.9	-	4.2	4.7	
15			-	28.6	-	3.9	3.9	
0	1:2.028:4.19	0.6	-	29.4	-	4.4	5.0	
10			-	28.8	-	4.0	4.1	
15			-	26.0	-	3.5	3.6	
0	1:1.33:2.27	0.42	-	48.10	58.3	5.37	-	[88]
5			-	60.40	62.00	5.79	-	

RHA (%)	Mix proportion	w/b ratio	SP (%)	Compressive strength (MPa)		28-day splitting tensile strength (MPa)	28-day flexural strength (MPa)	References
				28 days	90 days			
10	1:1.5:3.0	-	-	22.0	-	1.9	3.0	[104]
20			-	20.0	-	1.2	2.5	
25			-	29.0	-	0.9	2.5	
0	M20 1:1.59:2.075	0.4	-	30.30	-	3.91	-	[112]
5			-	31.50	-	3.12	-	
10			-	34.20	-	3.32	-	
15			-	23.00	-	2.83	-	
20			-	20.20	-	2.78	-	
0	1:1.64:3.41	0.55	-	27.0	-	2.2	2.1	[80]
5			-	24.8	-	2.3	2.5	
10			-	29.3	-	2.5	1.9	
15			-	17.6	-	2.1	-	
20			-	16.0	-	2.0	-	
0	1:1.51:2.93	0.45	0.90	41.0	-	2.9	4.1	[86]
5				39.5	-	2.8	4.0	
10				38.7	-	2.6	3.9	
15				37.1	-	2.5	3.8	
20				32.3	-	2.2	3.5	
25				28.9	-	2.1	3.3	
30				25.6	-	1.9	3.1	
35				21.2	-	1.6	2.7	
0	M20	0.50	-	34.5	-	2.9	4.5	[92]
5			-	36.2	-	3.4	4.6	
10			-	34.8	-	3.0	4.5	
15			-	27.2	-	2.4	3.5	
20			-	19.2	-	2.0	2.2	
25			-	14.5	-	1.9	1.8	

10			-	54.20	60.90	5.78	-	
0	1:1.51:3.06	0.50	-	30.6	-	4.0	-	[32]
5			-	31.5	-	4.1	-	
7.5			-	31.1	-	3.6	-	
10			-	30.7	-	3.3	-	
12.5			-	30.1	-	3.0	-	
15			-	25.3	-	2.0	-	
0	1:2.13:2.40	0.53	0	35.4	-	3.3	-	[24]
5			0.95	33.6	-	-	-	
10			0.98	32.4	-	-	-	
15			1.04	32.1	-	-	-	
20			1.07	30.8	-	3.0	-	
25			1.11	29.7	-	-	-	
30			1.15	26.6	-	-	-	
0	1:0.864:2.46	0.30	1.57	49.5	50.0	-	-	[30]
5			1.26	55.5	59.0	-	-	
10			1.32	53.0	60.0	-	-	
15			1.38	54.3	57.7	-	-	
20			1.32	48.3	51.2	-	-	
0		0.35	1.26	52.7	61.7	-	-	
5			1.26	60.0	66.5	-	-	
10			1.23	52.0	56.4	-	-	
15			0.94	50.4	55.9	-	-	
20			0.94	38.2	40.6	-	-	
0	1:1.29:1.97	0.32	0.40	55.5	60.60	3.63	-	[87]
10			0.20	60.4	64.30	3.57	-	
20			0.20	54.8	62.70	3.34	-	
0	1:1.875:2.10	0.4	0.10	42.3	45.60	-	-	
10			0.20	50.4	54.90	-	-	
20			0.40	40.7	51.40	-	-	
0	1:1.86:2.41	0.5	0	32.9	35.90	2.85	-	
10			0	31.5	35.50	2.32	-	

-	-	-	-	-	-	-	-	-
0	M25 1:1.5:3.0	0.53	-	37.1	38.3	4.5	-	[35]
5			-	40.0	43.3	4.7	-	
10			-	41.3	44.8	4.8	-	
15			-	41.8	45.7	5.0	-	
20			-	42.5	46.0	5.1	-	
25			-	38.8	43.0	4.7	-	
30			-	37.6	38.7	4.5	-	
35			-	35.1	37.2	-	-	
0	1:1.34:3.16	0.50	-	22.2	-	3.2	-	[100]
5			-	24.3	-	3.3	-	
10			-	28.6	-	3.4	-	
15			-	29.6	-	3.6	-	
20			-	33.5	-	3.9	-	
25			-	29.9	-	3.5	-	
0	1:1.875:2.1	0.4	3.75	83.4	-	5.83	-	[106]
5				85.1	-	5.95	-	
10				86.9	-	6.1	-	
15				92.5	-	6.47	-	
20				93.3	-	6.52	-	
25				89.1	-	6.23	-	
0	1: 1.75: 2.86	0.4	0.77	36.4	-	2.70	6.30	[81]
10			1.40	38.6	-	3.50	6.80	
0	1:1.40:1.96	0.28	2.00	63.10	-	-	7.60	[89]
10			2.05	63.60	-	-	7.60	
0	1:1.71:2.24	0.32	1.20	54.60	-	-	5.80	
10			1.88	56.60	-	-	6.10	
0	1:2.00:2.48	0.40	0.90	46.20	-	-	5.10	
10			0.91	49.70	-	-	5.00	
0	1:2.49:2.92	0.50	0.00	36.40	-	-	4.00	
10			0.00	38.40	-	-	4.50	
-	-	-	-	-	-	-	-	-

20			0	34.9	37.90	2.63	-	
0	M20	Not Given	-	31.04	-	-	3.06	[23]
5			-	31.52	-	-	3.12	
10			-	31.89	-	-	3.04	
15			-	32.06	-	-	2.53	
20			-	25.33	-	-	2.46	
0	M60	Not Given	-	60.00	-	-	-	[93]
5			-	64.50	-	-	-	
10			-	68.50	-	-	-	
15			-	61.50	-	-	-	
20			-	61.00	-	-	-	
0	1:1.5:3	Not Given	-	37.00	-	-	-	[107]
10			-	38.40	-	-	-	
20			-	36.50	-	-	-	
25			-	33.00	-	-	-	
0	1:2:3	0.55	-	22.69	-	-	-	[109]
2.5		0.56	-	23.20	-	-	-	
5.0		0.57	-	23.32	-	-	-	
7.5		0.58	-	23.50	-	-	-	
10.0		0.60	-	23.64	-	-	-	
12.5		0.61	-	17.26	-	-	-	
15		0.62	-	13.71	-	-	-	
0	1:2:4	Not Given	-	29.15	-	-	-	[102]
5			-	27.68	-	-	-	
10			-	20.88	-	-	-	
15			-	18.70	-	-	-	
20			-	18.59	-	-	-	
25			-	13.29	-	-	-	
0	M30 1:1.48:2.64	0.43	-	44.50	-	-	-	[113]
5			-	46.00	-	-	-	
10			-	47.50	-	-	-	
15			-	38.50	-	-	-	
20			-	36.50	-	-	-	
-	-	-	-	-	-	-	-	-
0	M60 1:1.34:2.35	0.35	-	61.50	-	-	-	[113]
5			-	64.50	-	-	-	
10			-	65.50	-	-	-	
15			-	62.00	-	-	-	
20			-	58.00	-	-	-	

-	-	-	-	-	-	-	-	-
0	1:1.5:3	Not Given	-	28.12	-	-	-	[1]
2.5			-	26.13	-	-	-	
5			-	24.96	-	-	-	
7.5			-	23.04	-	-	-	
10			-	21.09	-	-	-	
12.5			-	18.39	-	-	-	
15			-	16.49	-	-	-	
0	M35 1:1.16:2.73	0.42	-	44.80	-	-	-	[108]
5			-	47.08	-	-	-	
6			-	48.39	-	-	-	
7			-	47.25	-	-	-	
8			-	46.10	-	-	-	
9			-	45.12	-	-	-	
10			-	47.41	-	-	-	
0	1:0.985:1.98	0.31	1.2	81.80	86.20	-	-	[110]
5			1.8	88.50	90.00	-	-	
10			1.7	87.30	92.00	-	-	
0	1:2:4	0.56	-	29.24	-	-	-	[111]
10			-	22.99	-	-	-	
20			-	19.42	-	-	-	
30			-	15.49	-	-	-	
0	1:2:4	0.58	-	27.14	-	-	-	
10			-	23.26	-	-	-	
20			-	19.48	-	-	-	
30			-	15.51	-	-	-	
0	1:2:4	0.60	-	27.26	-	-	-	
10			-	23.48	-	-	-	
20			-	19.60	-	-	-	
30			-	15.83	-	-	-	
0	1:2:4	0.62	-	24.36	-	-	-	
10			-	21.26	-	-	-	
20			-	19.50	-	-	-	
30			-	16.15	-	-	-	
-	-	-	-	-	-	-	-	-
-			-	-	-	-	-	
-			-	-	-	-	-	
-			-	-	-	-	-	
-			-	-	-	-	-	

7.4. Rice Husk Ash Splitting Tensile Strength

Table 7 listed splitting tensile strength. Paramveer et al. [84] investigated on RHA concrete. The cement is partially substituted with RHA up to 20% by cement weight. The splitting tensile strength improved from 3% to 5% RHA replacement. But decrease afterward approximately 31.25% to the control mixes at 20% replacement. Some Researchers [35, 100, 105, 106] investigated RHA concrete. Splitting tensile strength increased at different water to cement ratios of 0.6, 0.53, 0.5 and 0.4 (as compared to referral mix) with the addition of 20% RHA by cement weight. Krishna et al. [80] suggested that at 10% replacement of cement by RHA Exhibits good splitting tensile strength. Numerous researchers [27, 86, 87, 91, 104, 112] investigated to examine the hardened properties of M20 concrete. The authors stated that the splitting tensile strength decreases with the addition of RHA in concrete. Bhushan et al. [92] evaluated the hardened properties for M20 concrete grade. Results showed that the 14.7% splitting tensile strength increased as compared to referral mix at 5% RHA. Kirti et al. [32] reported that the 5% replacement gave the maximum splitting tensile strength. Further investigation by [88] showed that 7.25% splitting tensile strength increased at 5% RHA replacement level.

7.5. Rice Husk Ash Flexural Strength

Flexural strength is shown in Table 7. Some researchers [23, 80, 84, 92] assessed the flexural strength of concrete at 0-25% replacement of RHA by cement weight and four different water-binder ratios (0.4, 0.55 and 0.5), were used. The authors concluded that the flexural strength at 5% replacement is higher as compared to control mix and the flexural strength at 10% replacement is equivalent to the referral mix. Further investigation by [81, 91] revealed that flexural strength improved with the increase in RHA up to 10%. Some researchers [27, 86, 91, 104, 105], also assessed the RHA concrete flexural strength. Flexural strength of RHA concretes decreased with increase in RHA content.

7. Elastic Modulus (EM)

The EM results for the concrete containing various RHA amount is listed in Table 8. The objective of this computation, tensile stress of test specimens shall be determined by dividing load to the test samples area. The output is presented in gigapascals (GPa) [48]. Padhi et al. [86] in their laboratory study on different properties of concrete prepared with various %age RHA as cement replacement. The authors revealed that the E-value of RHA concrete is not enhanced when matched with control specimens. Zareei et al. [106] performed the investigational work to studied the RHA characteristics of concrete. The authors described that the maximum E- value observed at 5% replacement level and the modulus of elasticity with 25% RHA is also greater to normal concrete. Kishore et al. [27] have experimented the influence of RHA as cement replacement in concrete. The results showed that the MOE attained with different percentage of RHA is satisfied with the design values for all percentage replacements. Tashima et al. [88] have worked to determine the optimum replacement of RHA in concrete. They revealed that all samples have approximately similar results in elasticity module at different percentages of RHA.

Table 8. RHA as partial replacement of OPC on the E-value of Concrete [27, 86, 88, 106]

RHA %	Modulus of Elasticity (GPa)				
0	32.2	39.3	47.3	50.7	40.9
5	32.1	49.3	44.6	47.2	40.7
10	32.1	40.1	39.5	43.5	40.2
15	31.5	41.6	35.6	38.9	-
20	31.1	41.9	-	-	-
25	30.4	40.9	-	-	-
30	29.7	-	-	-	-
35	29.3	-	-	-	-
Mix Proportions	1:1.51:2.93	1:1.875:2.10	M40 1:0.83:2.53	M50 1:0.78:2.36	1:1.33:2.27
W/b	0.45	0.40	0.36	0.35	0.42

8.Water Absorption

The effect of RHA as a supplementary cementitious on the water absorption of concrete mixes is shown in Table 9. Padhi et al. [86] have investigated the influence of RHA as cement replacement in concrete.in their investigational work the RHA is substituted up to 35%. The results showed that the water absorption of the referral mix is 5.55% and further increased up to 7.21% when RHA percentage increased from 5%-35%. The authors summarized that the water absorption of RHA concrete increased due to increase in water absorption of RHA particles. Further they described that this increment in water absorption shows the concrete that prepared with RHA is lesser durable than control mixes. Gaesan et al. [35] have worked to investigate the influence of RHA as cement replacement for M25 concrete grade. The RHA is substituted up to 35%.

The authors described the same as previous authors that the percentage of water absorption increases with the addition of RHA up to 35% at 28days of curing. The reason behind is that the RHA particles are finer than cement particles. Zareei et al. [106] investigated to study the RHA characteristic of concrete. 0-25% RHA used as cement replacement. It is concluded that water absorption of normal concrete mix is 4.12% and %age of water absorption decreases by increasing the RHA amount, at 25% RHA the water absorption is 3.05%.

Krishna et al. [80] have evaluated the effect of RHA on the water absorption of concrete. The water absorption of control mix is lower; from the results it is concluded that the water absorption of the concrete increases by increasing the amount of RHA. Further the authors described this increase in water absorption is due to the fact that the RHA is more porous material, water occupies these pores which rise the rate of water absorption. Tashima et al. [88] revealed that higher replacement amounts result in lesser water absorption values, this happens due to the RHA particles are finer than cement. The results showed that 38.7% reduction in water absorption is noted at 10% RHA replacement when compared to the referral mix. Siddika et al. [91] have worked to investigate the influence of RHA as cement replacement on the water absorption of concrete. W/B were kept 0.4, 0.5 and 0.6. The authors described that the rate of water absorption is varies with water-binder ratio if taking all the other contents same. Further they described that the concrete with different percentage of RHA has more water absorption as compared to referral mix. The results showed that the rate of water absorption varies about 10 - 28%. This phenomenon take place because of RHA concrete is more porous than referral mix. Furthermore, it is also reported that the concrete porosity increases with the increase in water-binder ratio.

Table 9. Water absorption of concrete for RHA replacement

RHA %	Water Absorption %							
0	5.55	4.71	4.12	-	1.80	4	3.60	3.40
5	5.65	4.83	3.95	1.28	1.65	-	-	-
10	5.68	5.02	3.70	1.49	1.40	4.40	4.00	3.60
15	6.00	5.58	3.46	1.64	-	5.00	4.70	4.00
20	6.30	5.81	3.23	1.85	-	-	-	-
25	6.70	6.09	3.05	-	-	-	-	-
30	6.90	6.35	-	-	-	-	-	-
35	7.21	6.92	-	-	-	-	-	-
Mix Proportions	1:1.51:2.93	1:1.50:3.00	1:1.875:2.10	1:1.64:3.41	1:1.33:2.27	1:2.028:4.19	1:1.65:3.40	1:1.26:2.61
W/b	0.45	0.53	0.40	0.55	0.42	0.60	0.50	0.40
References	[86]	[35]	[18]	[80]	[88]	[91]		

9.Sorptivity

Gaesan et al. [35] have worked to examine the influence of various RHA amount as cement substitute on concrete sorptivity. The sorptivity gradually reduces up to 25% RHA content and further increase in sorptivity is observed at 30-35% RHA content. The sorptivity value at 35% RHA is relatively lower to the referral specimens. The authors reported that long curing starts for reducing pore size. Abalaka et al. [30] have investigated RHA for cement replacement to concrete sorptivity. They performed sorptivity test at cured and uncured concrete specimens. The results showed that, sorptivity gradually enhance with the enhancement in RHA amount and value of sorptivity inf uncured specimen is higher than the water cured specimen at the same RHA content. In the other words, the water cured samples had dense microstructure as compared to the uncured samples. Furthermore, the authors also demonstrated that the concrete which prepared at lower water to cement ratios have better dense microstructure as compared to higher water cement ratio mixes.

10.Conclusions

To obtain RHAC is analyzed by available materials for RHA replacement as cement. The RHA physical and chemical characteristics were studied with OPC. The following results are achieved.

1. The replacement of RHA requires more water to obtain the similar workability and compaction factor.
2. RHAC Density is in between 2190 – 2430 kg/m^3 which lies as semi-lightweight and normal concretes, and therefore considered as the conventional RHA concrete which is the general purposes.
3. The RHA replacement for normal concrete between 5 to 10% showed the excellent durability and mechanical properties.
4. The RHA addition in the conventional concrete even enhance elastic modulus from 29.3 to 49.3 GPa, which is more than the normal and conventional concrete strength whose values vary in the range of 14 to 41 GPa Aslam et al. [72].
5. The RHA replacement in the conventional concrete enhances absorption of water up to 7%, that shows less that 10% for good concrete [95].
6. The RHA addition reduces the loss of ignition compared to the conventional cement concrete.

11.References

[1] Bawankule, S.P., P.D. Hiwase, and M.S. Balwani, *Effect of Partial Replacement of Cement by Rice Husk Ash in Concrete*. International Journal of Research in Engineering, Science and Technologies, 2015. **1**(8): p. 310-313.

[2] Hosseini, P., et al., *Use of nanoSiO2 to improve microstructure and compressive strength of recycled aggregate concretes*. In: Proceeding, nanotechnology in construction (NICOM3), 2009: p. 215-222.

[3] Calkins, M., *A Complete Guide to the Evaluation, Selection, and Use of Sustainable Construction Materials*. Materials for Sustainable Sites John Wiley, New York, 2009.

[4] Gopi, N. and P. Sruthi, *An Experimental Study On The Strength Of Concrete with Partial Replacement of Cement by Rice Husk Ash*. International Conference on Emerging trends in Engineering, Science and Sustainable Technology, 2017: p. 9-12.

[5] Ghosal, S. and S. Moulik, *Use of Rice Husk Ash as Partial Replacement with Cement In Concrete- A Review*. International Journal of Engineering Research, 2015. **4**(9): p. 506-509.

[6] Karri, S.K., G.V.R. Rao, and P.M. Raju, *Strength and Durability Studies on GGBS Concrete*. SSRG International Journal of Civil Engineering (SSRG-IJCE), 2015. **2**(10): p. 34-41.

[7] Mehta, P.K. and P.J.M. Monteiro, *Concrete: microstructure, properties, and materials*. 3rd ed. New York: McGraw-Hill, 2006.

[8] Altwair, N. and S. Kabir, *Green concrete structures by replacing cement with pozzolanic materials to reduce greenhouse gas emissions for sustainable environment. In.* American society of civil engineers, 6th international engineering and construction conference (IECC'6), June 28–30, Cairo, Egypt, 2010.

[9] Alex, J., J. Dhanalakshmi, and B. Ambedkar, *Experimental investigation on rice husk ash as cement replacement on concrete production*. Construction and Building Materials, 2016. **127**: p. 353-362.
[10] Bayasi, et al., *Properties of Silica Fume Concrete and Mortar*. ACI Materials Journal, 1993. **90**(4): p. 349-356.
[11] Cleetus, et al., *ANALYSIS AND STUDY OF THE EFFECT OF GGBFS ON CONCRETE STRUCTURES*. International Research Journal of Engineering and Technology (IRJET), 2018. **5**(3): p. 3033-3037.
[12] Coutinho, S., et al., *The combine benefit of CPF and RHA in improving the durability of concrete structures*. Cement and Concrete Composites, 2003. **25**(1).
[13] Özbay, E., M. Erdemir, and H.I. Durmus, *Utilization and efficiency of ground granulated blast furnace slag on concrete properties – A review*. Construction and Building Materials, 2016. **105**: p. 423-434.
[14] Muga, H., et al., *Development of Appropriate and Sustainable Construction Materials*. Sustainable Futures Institute, 2005: p. 17.
[15] Owaid, H.M., et al., *A Review of Sustainable Supplementary Cementitious Materials as an Alternative to All Portland Cement Mortar and Concrete*. Australian Journal of Basic and Applied Sciences, 2012. **6**(9): p. 2887-303.
[16] Gurunaathan, K. and G.S. Thirugnanam, *Effect of mineral admixtures on durability properties of concrete*. International Journal of Advance Structures and Geotechnical Engineering, 2014. **03**(01).
[17] Srivastava, V., et al., *Effect of Silica Fume in Concrete*. International Journal ofInnovative Research in Science, Engineering and Technology, 2014. **3**(4): p. 254-259.
[18] Johari, M.A.M., et al., *Influence of supplementary cementitious materials on engineering properties of high strength concrete*. Construction and Building Materials, 2011. **25**: p. 2639-2648.
[19] MADHANASREE, R.M., A.J. PAULSON, and R.A. PRABHAVATHY, *STUDY ON SILICA FUME REPLACED CONCRETE WITH SUPER PLASTICIZER*. Int. J. Chem. Sci, 2016. **14**(S1): p. 359-366.
[20] Bakar, B.H.A., R. Putrajaya, and H. Abdulaziz, *Malaysian Rice Husk Ash – Improving the Durability and Corrosion Resistance of Concrete: Pre-review*. Concrete Research Letters, 2010. **1**(1): p. 6-13.
[21] Rashid, M.H., M.A.M. Keramat, and T.U. Ahmed, *Durability of Mortar in Presence of Rice Husk Ash*. International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering 2010. **4**(7): p. 176-179.
[22] Zain, M.F.M., et al., *Production of rice husk ash for use in concrete as a supplementary cementitious material*. Construction and Building Materials, 2011. **25**: p. 798-805.
[23] Suman, A.K., A.K. Saxena, and T.R. Arora, *Assessment of Concrete Strength using Partial Replacement of Cement for Rise Husk Ash*. International Journal of Soft Computing and Engineering (IJSCE), 2015. **4**(6): p. 131-133.
[24] Madandoust, R., et al., *Mechanical properties and durability assessment of rice husk ash concrete*. Biosystems Engineering, 2011. **110**: p. 144-152.
[25] Hwang, C.L. and D.S. Wu, *Properties of cement paste containing rice husk ash*. In V. M. Malhotra (Ed.), Proceedings of the third CANMET/ACI international

conference on fly ash silica fume, slag and natural pozzolans in concrete 1989: p. 733-762.
[26] Bui, D.D., J. Hu, and P. Stroeven, *Particle size effect on the strength of rice husk ash blended gap-graded Portland cement concrete*. Cement and Concrete Composites, 2005. **27**: p. 357-366.
[27] Kishore, R., V. Bhishma, and P.J. Prakash, *Study on Strength Characteristics of High Strength Rice Husk Ash Concrete*. Procedia Engineering, 2011. **14**: p. 2666-2672.
[28] *Rice Market Monitor*. Food and Agriculture Organization of the United Nations, 2018. **XXI**(I).
[29] Habeeb, G.A. and M.M. Fayyadh, *Rice Husk Ash Concrete: the Effect of RHA Average Particle Size on Mechanical Properties and Drying Shrinkage*. Australian Journal of Basic and Applied Sciences, 2009. **3**(3): p. 1616-1622.
[30] Abalaka, A.E. and O.G. Okoli, *Strength Development and Durability Properties of Concrete Containing Pre-Soaked Rice Husk Ash*. Construction Science, 2013/2014: p. 4-12.
[31] Aleem, M., et al., *Incorporation of Rice Husk Ash as Cement Replacement*. IOSR Journal of Engineering, 2015. **05**(07): p. 25-30.
[32] Kirti, C., et al., *Experimental Study of RHA Concrete*. International Journal for Research in Applied Science & Engineering Technology (IJRASET), 2015. **3**(11): p. 77-82.
[33] Della, V.P., I. Ku¨hn, and D. Hotza, *Rice husk ash as an alternate source for active silica production*. Materials Letters, 2002. **57**: p. 818-821.
[34] Krishnarao, R.V., et al., 2011. **21**: p. PP.
[35] Gaesan, K., K. Rajagopal, and K. Thangavel, *Rice Husk Ash Blended Cement: Assessment of Optimal Level of Replacement for Strength and Permeability Properties of Concrete*. Journal of Construction and Building Materials, 2008. **22**: p. 1675-1683.
[36] Hwang, C.L. and S. Chandra, *The Use of Rice Husk Ash in Concrete*. 2016.
[37] Dolage, D.A.R., et al., *Use of Rice Husk Ash Blended Cement to Produce Cemnet Sand Blocks: Optimal Level of Cement Replacement for Compressive Strength*. ENGINEER, 2011. **XXXXIV**(02): p. 11-19.
[38] Fapohunda, C., B. Akinbile, and A. Shittu, *Structure and properties of mortar and concrete with rice husk ash as partial replacement of ordinary Portland cement—a review*. Int J Sustain Built Environ, 2017.
[39] Chandrasekhar, S., et al., *Review processing, properties and applications of reactive silica from rice husk—an overview*. Journal of Materials Science (Norwell). **38**(15): p. 3159-3168.
[40] Zhang, M. and V. Malhotra, *High-performance concrete incorporating rice husk ash as a supplementary cementing materials*. ACI Materials Journal (Detroit), 1996. **93**(6): p. 629-636.
[41] James, J. and S.M. Rao, *Reactivity of rice husk ash*. Cement Concrete Res 1986. **16**: p. 296-302.
[42] Mehta, P.K., *Rice Husk Ash - A unique supplementary cementing material Proceeding*. International Symposium on Advances in Concrete Technology. Editor. Malhotra,V.M. Athens, Greece, 1992: p. 407- 430.

[43] Nair, D.G., et al., *A Structural Investigation Relating to the Pozzolanic Activity of Rice Husk Ashes*. Cement and Concrete Research Letters, 2008. **38**: p. 861-869.
[44] Boating, A. and D. Skeete, *Incineration of rice hull for use as a cementitious materials; the Guyana experience*. Cement Concrete Res, 1990. **20**: p. 795–802.
[45] James, J. and S.M. Rao, *Silica from rice husk through thermal decomposition*. Thermochim Acta, Elsevier Science, Amsterdam, 1986(97): p. 329–336.
[46] Zhang, M.H., R. Lastra, and V.M. Malhotra, *Rice husk ash paste and concrete: some aspects of hydration and the microstructure of the interfacial zone between the aggregate and paste*. Cem Concr Res 1996. **26**(6): p. 963-977.
[47] Farooque, K.N., et al., *Characterization and utilization of rice husk ash (RHA) from rice mill of Bangladesh*. Bangladesh J Sci Ind Res, 2009. **44**(2): p. 157-162.
[48] Circuits, P.E. and O.T. Group, *Ipc-tm-650 test methods manual 1.0*. Deposited Dielectric Task Group (C-13a), 2009. **2**: p. 4-6.
[49] Yuzer, N., et al., *Influence of raw rice husk addition on structure and properties of Concrete*. Construction and Building Materials, 2013. **44**: p. 54-62.
[50] 50. Shodhganga, *Production Methodologies And Properties of RHA - A Review*. 2016.
[51] *ASTM Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete*. Designation: C 618 – 05, 2005.
[52] Chusilp, N., C. Jaturapitakkul, and K. Kiattikomol, *Effects of LOI of ground bagasse ash on the compressive strength and sulfate resistance of mortars*. Construction and Building Materials, 2009. **23**: p. 3523-3531.
[53] Qing Xu, Q., et al., *Characteristics and Applications of Sugar Cane Bagasse Ash Waste in Cementitious Materials*. Materials, 2019. **12**(39).
[54] Siddique, R., *Utilization of wood ash in concrete*. Resour. Conserv. Recycl., 2012. **67**: p. 27-33.
[55] Sadrmomtazi, A., et al., *Properties of multi-strength grade EPS concrete containing silica fume and rice husk ash*. Construction and Building Materials, 2012. **35**: p. 211-219.
[56] Rawaid, K., et al., *Reduction in environmental problems using rice-husk ash in concrete*. Construction and Building Materials, 2012. **30**: p. 360-365.
[57] Dabai, M.U., et al., *Studies on the Effect of Rice Husk Ash as Cement Admixture*. Nigerian Journal of Basic and Applied Science, 2009. **17**(2): p. 252-256.
[58] Ismail, M.S. and A.M. Waliuddint, *Effect of rice husk ash on high strength concrete*. Construction and Building Materials, 1996. **10**(7): p. 521-526.
[59] Habeeb, G.A. and H.B. Mahmud, *Study on Properties of Rice Husk Ash and Its Use as Cement Replacement Material*. Materials Research, 2010. **13**(2): p. 185-190.
[60] Zhang, M.H., R. Lastra, and V.M. Malhotra, *Rice-Husk Ash Paste and Concrete: Some Aspects of Hydration and the Microstructure of the Interfacial Zone Between the Aggregate and Paste*. Cement and Concrete Research, 1996. **26**(6): p. 963-977.

[61] Parande, A.K., et al., *Utilization of Agroresidual Waste in Effective Blending in Portland Cement*. ISRN Civil Engineering, 2011: p. 1-12.
[62] Zerbino, R., G. Giaccio, and G.C. Isaia, *Concrete incorporating rice-husk ash without processing*. Construction and Building Materials, 2011. **25**: p. 371-378.
[63] Jongpradist, P., et al., *Efficiency of Rice Husk Ash as Cementitious Material in High-Strength Cement-Admixed Clay*. Advances in Civil Engineering, 2018: p. 1-11.
[64] Binyamien, I., et al., *The Effect of Rice Husk Ash on the Strength and Durability of Concrete at High Replacement Ratio*. Mechanics, Materials Science & Engineering, 2017.
[65] Ramezanianpour, A.K., M. Balapour, and E. Hajibandeh, *Effect of nano rice husk ash against penetration of chloride ions in mortars*. 5th National and 1st Iternational Conference on Modern Materials and Structures in Civil Engineering, October 26-27, 2016.
[66] Chatveera, B. and P. Lertwattanaruk, *Durability of conventional concretes containin g black rice husk ash*. Journal of Environmental Management, 2011. **92**: p. 59-66.
[67] Hwang, C.L., B.A.T. Le, and C.T. Chen, *Effect of rice husk ash on the strength and durability characteristics of concrete*. Construction and Building Materials, 2011. **25**: p. 3768-3772.
[68] Banjare, V., et al., *An Experimental Study on Tensile Strength Behavior of Advance Concrete using Rice Husk Ash and Core Fiber*. International Journal for Innovative Research in Science & Technology, 2017. **4**(2): p. 149-154.
[69] Prasad, D.S. and D.A.R. Krishna, *Production and Mechanical Properties of A356.2 /RHA Composites*. International Journal of Advanced Science and Technology, 2011. **33**: p. 51-58.
[70] Tang, L.V., et al., *Effect of Rice Husk Ash and Fly Ash on the workability of concrete mixture in the High-Rise Construction*. E3S Web of Conferences, 2018. **33**(02029): p. 1-12.
[71] Givi, A.N., et al., *Contribution of Rice Husk Ash to the Properties of Mortar and Concrete: A Review*. Journal of American Science, 2010. **6**(3): p. 155-165.
[72] Oyetola, E.B. and M. Abdullahi, *The Use of Rice Husk Ash in Low - Cost Sandcrete Block Production*. Leonardo Electronic Journal of Practices and Technologies, 2006(8): p. 58-70.
[73] Rashid, M.H., *Strength Behavior of Cement Mortar Assimilating Rice Husk Ash*. Int'l Journal of Advances in Agricultural & Environmental Engg. (IJAAEE) 2016. **3**(2): p. 288-292.
[74] Karim, M.R., et al., *Strength of Mortar and Concrete as Influenced by Rice Husk Ash: A Review*. World Applied Sciences Journal, 2012. **19**(10): p. 1501-1513.
[75] Qamruddin, M. and P.L.G. Kalurkar, *EFFECT OF UNPROCESSED RICE HUSK ASH AS A CEMENTITIOUS MATERIAL IN CONCRETE (A COMPARISON WITH SILICA FUME)*. International Journal of Civil Engineering and Technology (IJCIET), 2013. **4**(2): p. 240-245.
[76] Yu, Q., et al., *The reaction between rice husk ash and Ca(OH)2 solution and the nature of its product*. Cement and Concrete Research, 1999. **29**: p. 37-43.

[77] Sarkar, B. and S. Hazari, *Behavior of Concrete Made with Rice Husk Ash as Mineral additives*. National Level Conference on Engineering Problems and Application of Mathematics, 2016: p. 1-6.

[78] Aslam, M., P. Shafigh, and M.Z. Jumaat, *Oil-palm by-products as Lightweight Aggregate in Concrete Mixture: A Review*. Journal of Cleaner Production, 2016. **126**: p. 56-73.

[79] Fapohunda, et al., *Structure and Properties of Mortar and Concrete with Rice Husk Ash as Partial Replacement of Ordinary Portland cement – A Review*. International Journal of Sustainable Built Environment, 2017.

[80] Krishna, N.K., S. Sandeep, and K.M. Mini, *Study on concrete with partial replacement of cement by rice husk ash*. Materials Science and Engineering 2016. **149**: p. 1-11.

[81] Zhang, M.H. and V.M. Malhotra, *High-Performance Concrete Incorporating Rice Husk Ash as a Supplementary Cementing Material*. ACI Materials Journal, 1996: p. 629-636.

[82] Nehdi, M., J. Duquette, and E. Damatty, *Performance of rice husk ash produced using a new technology as a mineral admixture in concrete*. Cem Concr Res, 2003. **33**(8): p. 1203–1210.

[83] Fapohunda, e.a., *Structure and Properties of Mortar and Concrete with Rice Husk Ash as Partial Replacement of Ordinary Portland cement – A Review* International Journal of Sustainable Built Environment, 2017.

[84] Paramveer, S., S. Tarunbir, and S. Gurpreet, *To Study Strength Characteristics of Concrete with Rice Husk Ash*. Indian Journal of Science and Technology, 2016. **9**(47): p. 1-5.

[85] Ahmed, M., S. Brijbhushan, and P.D. Maneeth, *Strength Characteristics of M25 Grade Concrete by Partially Replacing Cement with Rice Husk Ash and Fine Aggregate with Copper Slag*. IJSRD - International Journal for Scientific Research & Development, 2017. **5**(06): p. 743-746.

[86] Padhi, R.S., et al., *Influence of incorporation of rice husk ash and coarse recycled concrete aggregates on properties of concrete*. Construction and Building Materials, 2018. **173**(2018): p. 289-297.

[87] Sensale, G.R., *Strength development of concrete with rice-husk ash*. Cement & Concrete Composites 2006. **28**: p. 158-160.

[88] Tashima, M.M., et al., *Influence of Rice Husk Ash in Mechanical Characteristics of Concrete*. IV INTERNATIONAL ACI/CANMET CONFERENCE ON QUALITY OF CONCRETE STRUCTURES AND RECENT ADVANCES IN CONCRETE MATERIALS AND TESTING, Advancing Concrete Knowledge: p. 780-790.

[89] Giaccio, G., G.R.D. Sensale, and R. Zerbino, *Failure mechanism of normal and high-strength concrete with rice-husk ash*. Cement & Concrete Composites, 2007. **29**: p. 566-574.

[90] Ikpong, A.A. and D.C. Okpala, *Strength characteristics of medium workability ordinary Portland cement-rice husk ash concrete*. Building and Environment, 1992 **27**(1): p. 105-111.

[91] Siddika, A., M.A.A. Mamun, and M.H. Ali, *Study on concrete with rice husk ash*. nnovative Infrastructure Solutions, 2018: p. 1-9.

[92] Bhushan, E.R., et al., *Partial Replacement of Cement by Rice Husk Ash*. International Research Journal of Engineering and Technology (IRJET), 2017. **04**(10): p. 251-256.
[93] Nirubha, E. and V. Ponmalar, *Effect of Rice Husk Ash in Concrete*. Civil Engineering Systems and Sustainable Innovations: p. 191-194.
[94] Chatveera, B. and P. Lertwattanaruk, *Evaluation f Sulfate Resistance of Cement Mortars Containing Black Rice Husk Ash*. Journal of Environtal Management, 2009. **90**(3): p. 1435-1441.
[95] Chindaprasirt, P. and S. Rukzon, *Strength, Porosity and Corrosion Resistance of Ternary Blend Portland Cement, Rice Husk Ash and Fly Ash Mortar*. Construction and Building Materials, 2008. **22**(8): p. 1601-1606.
[96] Omotosoa, O.E., D.G. Ivey, and R. Mikulab, *Characterization of chromium doped tricalcium silicate using SEM/EDS, XRD and FTIR*. Journal of Hazardous Materials, 1995. **42**(1): p. 87-102.
[97] Sabir, B.B., *High-strength condensed silica fume concrete*. Magazine of Concrete Research, 1995. **47**(172): p. 219-226.
[98] Kulkarni, M., et al., *Effct of rice husk ash on properties of concrete*. Journal of Civil Engineering and Environmental Technology, 2014. **1**(1): p. 26-29.
[99] Singh, J. and H. Singh, *A REVIEW ON UTILIZATION OF RICE HUSK ASH IN CONCRETE*. INTERNATIONAL JOURNAL OF INNOVATIONS IN ENGINEERING RESEARCH AND TECHNOLOGY [IJIERT], 2015. **2**(11): p. 1-8.
[100] Abhijith, C., S, et al., *Partial Replacement of Binder Material With Rice Husk Ash (RHA) In Concrete*. International Journal of Scientific & Engineering Research, 2016. **7**(4): p. 200-204.
[101] Kachwala, A., A. Pamnani, and A. Raval, *Effect of Rice Husk Ash as a Partial Replacement of Ordinary Portland cement in Concrete*. International Research Journal of Engineering and Technology (IRJET), 2015. **2**(5): p. 175-177.
[102] Obilade, I.O., *USE OF RICE HUSK ASH AS PARTIAL REPLACEMENT FOR CEMENT IN CONCRETE*. International Journal of Engineering and Applied Sciences, 2014. **5**(4): p. 11-16.
[103] Neville, A.M., *Properties of Concrete*. Fourteenth Ed. CTP-VVP, Malaysia, 2008.
[104] Akeke, G.A., et al., *STRUCTURAL PROPERTIES OF RICE HUSK ASH CONCRETE*. International Journal of Engineering and Applied Sciences, 2013. **3**(3): p. 57-62.
[105] Anwara, M., T. Miyagawab, and M. Gaweesh, *Using of Rice Husk Ash as a Cement Replacement Material in Concerete*. WasteMaterialsin Construction: p. 671-684.
[106] Zareei, S.A., et al., *Rice husk ash as a partial replacement of cement in high strength concrete containing micro silica: Evaluating durability and mechanical properties*. Case Studies in Construction Materials, 2017.
[107] Ephraim, M.E., G.A. Akeke, and J.O. Ukpata, *Compressive strength of concrete with rice husk ash as partial replacement of ordinary Portland cement*. Scholarly Journal of Engineering Research, 2012. **1**(2): p. 32-36.
[108] Rambabu, P.V., V.C. Varm, and G.V. Ramarao, *Experimental Study on Rice Husk Ash for Optimum Level of Replacement of Cement in Concrete*.

International Journal of Engineering Research & Technology (IJETRT) 2015. **4**(10): p. 354-359.

[109] Bangwar, D.K. and M.A. Keerio, *Improvement of Mechanical Properties of Concrete with Rice Husk Ash*. International Journal of Scientific & Engineering Research, 2017. **8**(3): p. 1254-1260.

[110] Mahmud, H.B., N.A.A. Hamid, and K.Y. Chin, *Production of high strength concrete incorporating an agricultural waste - rice husk ash*. 2nd International Confeence on Chemical, Biological and Environmental Engineering (ICBEE 2010), 2010: p. 106-109.

[111] Kumar, P.R.S., *Experimental study on the properties of concrete made with alternate construction materials*. International Journal of Modern Engineering Research (IJMER), 2012. **2**(5): p. 3006-3012.

[112] Sundararaman, S. and S. Azhagarsamy, *A Study on Performance of Concrete by Partial Replacement of Cement with Rice Husk Ash and Silica Fume*. European Journal of Advances in Engineering and Technology, 2015. **2**(11): p. 69-72.

[113] Naveen, S. Bansal, and Y. Antil, *Effect of Rice Husk on Compressive Strength of Concrete*. International Journal on Emerging Technologies, 2015. **6**(1): p. 144-150.

[114] Van Tuan, N., G. Ye, and K. van Breugel, *Effect of rice husk ash on autogenous shrinkage of ultra high performance concrete*. In Proceedings of International RILEM Conference on Advances in Construction Materials Through Science and Engineering, Hong-Kong. , 2010.

[115] Mosaberpanah, M.A.a.O.E., *Statistical models for mechanical properties of UHPC using response surface methodology*. COMPUTERS AND CONCRETE, 2017. **19**(6): p. 667-675.

[116] Wang, D., et al.,, *A review on ultra high performance concrete: Part II. Hydration, microstructure and properties*. Construction and Building Materials, 2015. **96**: p. 368-377.

[117] Courtial, M., et al.,, *Effect of polycarboxylate and crushed quartz in UHPC: microstructural investigation*. Construction and Building Materials, 2013. **44**: p. 699-705.

[118] van Breugel, K.a.Y.G., *Analyses of hydration processes and microstructural development of UHPC through numerical simulation*. in Proceedings of the International Symposium on Ultra-High Performance Concrete, Kassel, Germany, Sept. 13. 2004.

[119] Van Breugel, K.a.N.V.T., *Ultra high performance concrete made with rice husk ash for reduced autogenous shrinkage*. in Proceedings of the 4th International FIB Congress, Mumbai, India Authors version. 2014. Universities Press, 10-14 February 2014.

[120] ößler, C., D.-D. Bui and H.-M. Ludwig, *Rice husk ash as both pozzolanic admixture and internal curing agent in ultra-high performance concrete*. Cement and Concrete Composites, 2014. **53**: p. 270-278.

[121] V. Nguyen, *Rice husk ash as a mineral admixture for ultra high performance concrete*. 2011.

[122] Mukarram, et. al., (2022), “Cellulose nanocrystals from office paper waste for green concrete: Process optimization modeling, characterization, and mechanical testing”, *Arabian Journal for Science and Engineering*, Vol. 1, No. 1, pp. 1-17. DOI: https://doi.org/10.1007/s13369-022-06609-8

[123] Aziz, et. al., (2023), “Destructive, Nondestructive and Thermal Testing of Biochar-Mortar composite”, *Biomass Conversion and Biorefinery*, pp. 1-14. DOI: https://doi.org/10.1007/s13399-023-03838-1