Characteristics of Calcium Silicate Hydrate (C-S-H) Reinforced Bonding in Retaining Wall Block Incorporating Cementitious Material: RECO Block

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Abstract
The Betoflor retaining wall blocks are dry-build mixtures of cement and aggregatewith interlocking joint design to prevent displacement in horizontal and vertical directions. The retained soils merely through its self-weight without internal reinforcement provide an uncomplicated solutionto withstand external subverting strength to earth and water retention.The hydration process between moisture and cement substantially liberates heat in retaining wall units and lead to rupturing after a significant period of exposure.Alternatively, this paper is presented to study the characteristics of partially reinforced cement using rice husk ash (RHA). The cementitious and pozzolanic naturesof RHA are essential to enhance the durability in concrete and subsequently reduce the environmental impact.RHA is processed through burning of raw rice husk (RRH) at controlled temperature of 600°C. Rice husk ash particulates replacement was set at 10%, 20%, 30%, 40% and for up to 50% by weight fraction. Compressive strength test was conducted to gauge the targeted strength performance of 30 ± 5N/mm^2. Additionally, water absorption tested at 100 minutes time intervals and age of 28 days of water curing respectively. The results indicated that replacement of 30% by weight fraction of RHA particulates postulates the optimum substitution value to obtain higher compressive strength, lower water absorption value and better resistance to deterioration by acidic attack.The crystal structure of calcium silicate hydrate (C-S-H) formation in the tested paste has significantly contributed to these enhanced properties.

Keywords: Rice husk ash, pozzolanic, cementitious.

1.0 Introduction

There are two groups of retaining walls using concept of gravity construction system, which are identified as conventional and reinforced soil retaining walls. Conventional retaining wall unit is a structure that is able to resists external de-stabilizing forces entirely through the batter of the retained soils constructed in the retaining wall units. Nevertheless, the reinforced soil retaining wall is a composite structure with combination of a coherent mass of reinforced soil stabilized by geo-synthetic metallic reinforcement layering horizontally. Typically, the metallic reinforcements are made of high tensile strength metallic sheet materials to enlarge the sufficient interlocking system. The structural coherence of a dry-stacked compression of retaining wall blocks is reached by integrating shear attachment to increase the strength capacity of the interface which requires a constant bonding configuration. Both conventional gravity and reinforced soil retaining wall function as gravity structures by relying on self-weight to resist the destabilizing forces due to the retained soil and surcharge loadings on the structure. The gravity wall system is constructed to form a coherent mass (weight) that has significance width to prevent both sliding at the base and overturning of the coherent mass. This construction design is to protect the gravity wall system from the toe of the structure under the action of lateral earth forces to keep stable. Requirement for compressive strength, water absorption and corrosion tolerance are governed by *NCMA TEK 2-4 Specification for Segmental Retaining Wall Units* (National Concrete Masonry Association, 2015). Apparently, reinforced soil retaining wall utilizes a method of geo-synthetic or metallic reinforcement to enlarge the effective width and weight of the gravity mass. Additionally, these geo-synthetic reinforcement products may be geo-grids or geo-textiles, though most reinforced soil retaining wall construction to date has used geo-grids. The geo-synthetic reinforcement extends through the interface between the reinforced soil retaining wall units and into the soil to create a composite gravity mass structure. This enlarged composite gravity wall system is composed of the reinforced soil retaining wall units. Nevertheless, a reinforced soil mass, offers the required resistance to external forces associated with taller walls, surcharged structures or more difficult soil conditions. In order to further investigate the feasibility of RHA replacement in concrete, freeze thaw action must be included in the scope of the study. Freeze-thaw action describes the crack in concrete due to the temperature drops and water freezes at night after a significant exposure period to the surrounding environment. The continuous increase in volume of the concrete exerts pressure on the initial cracks and gradually inducing a spilt in the concrete (Karakurt & Bayazit, 2015). At the present study, compressive strength and water absorption are the investigated properties to identify the strength performance of the retaining wall units which have been exposed to freeze-thaw resistance. The factors contributed to freeze-thaw deterioration are temperature cycles, exposure conditions, moisture content and pozzolanic reactivity of the block units(Singh, Patel, & Raza, 2014).Freeze-thaw action starts when the retaining wall units are severely saturated and subsequently leads to deterioration of the retaining wall units. Process of water freezing to ice occupies additionally volume of 1% of that initial volume when approximately 900m^3 of the retaining wall unit pores are filled with water. Lacking of space for this freeze-thaw expansion in a porous retaining wall unit would cause distress in the unit itself. Consequently, first freeze-thaw cycle will commence and continuous exposure to successive day and night routine resulting in surface loss of the retaining wall units. Therefore, in order to resist the retaining wall units from freeze-thaw damage, adding surface active substances to the mixture is proposed to promote air entrained(Jin, Zhang, & Huang, 2013). These surface active substances are highly pozzolanic and cementitious in nature that react with the cement and aggregates pastes to form a high intensity of closely packed structure and low volume of air bubbles in the hardened retaining wall units. This low volume of air bubbles are uniformly distributed with a distance of less than ¼ mm between each other in the mixture to relief the trapped pressure. Rice husk ash (RHA) is known as pozzolanic material processed through combustion of raw rice husk (RRH) that consists of high specific surface area. This high specific surface area is attainted during initial set and early strength development in cementitious materials. Significantly, the initial set and early strength of cementitious material is higher with increased weight fraction of tricalcium silicate (C_3S). The formation of tricalcium silicate (C_3S) produces higher heat of hydration and hardens the grain of the mixture in strength rapidly at early strength(Ghosal & Moulik, 2015).Pozzolanic reaction of rice husk particulates in concrete takes place when the amorphous phase ash contacts with calcium hydroxide in the existence of moisture or humidity (Ogork, Uche, & Elinwa, 2014). This will alternatively lead to the formation of cementitious compound. Therefore, it is crucial to investigate the potential of using RHA to partially replace cement in the fabrication of retaining wall blocks.

2.0 Material and method

Cement utilized in this experimental works is Lafarge Ordinary Portland Cement (OPC) Type I classified for general purpose. RRH used in the present study was collected from Parit Buntar, Perak. RHA in this study was produced by burning the RRH at controlled temperature of 600°C and properly stored. Material analysis using Energy-dispersive X-ray Spectroscopy (EDX) was performed to characterize the chemical composition of processed RHA. Particle size of fine and coarse aggregates at 500μm and 700μmwas kept constant to the mix proportion of the samples whereby the content of cement by weight was replaced by RHA varies in the range of 10%, 20%, 30%, 40% and 50% respectively. All retaining wall block samples were casted in cubic shape with dimension of 40mm x 40mm x 40mm and subjected to curing process accordingly. Samples for water absorption and compression strength testing were water cured at ambient temperature for up to 28 days. Nevertheless, the samples for corrosion resistance testing were immersed in sulphuric acid solution for curing. All the testing were conducted to establish a relationship between connected strengths defined by compressive strength, water absorption value tested at 100 minutes time intervals and corrosion resistance at age of 1, 7, 14, 21 and 28 days, accordingly. Additionally, a set of RRH samples with the same replacement parameters and curing methods were prepared as controlled specimens. Finally, the transformation of microstructures was characterized by using Field Emission Scanning Electron Microscope (FESEM). The methodology flow chart of the present study is illustrated in Figure 1.0.

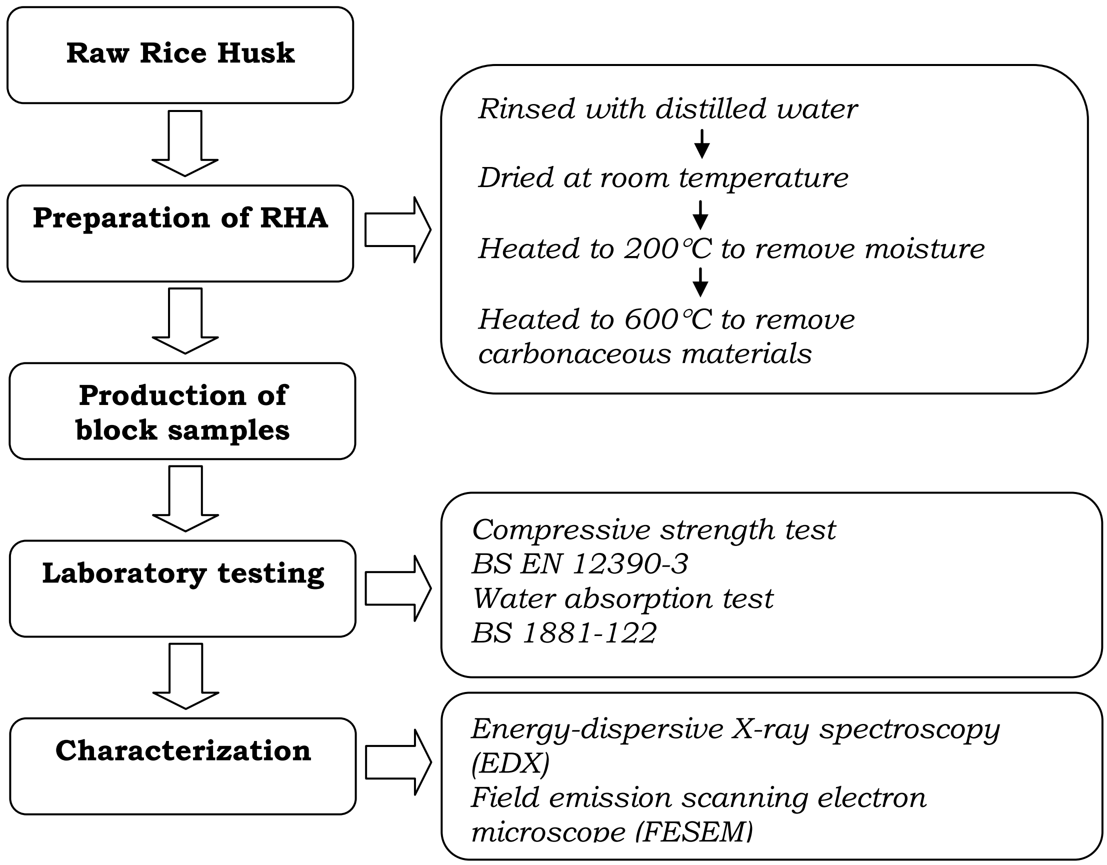

Figure 1.0: Methodology flow chart

3.0 Results and discussion

Compressive Strength (BS EN 12390-3)

The compressive strength of RRH-concrete and RHA-concrete samples was carried out with reference to the standard of BS EN 12390-3 standard. This test was conducted to gauge the behaviour of retaining wall samples while it experiences a compressive load. At the present study, the compression testing was carried out on retaining wall block samples using Universal Compression Testing Machine. Load bearing magnitude of the retaining wall units was applied on the samples gradually at the rate of 140kg/cm^2 and signified by compressive strength. The samples were tested after 28 days of curing period. Results recorded were drawn into a graph in Figure 2 to show the relative compressive strengths for variation of weight percentage admixture of RRH and RHA. All the substitution values of RRH and RHA are in percentage by weight of the total binder material. Results on inclusion of RRH and RHA as partial replacement of cement indicated that RHA-concrete attained higher compressive strength than RRH-concrete for all tested samples. Crystallization of silica ash is formed when the RRH is subjecting to burning process at 600°C. The chemical composition of this amorphous form of ash was characterized by Energy-dispersive X-ray spectroscopy (EDX) as shown in Table 1. RHA is highly siliceous material containing 95.23% of silicon oxide.

Table 1: The oxide compound for RHA

Oxide compound	Chemical composition (%)
SiO_2	95.23
CaO	1.03
MgO	0.52
K_2O	1.80
Cu_2O	1.42

Chopra et al. (Chopra, Siddique, & Kunal, 2015)reported that the reduced porosity, calcium hydroxide Ca $(OH)_2$ and surface area of the interfacial layer between the RHA paste and aggregate contributes to the increase of compressive strength and decrease of permeability in the RHA embedded retaining wall units. Hydrating reaction between RHA and $Ca(OH)_2$induces the development of C-S-H bond in the paste. Inclusion of RHA ameliorates the early strength of concrete during the process of setting and leads to denser and less porous structure (Bayuaji, 2015). This is occurred due to the formation of calcium silicate hydrate (C-S-H) gel around the cement particles when highly siliceous ash reacts with moisture. The formation of crystallized C-S-H is called cement gel which getting hardened with increase of aging period and thus, forms a continuous binding matrix within a large surface area. Samples with incorporation of 20% and 30% of RHA by weight showed compressive strength of more than 25N/mm^2 which are well within the targeted strength of 30 ± 5N/mm^2. The optimum compressive strength of 31N/mm^2 was reported for 30% cement replacement by RHA as shown in Figure 2.This is caused by the reduced calcium hydrate content during cement hydration where the calcium silicate is released within tricalcium silicate (C_3S) and dicalcium silicate (C_2S) (Habeeb & Fayyadh, 2009). However, the compressive strengths indicate a decreasing trend when the rice husk particulates rose up to 40% and 50% by weight fraction for both RRH-concrete and RHA-concrete. The increase of substitution with RHA at 40% and 50% by weight fraction may affect the primary product of hydration formed between cement and water. Therefore, the reduction of strength after 40% substitution of RHA in tested samples was significant. Khan et al. (Khan & Siddique, 2011)claimed the similar finding of strength reduction using RHA for up to 40% replacement in the concrete. Significantly, with increasing of replacement with RHA affect the primary hydrating reaction between cement and water. However, the addition of RHA shows promising effect in enhancement of secondary hydrating reaction due to the pozzolanic reaction between $Ca(OH)_2$ and aggregates even though the progress is slower than the primary reaction.

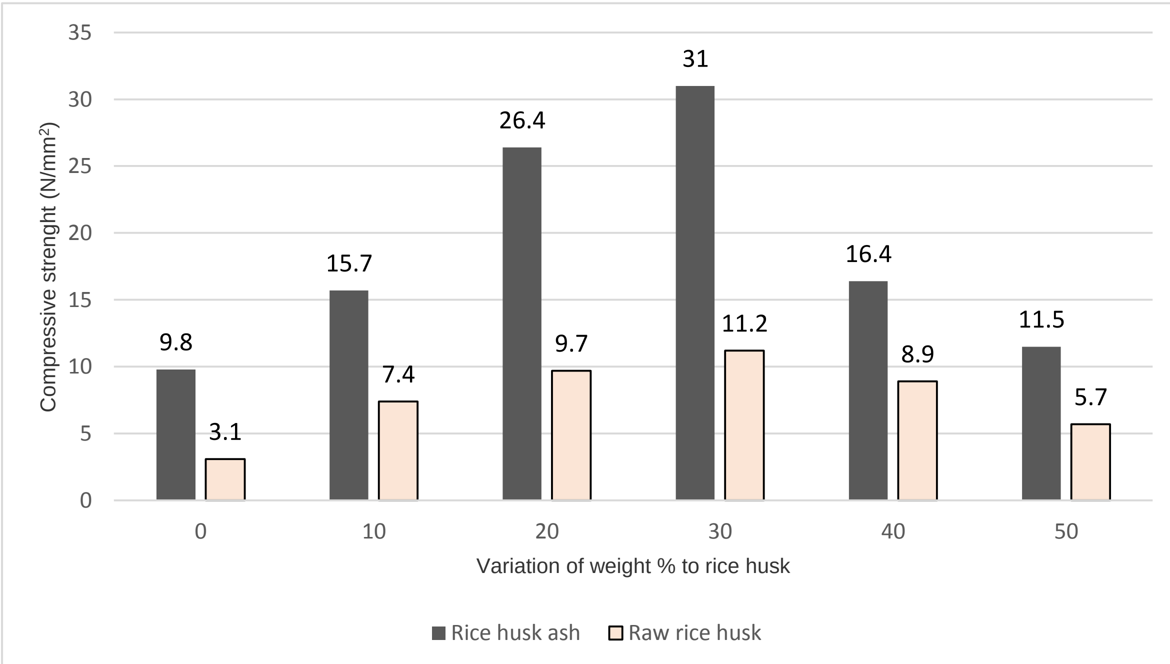

Figure 2: Variation of 28 days compressive strength for different mixture proportion

Water absorption (BS 1881-122)

Permeability of a retaining wall block can be measured by the value of water absorption. The more impermeable the retaining wall block, the greater the resistance to deterioration. Contamination in retaining wall block is one of the main sources where the risk of alkali aggregate reaction may take place. Therefore, the embedment of pozzolan, such as RHA in the present study would reduce the size of pores in structure and provide a less permeable paste in mixture. The water absorption percentage is indicated by weighing method with referring to equation (1):

$$\text{Percentage (\%) of absorption} = \frac{W_t - W_i}{W_i} \times 100 \quad \ldots\ldots\ldots (1)$$

Where W_t is the weight of sorbent contacting water (g) and W_i is the initial weight of sorbent (g).

The results determined that the incorporation of RHA in the retaining wall units could cause an extensive pore refinement between cement matrix and aggregates at the interface layer. And thus, result in decreasing of water permeability. Hydrating reaction in pozzolanic particles modified the pore sizes of the structure and therefore reduced the inter atomic bonding among each pores. Finally, radial expansion was observed in cement matrix. Progression of hydrating reaction reduces the permeability of the RHA-concrete. The presence of pozzolanic RHA induces the greater precipitation of RHA and cement mixture as compared to cement paste alone. This has effectively mitigated pores enlargement to reduce permeability. The present water absorption test was performed based on BS 1881-122 standard. The weight of absorbent was collected after 28 days of water curing. The test was conducted for 100 minutes interval and the percentages of increase in weight were calculated based on equation (1), where the initial weight of RRH-concrete and RHA-concrete before immersion (W_i) and the weight after immersion (W_t) in water. RRH-concrete and RHA-concrete samples subjected to water curing after 28 days were tested and their weights are collected for 100 minutes within intervals of 10 minutes. The values of the water absorption for these samples were tabulated in Figure 3.

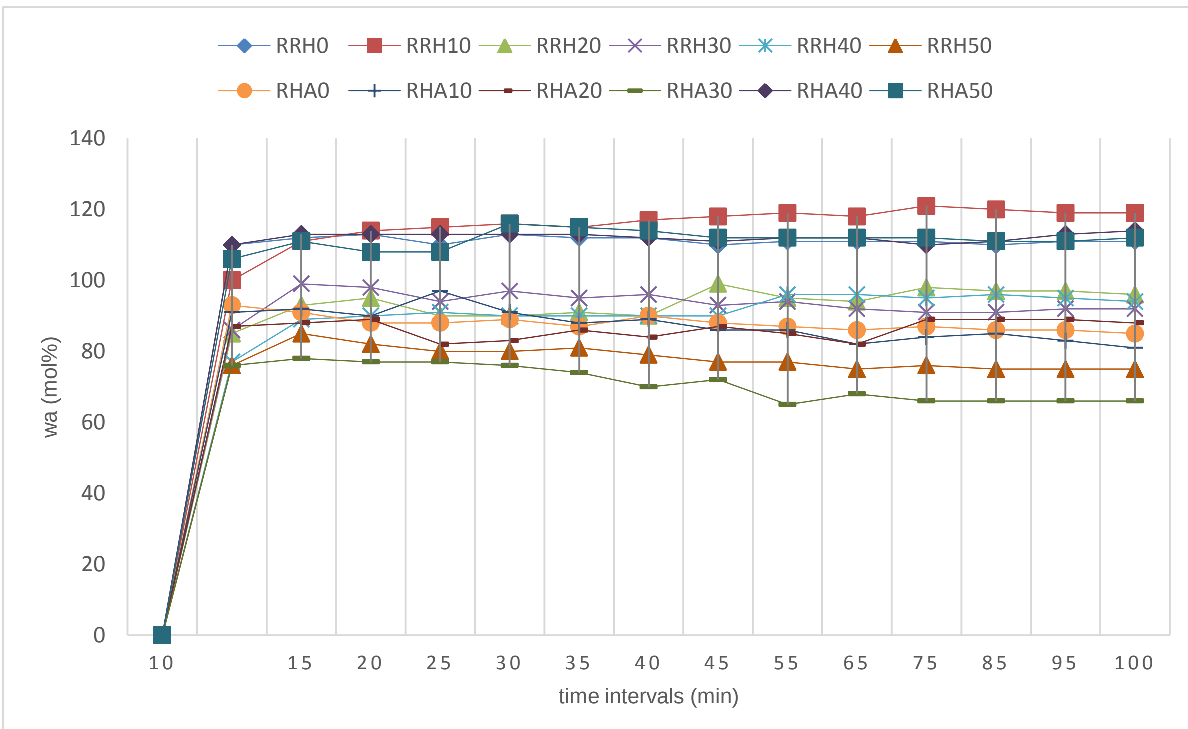

Figure 3: Water absorption value for RRH-RHA-concrete after 28 days of water cured

The results reveal that as percentage of replacement of rice husk particulates increases, the water absorption values for RRH-concrete increase substantially. However, the water absorption values for RHA-concrete decrease from 10% to 30% replacement by weight of rice husk particulates. Rice husk particulates replacement of 30% by weight achieved the lowest water absorption value at 71.2 mol% in average for the RHA-concrete. The pozzolanic reaction has significantly reduced the porosity of this concrete by producing more C-S-H gel to fill the voids created between cement particles with the presence of moisture and thus resist the capillary action (Kartini, Nurul Nazierah, Zaidahtulakmal, & Siti Aisyah, 2012). Therefore, it can be concluded that the replacement of cement with rice husk particulates contributes to improvement in rate of water absorption of the concrete. Figure 4 shows the bonding of C-S-H in RECO-block characterized by Field Emission Scanning Electron Microscope (FESEM) in 5.00kX and 2.50kX magnification, respectively.

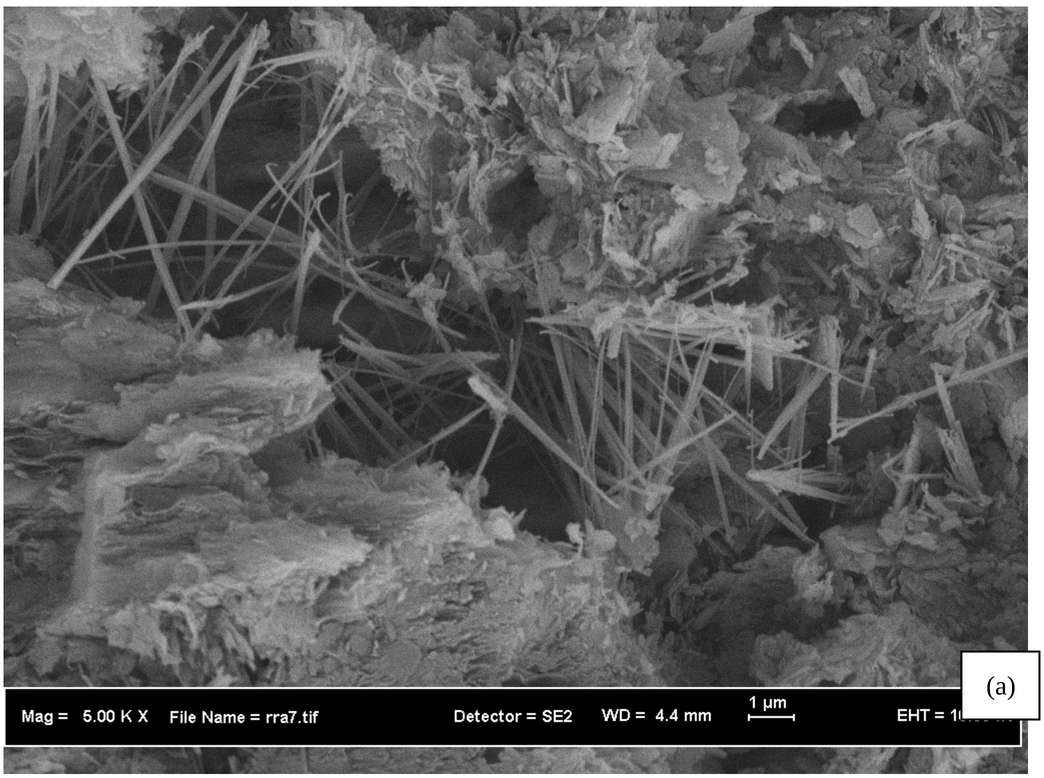

Figure 4: The bonding of C-S-H in Reco-block characterized by FESEM in (a) 5.00kX

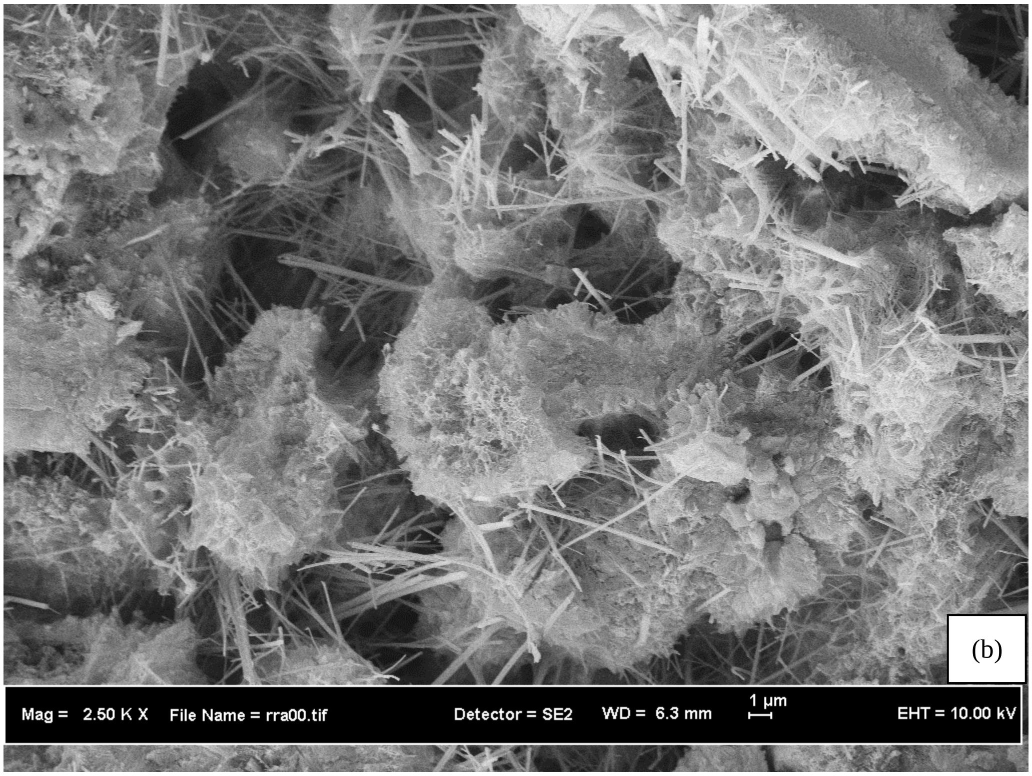

Figure 4: The bonding of C-S-H in Reco-block characterized by FESEM in (b) 2.50kX magnification

Effect of acids on RRH-RHA-concrete

The durability of retaining wall blocks is determined by their ability to withstand the degradation by environment chemically and physically during their service life. Acidic attack is the common issue dealt by the constructor where it is usually caused by the decomposition and straining of the element of cement matrix. The effects of acids on RRH-concrete and RHA-concrete were indicated by the behaviour of the rice husk particulates and period of exposure. The sample cubes of RRH-concrete and RHA-concrete were weighed after immersion in 10% of acid sulfuric solution at 7 days interval until the 28 days to indicate the weight loss due to acid degradation. The weight of RRH-concrete and RHA-concrete after subjection to acidic environment was plotted in Figure 5 respectively. The weight loss in average of RHA-concrete after 28 days immersion in sulphuric acid solution was 6.9% relatively opposed to 18.8% for RRH-concrete. The improvement in invulnerable to sulphuric acid solution attack could be attributed to the cement replacement by RHA particulates which provide better pozzolanic reaction than RRH particulates(Naji Givi, Abdul Rashid, A. Aziz, & Mohd Salleh, 2010). The small grain sizes of RHA acting as pozzolans is making nucleation available to hydration products C_3S in cement paste by dispersion mechanism. The denser paste is formed where the finer particles of RHA were reported to speed up the formation of C-S-H through this mechanism. Significantly, a dosage of 30% RHA replacement is effectively resisted to sulphate attack. RHA has refined the pores in RHA-concrete which has substantially reduced the penetration of chloride and decreased permeability, and thus, improved sulphate resistance.

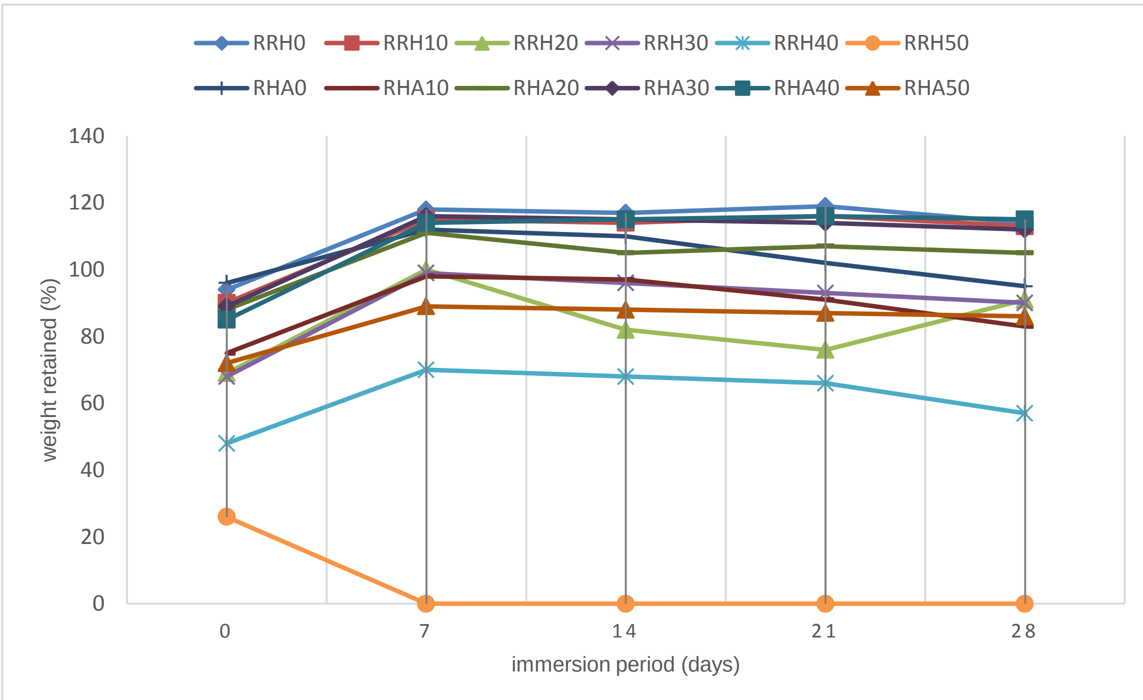

Figure 5: The weight of RRH-concrete and RHA-concrete after subjection in acid sulphuric solution

Conclusion

Incorporating of 30% RHA particulates by weight to partially replace cement contributes to enhanced compressive strength at 31N/mm^2, lower rate of water absorption value and offers better resistance to deterioration by sulphate attack.

Acknowledgment

The authors wish to thank Universiti Teknologi Malaysia for funding the research project and UTM Research Management Centre (RMC) for managing the research activities under Vote QJ130000.2524.10H22

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