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Strength of Mortar and Concrete as Influenced by Rice Husk Ash: A Review

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Abstract: Due to the pozzolanic reactivity, rice husk ash (RHA) is used as supplementary cementing material in mortar and concrete and has demonstrated significant influence in improving the mechanical and durability properties of mortar and concrete. It has economical and technical advantages to use in concrete. In this paper, a critical review on the influences of RHA on the strength of mortar and concrete are mainly presented. In addition, properties and pozzolanic activity of RHA, advantages and disadvantages of supplementary use of RHA in mortar/concrete are mentioned here. Based on the available documented literature, it can be concluded that RHA could be used as supplementary cementing material up to a certain level of replacement (about 20-30% of binder) without sacrificing strength of concrete. Proper consumption of these RHA contributes in solving environmental pollution and production of cost-effective concrete; it can also play a vital role for the production of sustainable concrete.

Key words: Rice husk ash · Mortar · Concrete · Pozzolanic activity · Compressive strength · Tensile strength

INTRODUCTION

The use of industrial and biogenic wastes in concrete as supplementary cementing materials is the present vital issue to obtain a sustainable environmental solution, save energy and natural resources. Some of the commonly used supplementary pozzolanic and cementing materials are rice husk ash (RHA), silica fume, ground granulated blast furnace slag, fly ash and ash from timber etc. These wastes can be found as natural materials, by-products or industrial wastes; these materials are also obtained with requiring low cost, energy and time. Unfortunately, having technical benefits, most of those wastes are dumped into environment without any commercial return. In consequence, environmental pollutions are increased day by day. However, RHA, an available waste material in the developing countries, is a by-product material obtained from the combustion of rice husk. It consists of non-crystalline silicon dioxide (SiO_2) with high specific surface area and high pozzolanic reactivity. Thus, due to growing environmental concern and the need to conserve energy and resources, utilization of industrial and biogenic wastes as supplementary cementing materials has become an integral part of concrete construction. During recent decades, many researches have been conducted for using the (i) different types of agro-waste ashes such as rice husk ash [1-6], bagasse ash [7], palm oil fuel ash [8-11] (ii) the industrial by products ground granulated blast furnace slag and fly ashes as cement replacement materials [12-20]. Their utilization not only improves properties and durability of concrete, but also makes it cost effective and environment-friendly [3-6; 21-28]. Nowadays, rice husk is generated from rice processing industries as a major agricultural by-product in many parts of the world, especially in developing countries. About 500 million tons of paddy is produced in the world annually. Rice husk is the outer covering of this paddy [29]. The ash obtained by burning this rice husk is known as RHA. As a waste material, rice husk is produced in agricultural and industrial processes. After incineration, only about 20% weight of rice husk are transformed to RHA [30]. Still now, there is no effective/useful application of RHA and is usually dumped into water

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streams or as landfills causing environmental pollution of air, water and soils. The use of this by-product is an environmental friendly method of disposal of large quantities of material.

It is well known that concrete has gained popularity in the construction industry due to its satisfactory performance in strength requirements, its easiness in construction and better durability in normal environment. However, ordinary Portland cement (OPC) is a most important ingredient for concrete construction of any type of structures. Nowadays, 5 billion tons of concrete is produced annually and cement production is expected to rise to nearly 2 billion tons by year 2010. The production of 1 ton of cement contributes to about 1 ton of CO_2 into the atmosphere [31]; approximately 7% world's carbon dioxide (CO_2) emission is accountable for production of OPC [32]. The present crucial issue - the global warming - is caused for the production of greenhouse gases (CO_2). During the cement production, in addition to CO_2 emissions, excess fuel is required for the burning of OPC clinker at temperatures around 1400°C [33]. This CO_2 emission can be reduced by improving the manufacturing/production process of OPC. The utilization of supplementary cementing materials - natural pozzolans, slag, fly ash, silica fume, metakaolin etc. - in concrete production is one of the solutions to reduce the cement content as well as CO_2 [9].

Recently, the interest for utilization of waste materials in cement or concrete has been increased significantly. Besides, during the 20th century, the development and use of blended cements increased rapidly in the concrete construction. A rising trend towards the use of waste material - RHA, Fly ash, silica fume, slag, palm oil fuel ash - in concrete as supplementary cementitious materials have been observed in the construction industry. The agricultural by-product (waste), RHA, has already been proved as pozzolanic material [6, 34-35]; more attention is now given to use this pozzolans in cement or concrete, since its contribution generally improves the properties of the blended cement and concrete [36]. Thus, in recent decades, RHA has been used as OPC replacement material in concrete industries [37-40]. The utilization of RHA in ternary blend (OPC, RHA and fly ash) produces better mortar strengths at the low replacement level of RHA. With the low replacement of up to 20% of pozzolan, the mortar containing these pozzolans reduces porosity [36]. Solution of disposal problem of these wastes and production of economic concrete could be assured by their proper consumption. Hence, utilization of RHA in concrete is not only a cement saving step but also has technical/engineering benefits. Substantial energy and cost saving can be made by using this waste material as partial replacement for the energy-intensive OPC. Therefore, based on the published literatures this paper summaries - different properties of RHA and its effects on mortar and concrete; strengths development of mortar and concrete containing RHA; pozzolanic activity of RHA; benefits of supplementary use of RHA in cement and concrete - to encourage researchers, construction companies as well as owner for the consumption of RHA as a supplement of cement and ingredient of concrete to achieve the goal of sustainable concrete.

Rice Husk Ash and its Properties: Rice husk, basically an agricultural residue, is obtained from rice processing mills of the developing countries. Only a small amount of produced husk is used as fuel in rice mill and electricity generating power plant. After burning rice husk, the RHA is produced as a by-product, about 20% of its original weight [21]. The unburnt rice husk contains about 50% cellulose, 25-30% of lignin and 15-20% of silica; burning the former two components leaves behind silica ash [41]. When rice husk is burnt at temperatures lower than 700°C, it shows a cellular microstructure which is highly reactive [36, 42]. RHA is a highly pozzolanic material; it contains non-crystalline silica and high specific surface area that are accountable for its high pozzolanic reactivity. The high silica content in the form of non-crystalline or amorphous silica of RHA is dependent on the burning temperatures; 95% silica could be produced after heating at 700°C for 6 hours [23]. During the growth of rice, it sucks up silica from the soil and incorporates it into its structure [43]. A high concentration of silica, generally more than 80-85%, is contained in rice husk - the outer covering of the grain of rice plant [44]. As shown in Table 1, the particle size of RHA ranges from 5 to 10 µm; the specific gravity ranges from 2.0 to 2.4; and the specific surface area varied from 20 to 50m^2/kg. When rice husk is burnt into ash it fulfills the physical characteristics and chemical composition of mineral admixtures. However, pozzolanic activity of RHA is influenced by: (i) silica content, (ii) silica crystallization phase and (iii) size and surface area of ash particles, in addition, ash must contain only a small amount of carbon [45]. Even for higher burning temperature with some crystalline silica, reactive RHA could be obtained by fine grinding [46-47]. In order to ensure the quality of ash, a suitable incinerator/furnace as well as grinding method is required for burning and grinding rice husk. The presence of

Table 1: Chemical and physical properties of RHA (Wt. %)

Chemical properties of RHA									
SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O_3	K_2O	LOI	Reference
92.5a	1.2	2.1	0.9	0.4	0.1	2.0	0.0	0.9	
88.5b	1.1	2.0	0.9	0.4	0.1	2.6	0.0	0.9	[2]
87.32	0.22	0.28	0.48	0.28	-	1.02	3.14	2.10	[34]
87.6	0.68	0.93	1.30	0.35	-	0.12	2.37	-	[35]
93.2	0.4	0.1	1.1	0.1	0.9	0.1	1.3	3.7	[36]
80.00	3.93	0.41	3.82	0.25	0.78	0.67	1.45	8.65	[41]
87.2	0.15	0.16	0.55	0.35	0.32	1.12	3.6	6.55	[42]
Chemical properties of OPC									
20.25	5.04	3.16	63.61	4.56	-	0.08	0.51	3.12	[34]
21.89	5.3	3.34	53.27	6.45	3.67	0.18	0.98	3.21	[35]
20.9	4.8	3.4	65.4	1.3	2.7	0.2	0.4	0.90	[36]

Physical properties of RHA			
Material specific gravity(gm/cm^3)	Mean particle size (μm)	Blaine Fineness	Reference
2.30^a; 2.27^b	-	4750(cm^2/gm); 5750(cm^2/gm)	[2]
2.06	2.50	36.47 (m^2/kg)	[34]
2.23	10.00	11200 (cm^2/gm)	[36]
2.11	-	-	[41]
2.06	8.0	28800(m^2/kg) nitrogen absorption	[42]
Physical properties of OPC			
3.11	-	3250 (cm^2/gm)	[2]
3.14	14.6	--	[10]
3.14	15.0	3600 (cm^2/gm)	[27]
3.10	22.5	326 (m^2/kg)	[34]

a, b - RHA obtained from electric power station and rice mill respectively

unburnt carbon can adversely affect the reactivity. Besides, duration and type of incineration are the important parameter influencing the reactivity of RHA as pozzolans [48].

Meanwhile, a typical chemical composition and physical properties of RHA are given in Table 1. It is observed from this table that RHA contains large amount of silica, more than 80%, which is an effective constituent for pozzolanic activity. Most of the ashes show a lower loss of ignition property. Specific gravity is also lower than OPC; fineness of RHA is much greater than that of OPC which is important for production of denser and durable concrete. The RHA with lower value of loss of ignition and higher value of surface area can result the production of relatively higher strength pozzolans [48].

Fineness Effect of RHA on the Concrete Strength: Similar to other hydraulic cement, the reactivity of rice husk ash cement extremely depends upon the specific surface area and or particle size. The hydration starts at the surface of cement particle; the rate of hydration depends on the fineness of cement and for rapid strength development, fineness is important factor [49]; similarly fineness of RHA is a valuable property for strength of blended concrete. The ultra fine RHA mixed concrete produces greater strength than that of control concrete as well as RHA (with average particle size of 95 μm) blended concrete at a level of 10% replacement of RHA [35].

The highest improvement in compressive strength for the ultra fine RHA mixed concrete was obtained similar to RHA (average particle size of 95 μm) -blended concrete for RHA content of 10% at 90 days. The compressive strength at replacement of 20% RHA at 90 days becomes approximately equivalent with control concrete at the same age. These positive results of ultra fine RHA-blended concrete obtained due to the rapid consumption of $Ca(OH)_2$ produced during hydration of Portland cement at early ages are associated to the high pozzolanic reactivity of ultra fine RHA. As a result, the hydration of cement is accelerated and larger volumes of reaction products are produced. Besides, the particle packing density of the blended cement is improved by fine RHA particles, directing to a reduced volume of larger pores in the cement paste [1]. At higher ages (90 days), the RHA concrete had higher compressive strength in comparison with that of concrete without RHA and the highest values of compressive strengths were achieved in concretes with 20% RHA. The long term compressive strength of the concretes with RHA is higher due to the filler effect of the smaller particles in the mixture [42].

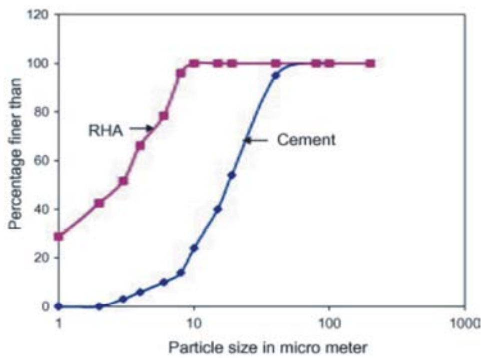

Fig. 1: Particle size distribution curves of OPC and RHA [34].

Nonetheless, properties of light weight aggregate produced from RHA are enhanced with increasing fineness of RHA [21]. A particle size distribution is shown in Figure 1; smaller particle size is observed in RHA than that of OPC that is important for strength achievement.

Supplementary Use of RHA in Concrete: The use of RHA in cement or concrete as a supplementary cementing material has been increased recently. Supplementary use of RHA in cement or concrete is not a new technique but it was started since early 1970 [50]. RHA has been used in concrete as high as 30% by weight of OPC without any adverse effect on compressive strength and permeability properties [34]. It was used by 10-20% replacement of OPC to produce high strength concrete as much as high strength of 70 MPa [41]. Besides, the properly burnt and ground rice husk can be used as a pozzolan in cement production [34, 36]. The incorporation of pozzolans such as RHA, palm oil fuel ash and fly ash are very beneficial to the performance of mortar in terms of chloride resistance. In addition, porosity and chloride induced corrosion resistance of mortar are significantly improved with the use of RHA [36]. Black RHA was used to investigate the sulfate resistance of concrete as a Portland cement Type 1 replacement at the levels of 0%, 10%, 30% and 50% by weight of binder. The study confirms that ground black RHA can be applied as a pozzolanic material to concrete and also improves resistance to sodium sulfate attack [2]. However, Basha *et al*. [51] was used RHA to investigate the stabilization property of soil and they found that RHA reduces the plasticity, decreases maximum dry density and increases optimum moisture content of soil; properties of soil improves at 15-20% replacement of RHA. The use of RHA in the ternary blend with OPC and fly ash performs a significant improvement of strength at low replacement level at the later age [36].

On the other hand, before burning, a chemical treatment of rice husk was performed by Salas *et al.* [52] to improve the effectiveness of RHA. They concluded that pretreated ash shows better mechanical and durable properties of concrete than that of ordinary RHA (produced by conventional incineration) mixed concrete as well as OPC concrete. These beneficial results are obtained due to high content of amorphous silica in the chemically treated RHA. They also suggested that this pretreated RHA could be used as supplement of OPC for the production of high performance concrete. Besides, Dakroury and Gasser [5] used RHA to the OPC in the production of high strength, low permeability concrete; for use in bridges, marine environments and nuclear power station. RHA has been used by Sakr [39] as partial replacement (5, 10 and 15%) of cement to produce heavy weight concrete. He investigated different mechanical properties - compressive, tensile, flexural and bond strengths; and modulus of elasticity- physical, shielding and durable properties of heavy weight concrete made with RHA and found good results than that of OPC concrete. RHA was produced by new technique (Torbed reactor) with control combustion of Egyptian rice husk in a research by Nehdi *et al*. [53]. They investigated the physical, mechanical and durability properties (resistance to surface scaling, chloride penetrability) of concrete made with this ash and found better result than that of reference concrete as well as concrete from silica fume. They also compared their result with other study (in which RHA produced by Fluidized bed technology in United State) and found significantly greater performance of concrete properties. Chindaprasirt *et al*. [21] used RHA to produce light weight aggregate and obtained better results in terms of expansion and solubility and disintegration. Besides ordinary concrete, RHA was included in self-consolidating high performance concrete; test results show that compressive strength, ultrasonic pulse velocity and electrical resistivity increased whereas the water absorption and total porosity decreased with lower w/b ratio and higher RHA content [6].

In contrast, RHA based sand-cement block was prepared in a research by Lertsatitthanakorn *et al*. [25] to investigate the heat gaining property of building; test results show that it performed better than that of ordinary clay brick. Based on the literature, RHA has been used in concrete as supplement of cement for about 40 years. All of these researchers found better performance of concrete in terms of strength, chemical and durability properties. Therefore, supplementary use of this waste

Table 2: Compressive strength of RHA mixed cement mortar

RHA:OPC	W/B ratio	Compressive strength (MPa) at days: 1	3	7	28	90	Reference
00:100	0.53	11.6	20.9	27.2	37.0		[34]
05:95		12.0	22.1	27.4	38.9	-	
10:90		12.8	24.4	27.8	42.8	-	
15:85		13.8	28.9	29.3	46.7	-	
20:80		12.2	24.8	28.3	39.8	-	
25:75		11.7	23.6	27.6	38.3	-	
30:70		11.1	20.7	27.4	37.0	-	
35:65		10.4	18.4	26.4	36.0	-	
0:100	0.40	-	-	27.3	36.8	42.3	[35]
05:95		-	-	25.7 [a];27.4 [b]	38.7 [a]; 39.9	43.5 [a]; 45.8 [b]	
10:90		-	-	25.1 [a]; 28.3 [b]	40.6 [a]; 43.8	46.1 [a]; 51.2 [b]	
15:85		-	-	23.7 [a]; 25.9 [b]	37.9 [a]; 39.1	42.7a; 44.4 [b]	
20:80		-	-	21.5 [a]; 24.4 [b]	36.7 [a]; 38.3	41.3 [a]; 42.8 [b]	

[a] RHA passing #200 sieve; [b] RHA passing #325 sieve

material up to a certain limit is now one of the solutions for fulfilling the present demand of cement, production of economic concrete and disposal of rice husk. It could be noted that most of the research performed based on the singular replacement of OPC by RHA. Thus, ternary blend of RHA with slag, fly ash, palm oil fuel ash or the natural pozzolans can be further studied. Besides, during the cement manufacturing process, the incorporation of RHA in cement can be investigated.

Compressive Strength of RHA Blended Mortar and Concrete: Compressive strength is the most valuable property of concrete, although in many practical cases other characteristics, such as durability, impermeability and volume stability, may in fact be more important [49]. It is well known that the calcium silicate hydrate (C-S-H) gel is the main source of strength of cement. After addition of RHA to the fresh cement, it chemically reacts to the CH to produce additional C-S-H gel which contributes to improve microscopic property of cement [5]. The production of more C-S-H gel in concrete with RHA may improve the concrete properties due to the reaction among RHA and calcium hydroxide in hydrating cement [54]. However, incorporation of RHA as partial replacement of cement improves the compressive strength of concrete for the optimum replacement level (10% to 30%) of OPC by RHA. In all of those researches, the replacement levels of RHA are considered as percentage by weight of the total binder material. The mortar strength as influenced by the RHA replacement for cement is shown in Table 2. Ganesan *et al*. [34] found that mortar containing 20% of RHA showed a greater compressive strength than that of OPC cement mortar as mentioned in this Table. For all content of W/C ratios, a high value of compressive strength of mortars was investigated by Dakroury and Gasser [5] by using 30% RHA as a replacement of part of cement; this percent could be considered optimum. Besides, maximum mortar strength was obtained by 10 percent RHA replacement by Givi *et al*. [35]. Saraswathy and Song [55] also concluded that at 25% optimum RHA replacement level better performance of concrete properties could be observed. In addition, Safiuddin *et al*. [6] suggested that 15% replacement could be the optimum limit. Mahmud *et al*. [56] also reported that 15% cement replacement by RHA is an optimal level for achieving maximum strength.

The compressive strengths of RHA blended concrete specimens, as obtained from different literatures, are presented in Table 3. It can be seen from the Table 3 that the compressive strength increases with RHA up to 20% and then at 30% RHA, the compressive strength of blended concrete attains equivalent strength to that of OPC concrete specimens. The value of compressive strength decreases than that of OPC concrete beyond 35% RHA mixture [34] Similar results - the compressive strength of concrete containing up to 30% RHA was higher than that of control concrete at 7, 14, 28 and 90 days - were observed by Zhang and Malhotra [47]. Therefore, 30% replacement of RHA appears to be the optimal limit for RHA blended concrete. On the other hand, the 90 days compressive strength of concrete made with RHA up to 40% was higher than the corresponding concrete mixtures without RHA [29]. The excellent pozzolanic activity and greater compressive strength of RHA blended concrete are due to the amorphous silica and the fine particle size of RHA [34].

Table 3: Compressive strength of RHA mixed concrete

RHA:OPC	W/B ratio	Compressive Strength (MPa) at days 7	14	28	90	References
0:100	0.53	27.2	32.3	37.1	38.3	[34]
05:95		27.6	34.2	40.0	43.3	
10:90		28.0	35.3	41.3	44.8	
15:85		29.3	36.0	41.8	45.7	
20:80		29.7	39.3	42.5	46.0	
25:75		28.7	36.1	38.8	43.0	
30:70		27.4	33.5	37.6	37.8	
35:65		25.7	31.1	35.1	37.2	
05:95	0.40	27.4	-	39.9	4.80	[35]
10:90		28.3	-	43.8	51.2	
15:85		25.9	-	39.1	44.4	
20:80		24.6	-	38.3	42.8	
00:100	0.50	43.5	-	57.0	60.0	[36]
20:80		44.2	-	58.2	62.0	
(10FA: 10RHA): 80		42.0	-	58.0	64.0	
40:60		33.5	-	55.0	62.0	
00:100	0.40	30.0	-	44.5	55.5	[39]
05:95		31.5	-	45.5	56.5	
10:90		32.5	-	49.5	63.0	
15:85		35.5	-	50.0	64.0	
20:80		31.0	-	43.0	61.0	
0:100	0.24	36.6	-	46.3	-	[41]
10:90	0.31	32.9[a]		43.3[a]		
	030	35.7[b]	-	45.7[b]	-	
20:80	0.33	26.3[a]		36.7[a]		
	0.32	33.8[b]	-	45.0[b]	-	
30:70	0.36	24.2[a]		31.0[a]		
	0.34	32.5[b]	-	39.7[b]	-	
00:100	0.32	48.4		55.5	60.6	
	0.40	35.8		42.3	45.6	
	0.50	24.6	-	32.9	35.9	[42]
10:90	0.32	51.1		60.4	64.3	
	0.40	41.1		50.4	54.9	
	0.50	24.1	-	31.5	35.5	
20:80	0.32	44.3		54.8	62.7	
	0.40	27.9		40.7	51.4	
	0.50	20.8	-	34.9	37.9	
00:100	0.35	58.3		62.2	76.1	
	0.50	36.4		47.7	53.5	
	0.65	24.6	-	28.0	31.9	[57]
20:80	0.35	54.2		69.7	83.4	
	0.50	36.4		48.1	53.9	
	0.65	17.7	-	27.0	33.6	
20:80[1]	0.35	59.2		73.3	82.8	
	0.50	39.5		50.7	56.5	
	0.65	25.3	-	36.8	42.5	
20:80[2]	0.35	65.9		77.4	91.0	
	0.50	47.2		54.3	71.8	
	0.65	28.9	-	38.9	48.3	
20:80[3]	0.35	54.2		74.4	77.5	
	0.50	37.4		48.7	53.8	
	0.65	29.1	-	40.3	45.1	
00:100	0.35		-	64.0	68.8	[58]
12.5:87.5		-	-	68.4	73.2	
25:75		-	-	75.6	79.4	
50:50		-	-	44.3	69.5	

Table 4: Split tensile strength (MPa) at 28 days

	Tensile Strengths (MPa) at 28 days as obtained from references:									
	[39]		[41]		[42]		[55]		[60]	
RHA:OPC	Strength	W/B ratio	Strength	W/B ratio	Strength	W/B ratio	Strength	W/B ratio	Strength	W/B ratio
00:100	2.7	0.4	4.17	0.24	3.63	0.32	4.49		2.6	0.53
10: 90	3.2	0.4	3.45a	0.31						
			3.80b	0.30	3.57	0.40	4.65		-	-
20:80	3.5	0.4	3.17a	0.33						
			3.72b	0.32	3.34	0.50	4.60	0.53	2.9[c]; 3.2[d,e]	0.53
30:70	-	-	2.97a	0.36						
			3.44b	0.34	-	-	3.67		-	-

[a] RHA passing #200 sieve; [b] RHA passing #325 sieve; c, d, e- Average particle size of RHA is 31.3, 18.3 and 11.5 μm respectively

For the 10% RHA replacement, Zhang *et al*. [40] obtained greater strength than control OPC at all ages. They observed a higher compressive strength and reduced permeability in RHA blended concrete; this could be occurred, perhaps, due to the reduced porosity, reduced calcium hydroxide content and reduced width of the interfacial zone between the paste and the aggregate. The RHA concrete achieved higher compressive strength at 91 days in comparison to that of the concrete without RHA as investigated by Rodriguez *et al*. [46]. Isaia *et al*. [58] investigated that compressive strength of concrete with RHA increases due to better pozzolanic and filler (physical) effect. This conclusion was also agreed by De Sensale [42] from his study.

At 10% replacement of RHA with fine and ultra fine particle, the greater compressive strength were found from a investigation of Givi *et al*. [35] that has been shown in Figure 2. They concluded - the rapid consuming of $Ca(OH)_2$ which is formed during hydration of Portland cement at early ages - is the reason for these favorable results of ultra fine RHA-blended concrete. As a consequence, the hydration of cement is accelerated and larger volumes of reaction products are formed, they also mentioned. In fact, based on the literature, generally RHA blended cement exhibits similar or higher compressive strength as compared to OPC for a particular level of RHA replacement (about 20-30%). It is concluded that RHA can afford a positive effect for early compressive strength achievement of concrete. On the other hand, the compressive strength of RHA (produced with controlled incineration) blended concrete shows better performance at the longer age.

Tensile Strength of RHA Concrete: Tensile strength of concrete is essential to evaluate the load at which the concrete structure may crack; its knowledge is useful in the design of pavement slabs and airfield runway [59].

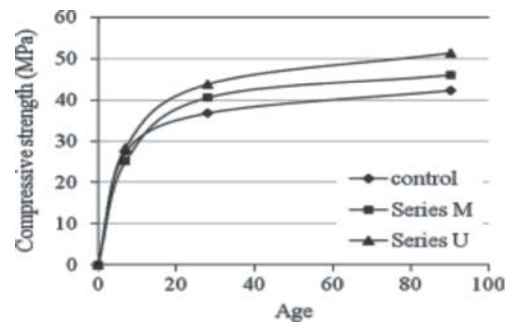

Fig. 2: Compressive strength development for M[a] and U[b] series at 10% level of cement replacement by RHA in comparison to control sample at the first 90 days. M series: RHA-blended concrete with average particle size of 95 μm. U series: ultra fine RHA-blended concrete [35].

A research work was performed by Habeeb and Fayyadh [60] to investigate the effects of concrete incorporating 20% RHA as partial replacement of cement at three different particle sizes. They found that the tensile strength of concrete increases systematically with increasing RHA replacement. The results of tensile and flexural strength are shown in Table 4. The utilization of RHA also shows significant improvement in flexural strength [42] and split tensile strength [39]. The results of splitting tensile strength and less air permeability are observed by De Sensale [42], which can be caused for residual RHA and the filler effect of the smaller particles in the mixture. However, the coarser RHA particle mixture shows smaller increment in tensile and flexural strength as reported by Habeeb and Fayyadh [60]. The greater flexural strength and the higher compressive strength was observed by Zhang *et al*. [40] in the RHA blended concrete for the finer RHA mixture due to the increased pozzolanic reaction and the packing ability of the RHA fine particles. Splitting tensile strength of RHA blended

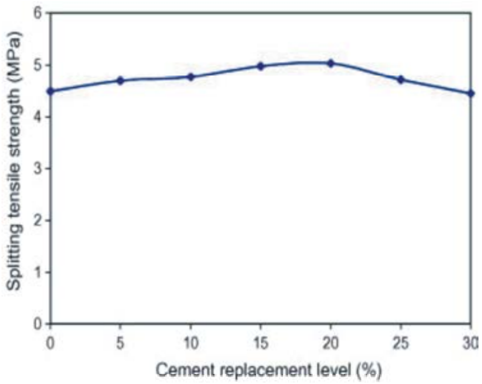

Fig. 3: Splitting tensile strength of RHA blended concretes [34]

concretes was investigated by Ganesan *et al*. [34]; these test results are presented in Figure 3. It is seen from this Figure that tensile strength of RHA blended concrete gradually increases up to 20% replacement of RHA.

Pozzolanic Activity of RHA: According to the definition of The American Society of Testing and Materials (ASTM), pozzolan is a siliceous or alumino-siliceous material that itself has little or no cementitious property but in finely divided form and in the presence of moisture it will chemically react with alkali and alkaline earth hydroxides at ordinary temperatures to form compounds that possess cementitious properties [61]. The improvement of rate of pozzolanic reaction and hardening of pozzolan-lime mortars can be done by restoring to different means: grinding firing pozzolans, compacting mixes and adding some chemicals [62]. The most important contribution of RHA is the pozzolanic activity that can be formed due to amorphous phase substance. Calcium hydroxide $Ca(OH)_2$ and calcium silicate hydrates C-S-H are the major hydration and reaction products for RHA paste. The incorporation of RHA in concrete reduces its porosity and the amount of $Ca(OH)_2$ in the interfacial zone; the width of interfacial zone between aggregate and the cement paste is also reduced as compared to OPC paste [40]. Approximately 85% to 95% by weight of amorphous silica can be originated by the production of rice husk ash [23]. Yu *et al*. [54] studied the reaction between RHA and $Ca(OH)_2$ solution and they suggested that in the presence of water, a kind of fine C-S-H gel is formed after their reaction. This result is in agreement with the findings of Feng *et al*. [63]. However, Lin *et al*. [64] reported that amorphous silica found in some pozzolanic materials reacts with lime more eagerly than those of crystalline form. As a result of this characteristic, RHA is an extremely reactive pozzolanic material and it is suitable to use in lime-pozzolan mixes and Portland cement as a supplement. According to Dakroury *et al*. [5], the reactivity of RHA associated to lime depends on the following two factors: (i) the non-crystalline silica content and (ii) its specific surface. RHA with fine particle when used as cement replacement material can accelerate the early hydration of tricalcium silicate (C_3S). The high specific surface area of the RHA is the main cause to produce this phenomenon [63]. They also stated that pozzolanic activity of RHA - produced by hydrochloric acid pretreatment of rice husk - is enhanced as compare to that of RHA without treatment (ordinary RHA). While the small particles of pozzolans are less reactive than Portland cements [65], they generate a large number of nucleation cites for the precipitation of the hydration products by dispersing in cement pastes.

Accordingly, more homogenous and denser paste is produced by this mechanism for the distribution of the finer pores as well as due to the pozzolanic reactions among the amorphous silica of the mineral addition and the CH [58]. There is no pozzolans (among slag, silica fume, fly ash) except RHA, that has the ability to contribute strength of OPC concrete at the early age. Malhotra [66] concluded that the strength development of RHA concrete is similar to fly ash/slag concrete but with a higher pozzolanic activity it helps the pozzolanic reactions occur at early ages rather than later as is the case with other replacement cementing materials. From a research work, Mehta [67] reported that the finer particles of RHA speed up the reactions and form smaller CH crystals. Berry *et al*. [68] revealed that high volume of RHA not completely reacted fill up the voids and enhance density of the paste. The pozzolanic reaction can be satisfactorily described by the Jander diffusion equation that is based on Fick's parabolic law of diffusion [69]. The Jander equation for three- dimensional diffusion in a sphere can be stated as: $F(G) = [1-(1-G)^{1/3}]^2 = (2kt/r^2) = Kt$. Where F (G) represents the equation $[1-(1-G)^{1/3}]^2$; G = fraction of the sphere that has reacted; r = initial radius of the starting sphere; k = parabolic rate constant and K= constant proportional to k, which indicates the reaction.

Advantages of Supplementary Use of RHA: RHA has been used as a good pozzolanic and supplementary material in concrete as investigated in different literatures. Besides that, it participates to produce denser and durable concrete with a particular level (about 20-30%) of replacement. Based on the discussions presented in this paper, various advantages of RHA - improved strength, reduced material costs due to cement saving, durability properties, environmental benefits to the disposal of RHA waste - have been observed to use in cement or concrete. The incorporation of RHA in concrete has the following essential benefits:

- Improves compressive strength [6, 35, 55], flexural strengths [22, 40, 41] and split tensile strength [39, 42, 60].
- RHA mixed concrete shows better bond strength as compared to OPC concrete [39, 55].
- Permeability of concrete decreases [55, 40, 46], chloride diffusion and chloride permeation reduces [34, 53].
- RHA makes a role to increased resistance to chemical attack [3].
- Shows better durability of concrete [22].
- Improves resistance to sulfate attack [2, 3, 39].
- Reduces the amount of cement for making concrete up to 20% by weight [35].
- Improves the corrosion resistance and strength of concrete as compared to that of OPC concrete [36, 55].
- Reduces effects of alkali-silica reactivity [37].
- Reduces shrinkage due to particle packing, making concrete denser [60].
- Enhances workability of concrete [22, 60].
- Reduces heat grow through the walls of buildings [25].
- Reduces amount of super plasticizer [38].
- Decreases air permeability due to the filler and pozzolanic effect [42].
- Binary mixture of RHA shows better performances than fly ash [58].
- Electrical resistivity [70] and ultrasonic pulse velocity of concrete increase [6].
- Reduces the plasticity of soil [51].
- Compressive strength is directly related to the concrete porosity [49], RHA reduces porosity of concrete [36, 40, 71].
- Increases compressive strength and decreases leachability [5].
- Reduces material cost and emission of CO_2 due to less cement utilization [55].
- Improves consistency of OPC- RHA blended paste with increasing RHA percent [72].
- RHA could be used as an alternative source for high surface area silica [23].
- Among the pozzolans (slag, silica fume, fly ash) RHA has the ability to contribute to gain early strength [73].

Disadvantages of Using RHA: Effective consumption of RHA in cement or concrete has a great importance regarding strength, durability and cost effectiveness of concrete up to a certain replacement percent. Having the more benefits using RHA in cement or concrete, it shows a few disadvantages that are mentioned below:

- Suitable incinerator/furnace as well as grinding method is required for burning and grinding rice husk in order to obtain good quality ash.
- Strength of concrete is reduced for larger (beyond 30%) replacement [34, 36].
- There is a little transportation problem.
- Unburnt RHA is not suitable for concrete production.

Concluding Remarks: There are huge amounts of RHA produced as by-product from the rice processing mills, mainly in developing countries, which are disposed to environment without any return price. Thereafter, disposal cost is increased in order to transport this ash; also a large land area becomes useless and the fertility of land is reduced. So the problem can be solved or minimized by properly utilizing the RHA through the production of cement or concrete as well as production of silica. Because, RHA contains a large amount of silica and also exhibits excellent pozzolanic property. In fact, incorporation of RHA either in cement or in concrete not only fulfills the demand of cement but also makes a role in production of durable concrete. The strength development of concrete produced with a particular level of RHA replacement is the same or higher as compared to OPC concrete. For about 20-30% replacement of RHA, no significant reduction in strength of concrete is observed. Furthermore, a valuable cement and energy saving consideration could be performed by proper utilization of RHA in the production of cement or concrete that can be beneficial for the present demand of concrete industry.

RHA based sand-cement block can significantly reduce room temperature; hence air conditioner operation time is reduced, resulting electrical energy savings [25]. The present essential issues - disposal solution, environmental management as well as sustainable concrete production - could be attained by effective consumption of RHA in cement or concrete. The addition of RHA to the cement or concrete is ecological, economic and energy saving step for building a clean and safe globe for the future generation. Furthermore, most of the cited research article are reported based on the study of binary blend (RHA and OPC) as a supplement (maximum 40%) of OPC; thus, a ternary blend of RHA with slag, fly ash, palm oil fuel ash or any other natural pozzolans can further be investigated; besides, more than 50% and even 100% replacement of these waste materials by OPC along with mechanical or chemical activation process can also be studied.

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