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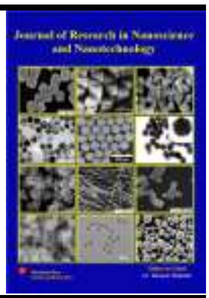

The Optimum Percentage of Rice Husk Ash (RHA) as Partial Cement Replacement in Engineered Cementitious Composite (ECC)

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ABSTRACT

Rice Husk Ash (RHA) is a potential supplementary cementitious material (SCM) in concrete production due to their capability of pozzolanic reaction. This research study on the fineness, workability and compressive strength of the RHA incorporated into Engineered Cementitious Composites (ECC) as a cement replacement alternative hence to determine the optimum percentage of RHA to be use in the ECC mix. The mix proportional of RHA-ECC was designed with RHA as the substitution of Portland cement at various percentages by volume, including 5%, 10%, 15% and 20% respectively. Physical characterization of RHA was determined by particle size distribution test. The workability of hand mixed mortar was determined by the flow table test. A total of 45 cubes of 50×50×50 mm was prepared and cured for 7, 14 and 28 days. These hardened mortars were test with the compressive strength test to study its mechanical property. Findings showed that the workability of RHA-ECC was decreased with increasing of the amount of RHA added. The compressive strength of RHA-ECC was best at 28 days with the 10% of replacement level compared to others. This study will provide both direction and knowledge on the application of RHA as a greener and sustainable cement replacement.

Keywords:
Compressive Strength Test; Engineered Cementitious Composite (ECC); Flow Table Test; Particle Size Distribution; Rice Hush Ash (RHA)

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1. Introduction

Rice milling produces husk as a byproduct. This encircles the paddy grain. Approximately 78% of the weight of paddy milled is as rice, broken rice and bran. The remaining 22 % of the paddy weight is received as husk [1]. According to Table 1, Malaysia produces 2.4-2.7 million tonnes of paddy per year. Excess RHA production poses a significant environmental risk, causing damage to land and surrounding area where it is dumped. As a result, the commercial use of rice husk and ash is the alternative solution to disposal problem [2]. On the other hand, environmentalist are concerned about agricultural waste, particularly RHA, because the ash could cause health problems for the people living nearby [3].

Table 1
Generation of paddy and RHA in Malaysia (Malaysia Department of Agriculture [25])

	Amount generated per year (million tonnes)				
	2016	2017	2018	2019	2020
Paddy	2.7	2.6	2.6	2.4	2.3
RHA	0.60	0.57	0.57	0.53	0.51

RHA is used in a variety of industrial applications, including refractory industry processing, ceramic, cement, fillers of rubber and plastic composites, cement, adsorbent, and heterogeneous catalyst support [4]. RHA is used in the construction industry as pozzolan, as a filler, additive, abrasive agent, oil adsorbent, sweeping component, and as a suspension agent for porcelain enamels. RHA can be used as a partial replacement for cement in the construction industry [5].

RHA contains a high percentage of silica (SiO2) which determines its reactive pozzolanic property [6]. The majority of the husk is used as a highly reactive pozzolanic material in the production of concrete, and the ash properties vary due to the differences in incinerating conditions, rate of heating, geographic location and fineness. Furthermore, most of the mortar specimens with 10% RHA replacement of cement achieved higher strength than the reference mix (without RHA) [7]. When used in the production of cement, the use of rice husk ash will reduce the amount of energy consumed. Rice Husk will now be considered as agricultural product that can be used as an alternative material for cement with sacrificing strength and durability [8].

The paper describes an investigation into the behaviour of concrete produced by partial replacement of cement with RHA. RHA's effects on concrete properties were investigated using the mechanical properties of concrete, namely workability and compressive strength.

2. Literature Review

2.1 Properties of RHA

Many factors influences the composition of Rice Husk, including rice variety, fertilizer type, soil chemistry, and even production location [4]. Table 1 shows the typical chemical composition and physical property of RHA [9-11].

Table 2
Chemical and physical properties of RHA (*Wt*. %)

Chemical properties									
Constituent	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	Loss in ignition
Habeeb and Hilmi [9]	88.32	0.46	0.67	0.67	0.44	*	0.12	2.91	5.81
Ramezanianpous *et al.*,[10]	89.93	0.06	0.11	0.88	0.39	0.14	0.09	1.48	6.01
Costa *et al.*, [11]	65.83	0.06	0.34	0.44	0.08	0.05	*	1.07	13.99
Physical properties									
	Specific gravity								
Habeeb and Hilmi [9]	2.11								
Ramezanianpous *et al.*,[10]	2.15								
Costa *et al.*, [11]	13.99								

*Not reported

2.2 RHA as Cement Replacement

Converting wastes into building materials has become an important component of sustainable development [12]. RH's unique physical and chemical properties, such as high ash content and silica content, allow it to used effectively in domestic and industrial processing [4]. Previous research focused on amorphous RHA because amorphous ash has higher pozzolanic reactivity. Because RHA has pozzolanic properties, it will produce cementitious materials when finely grind and combined with calcium hydroxide at room temperature in the presence of moisture [3]. Pozzolanas are a key component in the manufacture of alternative cementing materials to Portland cement (OPC) [1]. RHA incorporation in concrete increased water demand, for the hardened properties, RHA concrete provided excellent improvement in strength for 10% replacement, and up to 20% of cement could be valuable replaced with RHA without affecting the strength [13].

3. Method

3.1 Preparation of Materials

The cement, rice husk ash, fine aggregates, water, and superplasticizer are the main components of the RHA-ECC. In this study, Ordinary Portland Cement was used. The fine aggregates used are dry graded silica sand from Simpang Pulai, Perak-based L.S.K Enterprise Sdn Bhd. A superplasticizer is a chemical additive that increases the workability of mortar and concrete without increasing the water-cement ratio. In this study, a superplasticizer named Sika ViscoCrete- 2192 was used. Polyvinyl Alcohol (PVA) Fiber with a length of 6 mm was used to make the mortar mixture in the study. 1.5% PVA fiber by volume of the mixture is present in the mixture. PVA fiber is distinct in that it can form a molecular bond with cement and concrete, making 300% stronger than other fiber.

3.2 Preparation of Rice Husk Ash

Pertama Padi Sdn Bhd provide rice husk ash in 500 μm size. Husk produced by husk burning has a high silica content (87-97%) and only trace amounts of salts and other trace components. Rice husk ash has a moisture content of 2% and mean particle size of 25 microns. It is a non- hazardous, solid grey powder. To maximise the compressive strength and bonding between RHA other materials, the

RHA particle size must be reduce. According to Leong [14], finer average particle size can improve concrete strength by increasing the pozzolanic reaction with CH to produce more C-S-H gel. Furthermore, the fine RHA particle can acts as microfiller and refine the pore structure. The dried oven RHA was sieved in the laboratory to obtain a particle size of 63 µm in according to BS EN 1015-1.

3.3 Mix Proportion

The material proportions were determined using the mortar's modified mix design. The mix design was revised in light of a previous study by Wang *et al.*, [15]. As a partial replacement of cement, various percentages of RHA (0, 5, 10, 15, 20%) were used in the mortar. Meanwhile, the mortar mix contained the same amounts of water, cement, superplasticizer, and water-cement ratio. In this study, 25% of waste was used in the mixing procedure. Table 3 shows the proportions of the ingredients in the mortar mix.

Table 3
Mix proportion

Mixture	Cement (kg)	Silica Sand (kg)	Water (L)	RHA (kg)	PVA Fiber (kg)	SP (kg)	Number of Samples (Days)		
							7	14	28
M1-0	1.677	1.392	0.587	0	0.027	0.015	3	3	3
M2-5	1.593	1.392	0.587	0.053	0.027	0.015	3	3	3
M3-10	1.510	1.392	0.587	0.107	0.027	0.015	3	3	3
M4-15	1.426	1.392	0.587	0.160	0.027	0.015	3	3	3
M5-20	1.342	1.392	0.587	0.213	0.027	0.015	3	3	3

3.4 Mixing and Casting

A hand mix was carried out for preparing the RHA-ECC mixes. The dry ingredients such as cement, RHA and silica sand were added into the mixing pail. After that, water was added slowly into the dry mix, and the mix was mixed homogeneously. Then, the superplasticizer was then added to the cement paste to ensure it could react well with the cement to produce higher workability. Lastly, the PVA fibers were added gradually to the wet mix and the mixing process continued slowly.

The fresh mortar was immediately cast into cube moulds and the vibration machine was used for vibrating the ECC mix. After that, the mould was kept at a standard laboratory temperature. A cube mould with a size of 50 mm was used for finding the 7, 14 and 28 days of compressive strength. A total of 9 numbers of cube specimens were cast for all types of ECC mix. All the specimens have been removed from the mould after 1 day of casting and kept in a sealed plastic bag for curing up to the age of testing. Air curing was chosen over water curing because the PVA fiber present in the hardened specimens absorbs water and diminishes the specimen's compressive strength.

3.5 Wet State

The most important property of mortar is its workability. Workability is the property of fresh concrete that determines its ease of handling, placing, consolidating, and compacting as well as its resistance to segregation [14]. The flow table test according to ASTM C 1437 was used in this study to determine the workability of mixed RHA-ECC. The flow table test, also known as the flow test, determines the consistency of fresh concrete. The flow table test can also be used to determine the allowable moisture limit of solid bulk goods for transport. It is critical to perform the floatable test before casting the concrete sample for any test to ensure the concrete's workability. The surface where the concrete will be placed is cleaned to remove any contaminants that may interfere with the test, such as dust or residual concrete from previous tests [16]. Eq. (1) was used to calculate the flow value.

$$Flow = \frac{Diameter\ Average - Base\ Diameter}{Base\ Diameter} x100 \quad (1)$$

3.6 Hardened State

Hardened concrete tests can be divided into mechanical and non-destruction tests, allowing for a study of property changes over time [17]. In this study, the compressive strength test was used. The compressive strength of mortar containing RHA amounts to partially substitute cement was determined using a compression test machine. The procedure followed ASTM C109/109M.

4. Results and Discussion

4.1 Sieves Analysis

The sample RHA must be sieved because the filler and pozzolanic effect of RHA in mortar is much more significant when the filler particles size is smaller. Furthermore, the filler effect is affected by replacement level, curing age and water cement ratio. Furthermore, the granular structure of mortars accounts for approximately 4% of the workability loss, whereas RHA's porous structure accounts for 96%. As a result, it is possible to conclude that the physical structure of the RHA played an important role in the mortar's behaviour on the flow table. Table 4 shows the percentage of Rice Husk that passes.

Table 4
Particle size of distribution of RHA

Grain size (mm)	Cumulative Percentage of Passing (%)
5	100.00
3.35	99.94
2	99.88
1.18	99.81
0.425	99.51
0.212	93.74
0.15	83.79
0.063	11.90
pan	0.00

4.2 Flow Table Test

ECC is a type of High-Performance Fiber-Reinforced Cementitious Composites with high workability and homogeneity due to the absence of coarse aggregate, the use of fine silica sand, and the addition of some additives [18]. According to Padhi *et al.*, [19], using RHA as a replacement for cement in concrete reduces the mix's workability. Gill & Siddique [20] reported that the mixed incorporating RHA would have better fresh properties because the RHA particles' round shape and fine size replaced the fine aggregate. However, as the RHA replacement level increased, the slump flow values decreased due to a decrease in the fineness modulus of the fine aggregate containing RHA. Figure 1 depicts the tabulation of the mixture's workability versus the percentage of RHA replacement obtained from the flow table test.

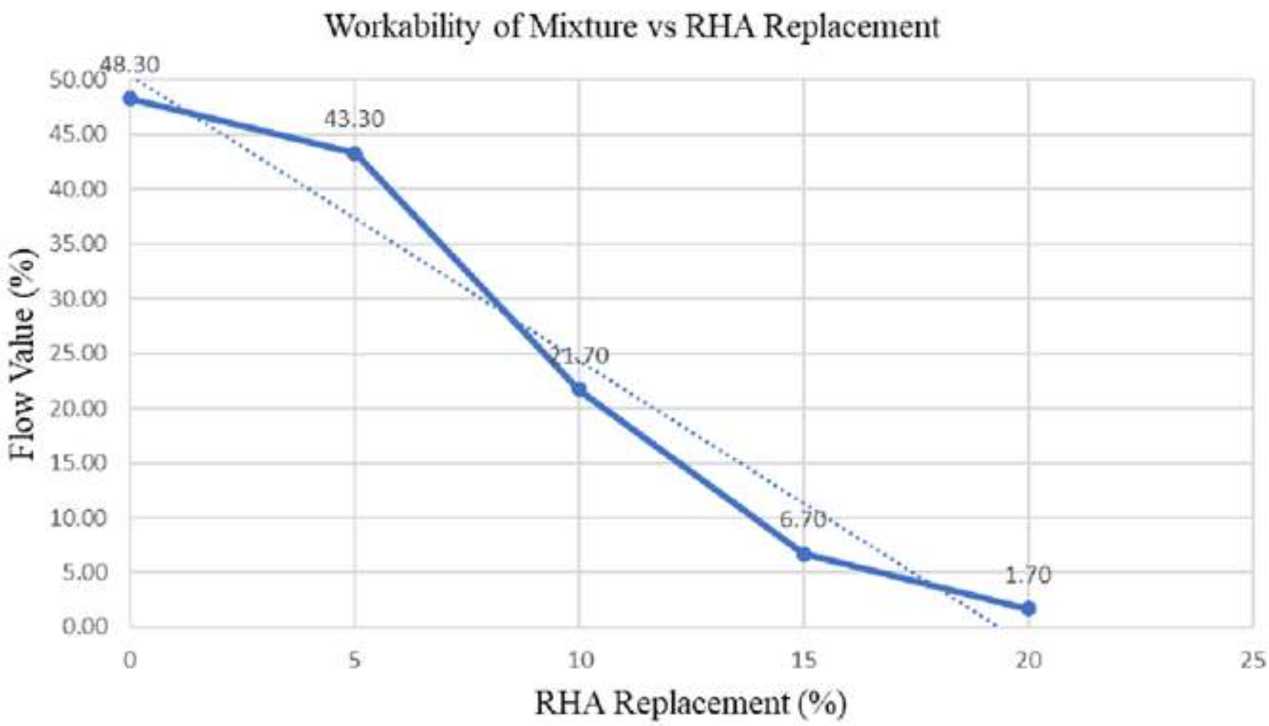

Fig. 1. The workability of mixture vs the percentage of RHA replacement

The literature was attributed the low workability to an increased volume of RHA replaced mixes to water cement ratio due to RHA's very low density [21]. The graph shows a decreasing pattern when the amount of RHA in the sample increases, indicating that the workability is decreasing. Because of its high specific surface area, RHA-ECC's workability has been found to decrease with increasing RHA in the mixture due to its water-absorbent property [22]. Tayeh *et al.*, [13] and Singh *et al.*, [23] also agreed that the decrease in workability with increasing RHA dosage in concrete can be attributed to RHA's water absorption capacity.

4.3 Density Test

Figure 2 illustrates the density of concrete determined followed ASTM C 138 with varying amount of RHA. The density of control concrete mix is 2084 kg/m3 which decreases to 2078 kg/m3 with the 5% replacement of RHA. The density value follows the similar trend of decreasing as in case of workability properties. The decreasing values of density indicate increasing void content of RHA-ECC leading to less durable mixture, also leading to lower strength properties as compare to normal mix.

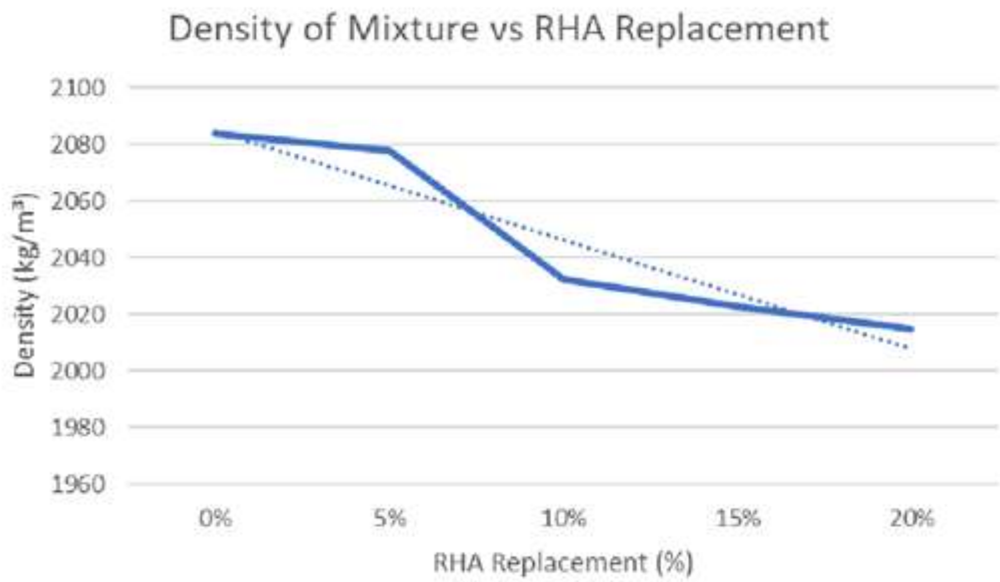

Fig. 2. The density of mixture vs the percentage of RHA replacement

4.4 Compressive Strength Test

RHA-ECC compressive strength is calculated in 7 days, 14 days, and 28 days after curing. Figure 3 depicts the compressive strength of the mixture in terms of RHA replacement.

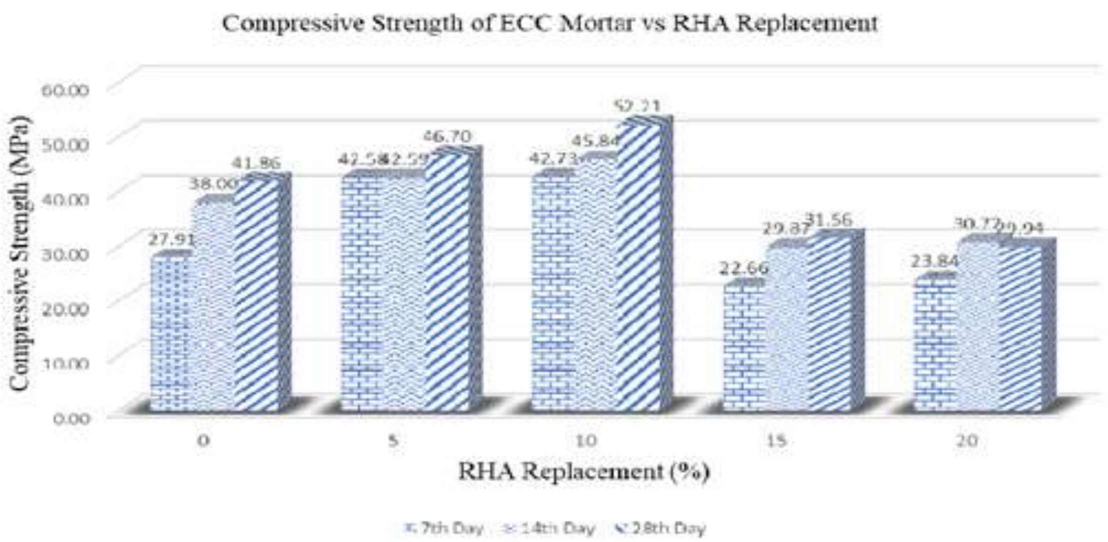

Fig. 3. The compressive strength of mixture vs the percentage of RHA replacement

Maximum compressive strength was observed at 10% cement replacement of cement with RHA, with results of 42.73%, 45.84%, and 52.21%, respectively, greater than the control mix. Up to 10% RHA replacement with cement improves the mechanical properties of aerated concrete with RHA. The results show that the increase in strength is due to the increase in density. Because of the direct relationship between density and strength, the strength increases. It has also been discovered that the increase in strength is caused by presence of reactive silica in RHA. Furthermore, as RHA percentage replacement increases to 15% and 20%, a downward trend in strength is observed. The decrease in compressive strength caused by the replacement of cement with RHA increased water demand, which harmed the compressive strength of the ECC [24].

5. Conclusions

According to the findings of the study, using RHA as a supplementary material can provide dual benefits. The first is that 10% RHA replacement yields comparable results, and the second is that RHA plays an important role in maintaining an environmentally friendly environment.

The following are the findings of an experimental study on Rice Husk Ash:

1. Rice Husk Ash, a very potential supplementary cementitious material in concrete, can be used to partially replace cement in the production of long-lasting and environmentally friendly concrete.
2. When compared to other replacements levels, replacing RHA with 10% OPC by volume resulted in the highest compressive strength.
3. The workability of the concrete is reduced while the amount of RHA is increased.

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