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Pozzolanic Effects of Rice Husk Ash (RHA) in Cement Based Construction Materials

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Abstract: The supplementary cementitious materials (SCM) are becoming very popular nowadays due to its' environmental friendly behaviour. Rice husk ash (RHA) is a well-known SCM that contains more than 80% active silica (SiO_2). RHA contributes to the strength and durability enhancement of cementitious system in two ways. Firstly, silica reacts with the hydration product $Ca(OH)_2$ (calcium hydroxide) to form secondary C-S-H gel, which is defined as chemical or pozzolanic effect of RHA. Secondly, it fills the internal voids in the microstructures physically because of its higher fineness, which is considered as filler or physical effect. The exact physical or chemical contribution of RHA separately still not well determined. Very few studies have been done before on separating these two effects. This chapter discusses the chemical or pozzolanic effect of RHA in conventional cement mortar. The pozzolanic effect is determined using both analytical and experimental procedure.

Keywords: *Rice husk ash; Supplementary cementitious materials; Pozzolanic effect*

Introduction: Cement based construction materials (concrete and mortar) have become the most consumed building material in both developed and developing world. This is because of the excellent mechanical & durability properties and its versatility of production that gives architectural freedom. It contains cement, fine and/or coarse aggregates, water, and in some cases mineral and chemical admixtures. During mixing, cement particles undergo a hardening reaction with water that bonds aggregates together to form a solid mass [1].

The total concrete production is around 1.5 to 3 tons per capita per annum in the industrialized world [2]. Cement is the primary element of concrete, which is produced and utilized in large quantity. Total production of cement is about 237 million tons in European Union alone [3] and 2.6 billion tons worldwide [4]. However, cement production involves significant amount of CO_2 emissions. Each ton of cement normally produce 1 ton of carbon-di-oxide (CO_2), approximately [5, 6]. The cement industries alone produce approximately 5% of global emissions of CO_2 [7]. CO_2 emits from both fuel combustion and industrial process during cement production. At the time of industrial process, CO_2 emits from limestone heating to obtain CaO (calcium oxide), which is the main oxide in the OPC. Relating to the industrial process, mineral addition in replacement of clinker can be an alternative. Added minerals must also be any cementitious materials such as some industrial waste materials and natural pozzolans [8]. The main pozzolanic materials currently utilized in cement industry are blast furnace slag, fly ash, and silica fume. Other pozzolans, such as natural pozzolans (metakaolin), have also been utilized in a small scale [1]

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Ocean Shipping Consultants of Surrey, UK estimated an expansion of approximately 30% growth rate by the year 2020, even for the scenario of low growth rate. For the scenario of high growth rate, it is approximated to 85% [9]. Therefore, the challenge now is to encounter the growing demands for cement and concrete together with reducing emission of CO_2. The current development of cement in Japan is produced from municipal waste by replacement of clinker up to 40%-50%. It has been reduced CO_2 emission against the normal OPC production but still required clinkering. Thus, this research is planned with the aim to carry out feasibility study on the potential of carbon neutral cementitious material from local agricultural waste. Palm oil fuel ash (POFA) and Rice husk ash (RHA) are abundantly available in Malaysia and proven pozzolanic agro-waste materials. Therefore, RHA and POFA have been selected for the initial investigation.

Literature Review on RHA as SCM: Rice husk is considered as an agricultural by-product. Its annual production is quite lot around the world. Even alone in Thailand, the annual rice production is approximately 5 million tons [10]. The raw husk of rice contains about 20% silica, 30% lignin, and 40% cellulose group. Upon combustion, the matrix of cellulose-lignin burns away and leaves only porous skeleton of silica. Thus, RHA contains large volume of reactive silica [11-13]. After grinding this porous skeleton of rice husk, fine powder (called RHA) with high surface area is produced. Owing to its' high content of silica, RHA is recognized as highly reactive pozzolan in producing mortar and concrete. Reactivity of RHA is mainly due to the high silica content in amorphous form and very large surface area governed by the porous skeletal structure of its particle. RHA having high reactivity can be obtained when burning under controlled environment. Such RHA contains high amorphous silica up to 95%. Its reactivity can also be increased by increasing the fineness [14-17]. However, some researchers suggested avoiding high degree of fineness as RHA derives its pozzolanic activity mainly from the particles internal surface area [11]. The optimized RHA produced under controlled burning and/or grinding can be utilized as a pozzolan in producing concrete and mortar. Incorporation of RHA in mortar and concrete provides several benefits, such as enhanced durability and strength of concrete; reduced environmental impact owing to waste disposal; and reduced carbon dioxide emissions, etc., [16; 18-20]. Table 1 shows typical chemical compositions of RHA obtained by previous researchers.

Table 1. Chemical composition of RHA (in percentage)

Chemicals	Zain et al. [21]		Cook et al. [22]	James and Rao [23]	Mahmud et al. [24]	Nehdi et al. [25]	Zhang and Malhotra [26]
Silicon dioxide (SiO_2)	79.84	86.49	93.15	94.43	92.7	94.6	87.2
Aluminium oxide (Al_2O_3)	0.14	0.01	0.41	-	0.2	0.3	0.15
Ferric oxide (Fe_2O_3)	1.16	0.91	0.2	1.3	0.4	0.3	0.16
Calcium oxide (CaO)	0.55	0.5	0.41	0.9	0.8	0.4	0.55
Magnesium oxide (MgO)	0.19	0.13	0.45	0.65	0.2	0.3	0.35
Sodium oxide (Na_2O)	0.08	0.05	0.08	0.55	0.2	0.2	1.12
Potassium oxide (K_2O)	2.9	2.7	2.31	1.32	-	1.3	3.68
Phosphorus oxide (P_2O_5)	0.8	0.69	-	-	-	0.3	0.5
Titanium oxide (TiO_2)	0.01	0	-	-	-	0.03	0.01
Sulphur trioxide (SO_3)	-	-	-	-	-	-	0.24
Manganese oxide (MnO)	0.07	0.07	-	0.38	-	-	-
Carbon (C)	7.75	3.21	-	-	-	1.0	5.91

Experimental Study: An experimental program was carried out in order to determine the pozzolanic or chemical contribution of RHA in the strength enhancement of cement mortar. The strength of RHA-incorporated mortar is contributed from cement hydration reaction, filler and pozzolanic contribution of RHA. For mortar incorporating non-reactive material (NS), the compressive strength is mainly owing to cement hydration reaction and filler effect of NS. Therefore, compressive strength owing to chemical or pozzolanic reaction of RHA can be obtained from the difference of compressive strength between RHA mortar and NS mortar. While both mortars contain materials that are approximately the same particle size, same cement replacement level as well as curing condition. This method of determining the pozzolanic or chemical contribution of pozzolan is reported in several studies [31-33].

Materials and specimen preparation: Mortar specimens of 50 mm cubic size were prepared keeping a constant water to cement ratio (0.485) and cement to sand ratio (2.75) according to ASTM C109. RHA and river sand was ground using a Los Angeles machine in order to achieve desired fineness. Particles size of ground RHA and river was less than 7 μm and were named as SRHA and SFNS respectively. Ordinary Portland cement (OPC) was used and replaced by ground SRHA or SFNS at 2.5%, 5%, 7.5%, 10%, 12.5%, 15%, 17.5% and 20% by weight of cement. All the materials were mixed appropriately using Hobart mixing machine. Casting of mortar into molds was done by three layers. Table vibration was applied for proper compaction. All specimens were cured in clean water bath at room temperature of 25 ± 2°C for desired testing age of 7, 28 and 90 days.

Experimental results and discussion: All the tests were performed in a compressive testing machine maintaining 1600 N/sec loading rate. Compressive strengths of the specimens are reported in Table 2; whereas, Table 5 shows the compressive strength of RHA mortar owing to pozzolanic reaction only. The tables indicate that, strength development of mortars with SRHA ash or ground sand is less depended on pozzolanic activity at early age less. Because, the highest strength of SRHA-mortar is only 4 MPa owing to the pozzolanic reaction. However, at 28 days, maximum compressive strength because of the pozzolanic/chemical reaction is 21.3 MPa when 20% SRHA used. It is observed that maximum strength of mortar containing 20% SRHA is 21.6 MPa owing to the chemical/pozzolanic reaction. The difference in strength due to pozzolanic reaction between 28 and 90 days is only 0.3 MPa for SRHA20 mortar. Therefore, pozzolanic reaction in mortar influences slightly over the age. Though at early ages (7 days or below) pozzolanic performance of small size pozzolans in mortar is not good enough; but, after 28 days it shows higher strength compared to OPC mortar.Table 3 shows that compressive strength owing to the chemical/pozzolanic reaction of SRHA particles is increasing with the increase of percentages replacement and age. At lower cement replacement level (up to 7.5%); the pozzolanic effect of RHA is not significant over the filler effect. However, at higher replacement level, significant enhancement of compressive strength was achieved owing to the chemical/pozzolanic reaction of RHA.

Microstructure development: Figure 1 shows the scanning electron microscope (SEM) image of the microstructure development of SRHA (Figure 1a) and SFNS (Figure 1b) incorporated mortar at 10% replacement of cement. The SEM image was taken at 28 days of curing.

It is observed that the fine particles improve the density of mortar. The main difference in microstructure of these two types of specimens is the amount of un-hydrated cement grains. SFNS mortar shows more un-hydrated cement grains compared to SRHA mortar, which confirms the slow reaction rate in this type of specimens.

Table 2. Compressive strength of SRHA-mortar and SFNS-mortar

	Compressive strength (MPa)		
Specimen	7 days	28 days	90 days
Control	36.4	58.2	62.2
SRHA 2.5	35.4	59.0	62.3
SRHA 5	34.3	59.2	62.5
SRHA 7.5	34.0	60.0	63.0
SRHA 10	33.6	60.2	63.2
SRHA 12.5	33.6	60.3	63.6
SRHA 15	33.5	60.7	63.8
SRHA 17.5	32.9	61.8	64.2
SRHA 20	32.8	62.3	64.4
SFNS 2.5	34.3	57.9	61.2
SFNS 5	33.4	56.7	60.9
SFNS 7.5	32.9	56.2	59.9
SFNS 10	31.0	52.5	57.0
SFNS 12.5	30.6	50.2	52.7
SFNS 15	30.1	44.6	48.1
SFNS 17.5	29.1	42.9	45.5
SFNS 20	29.3	41.0	42.8

Table 3. Compressive strength of RHA mortar due to pozzolanic reaction

	Compressive strength due to the pozzolanic reaction (MPa)		
Compared mortar	7 days	28 days	90 days
SRHA 2.5- SFNS 2.5	0.6	1.1	0.5
SRHA 5- SFNS 5	0.9	2.5	1.6
SRHA 7.5- SFNS 7.5	1.1	3.8	3.1
SRHA 10- SFNS 10	2.9	7.7	6.2
SRHA 12.5- SFNS 12.5	2.5	10.1	10.9
SRHA 15- SFNS 15	3.7	16.1	15.7
SRHA 17.5- SFNS 17.5	3.8	18.9	18.7
SRHA 20- SFNS 20	4.0	21.3	21.6

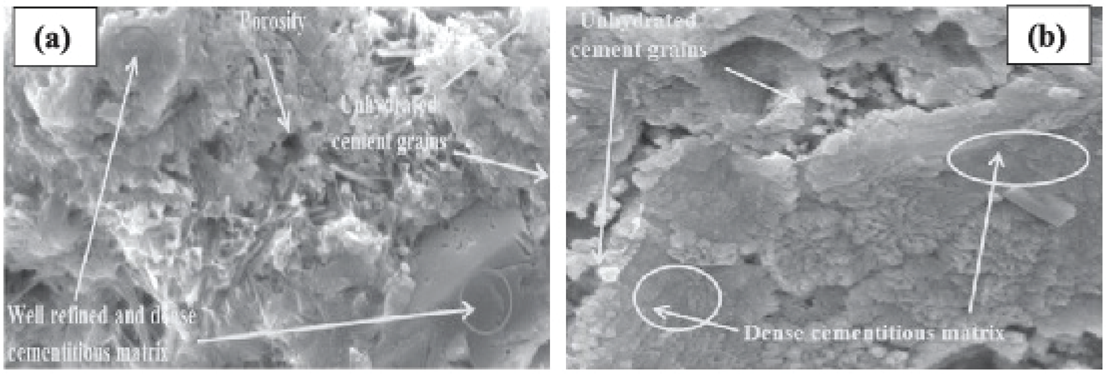

Fig. 1: Microstructure development of mortar, (a) SRHA mortar; (b) SFNS mortar

Conclusions: Rice husk ash (RHA) plays an important role as a SCM on the improvement of strength and durability of cement based materials. Based on a previous study, the maximum compressive strength can be achieved at 14 to 20 percent cement replacement level by RHA due to its pozzolanic effect [34]. However, experimental results suggested that maximum strength can be achieved even more than 20% cement replacement level. This higher ratio might be due to synergic effect of filler and pozzolanic effects of RHA. Therefore, it can be concluded that more study is still required to confirm the exact pozzolanic contribution of RHA in cement based construction materials.

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