Rice husk ash and sewage sludge ash as sustainable replacement material for concrete

N Tutur*, N H Dahalan, S R Rosseli and M A Johari

Fakulti Kejuruteraan Awam, Universiti Teknologi MARA Cawangan Pulau Pinang, MALAYSIA.

*nuraini.tutur@uitm.edu.my, nurolhuda@uitm.edu.my, rahimahrosseli@uitm.edu.my, akmaljohari@yahoo.com

Abstract. The development of supplementary cementitious materials (SCMs) has become essential in the advancement of low-cost construction materials for production of self-sufficient housing especially in developing countries. The use of these SCMs as admixtures not only improves concrete properties but protects and conserves the environment by saving energy and natural resources. Thus, studies have been conducted to find the suitability of combination of sewage sludge ash and rice husk ash to replace cement partially in conventional concrete. The effects on the nature of concrete exhibited mechanical properties of concrete such as compressive strength from a combination of sewage sludge ash and rice husk ash at different proportions. Sewage sludge ash (SSA) and rice husk ash (RHA) are used as partial replacement of cement for 10%, 20%, 30%, 40% and 50% in the concrete. The samples had been tested with compressive test to compare with normal concrete (OPC). There was an increment compressive strength of concrete at 10% amount replacement SSA and RHA, but the compressive strength declined when the amount replacement SSA and RHA are developing more than 10%. In addition, the concrete also showed increasing of compressive strength within the additional curing period, which was 7 days, 14 days and 28 days.

1. Introduction

Replacing partially cement with waste materials in construction is well known for conservation of dwindling resources and preventing environmental and ecological damages caused by quarrying and depletion of raw materials. Many researches had shown that some of these wastes such as Rice Husk Ash have good pozzolanic properties that would improve the quality of concrete produced [1,2].

[3] reported that components like cement can be replaced partially or fully with ashes like rice husk ash and sewage sludge ash, which have almost similar properties. With the current rate of urbanization, it is expected that the demand of cement will increase further. An increase in concrete structure, demand for cement are expected to increase in the similar trend [4]. The largest carbon dioxide emission source is the cement industry. Almost 5-7% of global CO2 emissions are caused by cement plants; 900 kg of CO2 is emitted to the atmosphere for producing one ton of cement [5]. The increasing demand for cement and concrete can be made possible with the introduction of cement replacement by using the waste materials, the uses of cement can be minimized and saved the cost of building material. In the cement manufacturing process, the introduction of waste materials as sustainable raw materials have been advanced in recent years. The waste materials that consist natural material has been proposed to replace the cement partially because it can maintain a clean and healthy environment since the raw material was already available and the consumption of energy in manufacturing is very low.

Malaysia is also facing a severe problem in handling a large amount of agrowastes and wastewater produced throughout a year. For example, rice husk and sewage sludge disposal. These big quantities of rice husk and sewage sludge are uncontrolled and have affected the land, and environments [6]. Increasingly strict environmental control regulations have also resulted in limitations on sludge disposal options. one of the alternative solutions for the disposal of sewage sludge is by incineration. [7] reported
that the principal component of sewage sludge after going through the high temperature incineration such as SiO₂, CaO, Al₂O₃, are the components of ordinary cements. The residue is practically inert and odorless, diverse solutions. The product of incineration will be utilised or recycled into building and construction materials, resulting in economical, technological, ecological and sustainable advantages. This will dramatically reduce or overcome the current sludge disposal problem.

Waste materials such as RHA have great potential to be used as building materials. RHA content a very high silica – above 70%. Reported by [8] the high silica content measure of the reactivity of RHA and established RHA as having the ability to contribute to the strength development process if used in concrete production. Also the fact that the sum of SiO₂+Al₂O₃ + Fe₂O₃ exceeds 70% for all the RHA specimens demonstrated that the RHA are in the same category with the Class F fly ash (ASTM C618, 2005) with high pozzolanic characteristics.

Pozzolanic properties which influence the strength development abilities is a necessary condition for any material to be considered for structural applications. This property is of utmost importance for it is an indication of its ability to participate in the reaction that lead to the formation of strength in concrete. Study on pozzolanic properties in RHA done by [1,2] showed that the presence of amorphous silica in RHA, its fineness and high specific surface area contribute to high pozzolanic activities. [9] found out that the pozzolanic activities increased with increase in the degree of its amorphismess but decrease with the particles size of the RHA. The major elements of SSA, such as Si, Al, Ca, Fe and P are always have quartz (SiO₂), whitlockite (Ca₃(PO₄)₂) and hematite (Fe₂O₃) to form crystalline. This is an important characteristic when considering SSA as a potential pozzolanic additive in blended cements [10]. Knowing the potential of this Sewage Sludge Ash (SSA) and Rice Husk Ash (RHA) as building material, a study was initiated to investigate the potential use of the locally available SSA and RHA as partial replacement for cement in Grade 30 concrete in terms of its compressive strength. The use of wastes in construction can conserve non-renewable resources, make products more cost competitive and reduce the amount of waste disposed of to landfill.

2. Methodology

2.1 Materials

Rice Husk Ash (RHA) was originated from the rice mill Padiberas Nasional Berhad (BERNAS) in Pinang Tunggal, Pulau Pinang while sewage sludge ash (SSA) is generated from the sewerage treatment plant (STP) from UiTM. RHA and SSA were used as partial replacement of cement. The design mix for a proportion of Portland cement (OPC), Sewage Sludge Ash (SSA), Rice Husk Ash (RHA), coarse, fine aggregate and water were prepared. The water cement ratio consumed was 0.54

2.2 Mix proportion

The mix design adopted for the preparation of the concrete specimens in this research was based on methods used by the British Department of Environment (1986). In this present study, six (6) series of concrete specimens were prepared based on replacement level of 0 %, 10 %, 20 %, 30 %, 40 % and 50 % of RHA and SSA to the OPC by weight. Table 1 gives details of the series of the mix proportion prepared.

| Design mix          | % Cement | % RHA | % SSA |
|---------------------|----------|-------|-------|
| Control OPC         | 100      | 0     | 0     |
| 5% RHA + 5% SSA     | 90       | 5     | 5     |
| 10% RHA + 10% SSA   | 80       | 10    | 10    |
| 15% RHA + 15% SSA   | 70       | 15    | 15    |
| 20% RHA + 20% SSA   | 60       | 20    | 20    |
| 25% RHA + 25% SSA   | 50       | 25    | 25    |
Total numbers of 108 cube sample with the dimension of 100 mm × 100 mm × 100 mm had been casted. The samples have been subjected to 5 different percentages of cement replacement, which are 10%, 20%, 30%, 40% and 50% as shown in Table 2.

Table 2. Series of Specimens and Testing conducted in this study

| No. | % of RHA + SSA | Mixture Designation | Number of samples | Compressive Strength Test | Water Absorption Test |
|-----|----------------|---------------------|-------------------|---------------------------|----------------------|
|     |                |                     |                   | 7  | 14  | 28  | 7  | 14  | 28  |
| 1   | 0              | Control OPC         |                   | 3  | 3   | 3   | 3  | 3   | 3   |
| 2   | 10             | 5%RHA+5% SSA        |                   | 3  | 3   | 3   | 3  | 3   | 3   |
| 3   | 20             | 10%RHA+10% SSA      |                   | 3  | 3   | 3   | 3  | 3   | 3   |
| 4   | 30             | 15%RHA+15% SSA      |                   | 3  | 3   | 3   | 3  | 3   | 3   |
| 5   | 40             | 20%RHA+20% SSA      |                   | 3  | 3   | 3   | 3  | 3   | 3   |
| 6   | 50             | 25%RHA+25% SSA      |                   | 3  | 3   | 3   | 3  | 3   | 3   |
|     |                | Total nos           |                   | 54 | 54  |
|     |                | Total no of all sample |                | 108 |

2.3 Testing
Concrete cube with the dimension of 100 mm x 100 mm x 100 mm were used for casting the cube specimen. The mixes of 100 % OPC were used as control reference. After 24 hours of casting, the specimens were cured in water for 7, 14, 28 days before being tested.

For hardened concrete, the compressive strength of 100 mm cube specimens was conducted based on BS EN 12390-3:2000. The water-cured specimens were tested at the age of 7, 14 and 28 days. For determination of the durability properties of the concrete specimens, the water absorption test was conducted on the cylindrical specimens of 50 mm in diameter by 100 mm height. The specimens were oven-dried to constant mass at 105 ± 5ºC for 72 ± 2 hours and then stored in air-tight containers as stipulated in BS 1881-122:2011. The specimens were water-cured until ages of 28 and 60 days before testing, and the specimens were weighed before the immersion in water for 30 minutes, 60 minutes, 120 minutes and 240 minutes.

3.0 Results and discussion
3.1 Compressive Strength
Table 3 shows the results of compressive strength and the percentage increase or decrease of the compressive strength obtained for different concrete grades, mixes and ages of water curing. For Grade 30 concrete, the 28-day strength of all the RHA+SSA concrete was below the control concrete (OPC) for replacement of 30% to 50%. It also shows that as period of curing increased, strength also increased. This is true as there is still reaction of the organics sludge with cement that occurs at a slow rate.
### Table 3. Compressive Strength of OPC and RHA+SSA concrete of various mixes

| Mixture Designation | 7 days (Compressive strength (N/mm²)) | 7 days (% compared to control sample) | 14 days (Compressive strength (N/mm²)) | 14 days (% compared to control sample) | 28 days (Compressive strength (N/mm²)) | 28 days (% compared to control sample) |
|---------------------|-------------------------------------|--------------------------------------|---------------------------------------|----------------------------------------|---------------------------------------|----------------------------------------|
| OPC                 | 28.86                               | -                                    | 30.94                                 | -                                      | 35.09                                 | -                                      |
| 5% RHA+5% SSA       | 27.73                               | 3.92 (-)                             | 31.87                                 | 3.01 (+)                               | 40.15                                 | 14.42 (+)                              |
| 10% RHA+10% SSA     | 27.29                               | 5.44 (-)                             | 31.30                                 | 1.16 (+)                               | 39.32                                 | 12.05 (+)                              |
| 15% RHA+15% SSA     | 16.94                               | 41.3 (-)                             | 19.24                                 | 37.82 (-)                              | 23.83                                 | 32.09 (-)                              |
| 20% RHA+20% SSA     | 8.8                                 | 69.51 (-)                            | 13.30                                 | 57.01 (-)                              | 22.28                                 | 36.51 (-)                              |
| 25% RHA+25% SSA     | 1.72                                | 94.04 (-)                            | 1.49                                  | 95.18 (-)                              | 1.03                                  | 97.06 (-)                              |

From the Figure 1, the highest value of compressive strength is 5% RHA+5% SSA which is 31.87 N/mm² at 14 days and 40.15 N/mm² at 28 days. Meanwhile, the 25% RHA+25% SSA combination achieved the lowest value of compressive strength for all curing times, which is 1.72 N/mm², 1.49 N/mm² and 1.03 N/mm² respectively.

There are several factors that affected the declination of strength in RHA and SSA concrete. One of the factors is the reduced amount of cement in the concrete. According to [11] and [12] stated that the reduction of the amount of cement concrete will lessen the hydration process. When the amount of cement reduced, the hydration and hardening process will become less. Hence, the components of mixed concrete will not effectively combined.

![Compressive Strength vs Percentage of RHA and CF Replacement](image)

**Figure 1.** Compressive Strength of OPC and CF+RHA Concrete Grade 30

#### 3.2 Water absorption

The purpose of water absorption is to measure how much water can be absorbed by the concrete. The amount of water absorption can affect the durability of concrete.
Table 4 shown the water absorption result of different mixes and ages of curing. The percentage of OPC for 7 days, 14 days and 28 days curing time are 2.85%, 2.44% and 2.18% respectively. At 7 days curing, the percentage of water absorption for 5%RHA+5%SSA, 10%RHA+10%SSA, 15%RHA+15%SSA, 20%RHA+20%SSA, 25%RHA+25%SSA are 2.85%, 1.68%, 2.07%, 3.13%, 3.27%, 10.22% respectively. While at 14 days curing, the percentage of water absorption for 5%RHA+5%SSA, 10%RHA+10%SSA, 15%RHA+15%SSA, 20%RHA+20%SSA, 25%RHA+25%SSA are 1.55%, 1.86%, 3.13%, 2.85%, 3.1% and 8.68% respectively. Then for 28 days curing times, the percentage of water absorption for all replacements are 2.18%, 1.26%, 1.52%, 2.62%, 2.75% and 7.75% respectively.

Table 4. Water Absorption Result

| Mixture designation | Absorption rates (%) |
|---------------------|----------------------|
|                     | 7days | 14days | 28days |
| OPC                 | 2.85  | 2.44   | 2.18   |
| 5%RHA+5%SSA         | 2.07  | 1.68   | 1.26   |
| 10%RHA+10%SSA       | 3.13  | 2.85   | 2.62   |
| 15%RHA+15%SSA       | 3.27  | 3.1    | 2.75   |
| 20%RHA+20%SSA       | 10.22 | 8.68   | 7.75   |
| 25%RHA+25%SSA       | 1.15  | 1.86   | 3.13   |

Recorded at Figure 2 the highest percentage of water absorption rate at is 25%RHA+25%SSA which is 10.22% at 7 days of curing. Meanwhile, the 5%RHA+5%SSA combination achieved the lowest percentage of water absorption for all curing times, which is 1.72 N/mm², 1.49 N/mm² and 1.03 N/mm² respectively. Figure 2 indicated the percentage water absorption rates for OPC and RHA and SSA concrete.

Figure 2. Percentage water absorption rates for OPC and RHA and SSA concrete.

As the percentages of mixture increased, the RHA and SSA concrete surfaces become more porous
because of many voids appeared due to low hydration and hardening process. As shown in Figure 3, the void obviously seen when the percentages replacement increased. According to [13] stated that the porosity will be less due to additional in curing time. The fibre in RHA absorbs more water during the mixing process. When the water cement ratio decrease, the hardening process will not fully take place which creates the honeycomb.

Figure 3. Type of surface concrete at 40% and 50% of replacement.

4. Conclusion
Rice Husk Ash and Sewage Sludge Ash are big sources of waste disposal that be used as an alternative to cement. The new idea has been generated to overcome the side effects of production cement. From this study, the result can be concluded which are:

i. The best performance of RHA and SSA concrete is at 10% replacement, which is high compressive strength, 40.15 N/mm² and low water absorption, 2.18% at 28 days. The pozzolan effect developed at optimum which makes the concrete become durable than OPC.

ii. At 50% of replacement cement, the rate of water absorption is highest which is 10.22% and more voids appear on the surface. The hydration and hardening process are not fully taking place because of the effect of the characteristic of RHA and SSA.

iii. The concrete become brittle as the replacement of cement was increased. This condition affects the strength of concrete.

Acknowledgement
The authors would like to thank the Universiti Teknologi MARA Cawangan Pulau Pinang for the facilities provided to conduct this study and to the Ministry of Education, Malaysia for the support of Research Acculturation Grant (RAGS) SCHEME- RAGS/1/2014/TK08/UITM/5.

References
[1] Antiohos S K Papadakis VG and Tsimas S 2014 Rice Husk Ash (RHA) Effectiveness In Cement and Concrete as A Function of Reactive Silica and Fineness Cement and Concrete Research 61-62, p. 20-27.
[2] Kartini K 2011 Rice Husk Ash – Pozzolanic Material for Sustainability International Journal of Applied Science and Technology 1, 6 p. 169-178.
[3] Chen and Maozhe 2013 Environmental and Technical Assessments of The Potential Utilization of Sewage Sludge Ashes (SSA) As Secondary Raw Materials in Construction Waste Management 33.5, p. 1268-1275.
[4] Jamshidi A Jamshidi M Mehrdadi N Shasavandi A and Pacheco-Torgal F 2012 Mechanical Performance of Concrete with Partial Replacement of Sand by Sewage Sludge Ash from Incineration Materials Science Forum 730-732, p. 462-467.
[5] Benhelal E Zahedi, G Shamsaei E and Bahadori A 2013 Global Strategies and Potentials to
Curb CO2 Emissions in Cement Industry *Journal of Cleaner Production* 51, p. 12–16.

[6] Khan 2012 Reduction in Environmental Problems Using Rice-Husk Ash In *Concrete Construction and Building Materials* 30, p. 360-365.

[7] Tenza-Abril AJ Saval JM Cuenca A 2014 Using sewage-sludge ash as filler in bituminous mixes *J. Mater. Civ. Eng.* http://dx.doi.org/10.1061/(ASCE)MT.1943-5533.0001087

[8] Nair D Fraaij A Klaassen A and Kentgens A 2008 A structural investigation relating to the pozzolanic activity of rice husk ashes *Cement and Concrete Research* 38, 6 p. 861-869.

[9] Mehta PK 1992 *Rice Husk Ash – A unique supplementary cement material* Proceeding of International Conference on Advance in Concrete Technology – CANMET. Greece, p. 407-431

[10] Doh SI Siew CC Tan KG and Adilen S 2016 The Use of Sewage Sludge Ash (SSA) As Partial Replacement of Cement in Concrete *ARPN Journal of Engineering and Applied Sciences* 11, 6 p. 3771-3775.

[11] Alwani WC Farah & Putra Jaya, Ramadhansyah & Bakar B H & Megat Johari Megat Azmi 2011 Effect of Rice Husk Ash to The Performance of Concrete Block *International Journal of Applied Science and Technology* 1, 3 p. 53-61.

[12] Kartini K Dahlia LAM Dyg SQ Anthony AD, Nuraini T and Siti RR 2015 Incinerated Domestic Waste Sludge Powder as Sustainable Replacement Material for Concrete *Pertanika J. Sci. & Technol.* 23, 2 p.193 – 205.

[13] Chopra, Divya Rafat S and Kunal 2015 Strength, Permeability and Microstructure Of Self-Compacting Concrete Containing Rice Husk Ash *Biosystems Engineering* 130, 2015 p. 72-80.