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Research Article

Properties of Rice Husk Ash (RHA and MIRHA) Mortars

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Abstract: Rice husk Ash (produced by traditional burning called RHA and by using microwave incinerator called MIRHA) has shown promise as a cement replacement material. This study investigated the properties of RHA and MIRHA mortar used for brick manufacture at binder sand proportions of 1:3 and 1:4. RHA and MIRHA were intermediate in particle size to cement and sand particles. Percentages of replacement were 5, 10, 15, 20, 25 and 30%, respectively. Strength at w/c ratios (0.5, 0.55, 0.6 and 0.65, respectively) was investigated to identify optimum w/c ratios as well as optimum percent replacement of RHA and MIRHA. Variations of IRS, density and water absorption were investigated. Generally 1:3 RHA and 1:3 MIRHA mortars strength showed decreasing trend with increasing percentage replacement with RHA and MIRHA. Whereas 1:4 RHA and 1:4 MIRHA mortars showed increase in strength at 5% replacement and decrease thereafter. IRS values for RHA mortars are generally within limits (0.25-1.5 kg/m^2.min) recommended. Water absorption values of RHA mortars are generally higher than control mortar. IRS values for MIRHA mortars with w/c 0.5 and 0.55 ranged between 1.4-2.0 kg/m^2.min; indicating the need for wetting the bricks before use. IRS values for 1:3 MIRHA mortars with w/c 0.6 and 0.65 were below 1.0 kg/m^2.min indicating low suction values. For 1:4 MIRHA mortars, IRS values were very low in all cases. Water absorption values of MIRHA mortars are generally higher than the control mortar. MIRHA mortars with w/c 0.6 and 0.65 showed low percentages of water absorption.

Keywords: Cement replacement material, density, initial rate of suction, microwave incinerated rice husk ask, mortar brick, strength, water absorption

INTRODUCTION

The availability of cement used as binder in concrete is reducing worldwide due to extensive use. There is a need to find new renewable source to replace or reduce the use of Ordinary Portland Cement (OPC). Many Cement Replacement Material (CRM) have shown promise; but this research is focussed on Rice Husk Ash (RHA) and Microwave Incinerated Rice Husk Ash (MIRHA). RHA is produced in traditional way by uncontrolled combustion of rice husk and grinding using Los Angeles Abrasion machine whereas MIRHA is produced in microwave incinerator under controlled burning method at 800°C which reduces carbon emissions. Such concrete is environmental friendly (Nuruddin *et al*., 2008), as resources are saved by using industrial waste products like rice husk ash and micro silica. Green concrete is cheap to produce as it reduces the production cost of per unit of cement (Nuruddin *et al*., 2008).

LITERATURE REVIEW

The use of CRM to form mortar (like in concrete) will reduce the use of cement. Mortar bricks are commonly used in building construction, road pavement, etc. For road pavement application the technology is 5000 years old (Singh, 2007). Brick pavements highways are seen in old ruins in the West Asian Region (Mesopotamia). Nowadays it is used in road pavement to increase the aesthetics of building design. Eco-friendly bricks are not as cheap as the common bricks due to additional procedure in making the bricks. The difference in price between normal cement bricks and green bricks is affected by the percentage of CRM used in the green bricks. Higher replacement results in higher price since production of MIRHA can be expensive although the source is free. The compressive strength of mortar bricks decreases with a higher water-cement ratio but is not influenced much by the cement content (Schulze, 1999).

Paddy has 25 and 75% by weight of husk and rice respectively. Seventy five percent of husk is volatile

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and the balance can be converted to RHA or MIRHA. Thus out of the 2.2 Million tones of paddy available in Malaysia (2007 statistics), 121 thousand tones of RHA can be produced. This huge renewable resource should not be wasted and if not used poses disposal problems (International Rice Research Institute, 2008; Jha and Gill, 2006).

Many researchers have studied the utilization of this waste agricultural by-product as CRM. RHA is whitish or gray (Safiuddin *et al*., 2009), consisting of non-crystalline silicon dioxide with high specific surface area and high pozzolanic reactivity (Tashima *et al*., 2004; Naji Givi *et al*., 2010). It possesses excellent pozzolanic reactivity due to high silica content, reportedly about 90 to 95% amorphous silica (Safiuddin *et al*., 2009; Mehta, 1992). Burning conditions play an important role in determining the physical properties of RHA. Highly pozzolanic RHA could be produced if the temperature of burning and the residency time inside the furnace are controlled (Pitt, 1976). This was later supported by Nagataki (1994) and Nehdi *et al*. (2003) which showed that the microstructure and characteristics of RHA are affected by the period and burning temperature. Few studies found that controlled burning at about 500 to 800°C produced non-crystalline or amorphous silica, which shows very high pozzolanic activity (Nagataki, 1994). Conversely, crystalline RHA which has poor pozzolanic property is produced when uncontrolled burning at high temperature is used (Safiuddin *et al*., 2009).

The relative density of RHA is also affected by the burning conditions (Safiuddin *et al*., 2009). Generally, grey RHA from complete burning has a relative density of 2.05 to 2.11 (Ismail and Waliuddin, 1996; Nehdi *et al*., 2003). In addition, Mehta (2002) found out that most particles of RHA are in the size range of 4 to 75 μm. The median particle diameter is larger than that of silica fume which ranges from 6 to 38 μm. However, RHA has an extremely high specific surface area as its particles are porous and possess a honeycomb microstructure, unlike silica fume (Zhang and Malhotra, 1996; Safiuddin *et al*., 2009).

The incorporation of RHA in OPC concrete results in increased water demand during its fresh state due to high specific surface of RHA (Malhotra, 1993). Rashid *et al*. (2010a) have found out the water demand for mixtures containing different level of OPC replacement by RHA with fixed water cement ratio. The water cement ratio was fixed by flow table test and confirming a flow value of 110±5 mm in 25 drops. The water demand was observed from the result of flow table test. The water demand increases when RHA increases due to high fineness and porous surface of RHA. This finding supports (Sumrerng *et al*., 2009; Rukzon and Chindarprasirt. 2006).

Abdelalim *et al*. (2002) investigated the mechanical properties of the cementitious materials containing RHA. Various 0.5 w/c OPC mortar mixes with RHA (0, 5, 20, 15, 20, 25 and 35%, respectively) were prepared and cube specimens cast for compression strength test at 56 days of curing. The study showed that compressive strength of OPC mortar increases with increasing the amount of OPC replacement level by RHA till a certain optimum content of RHA which is 25% in this case. The compressive strength decreases afterwards with increasing RHA content. These findings further support (Zhang *et al*., 1996). Figure 1 shows the compressive strength of mortar at 56 days of curing period.

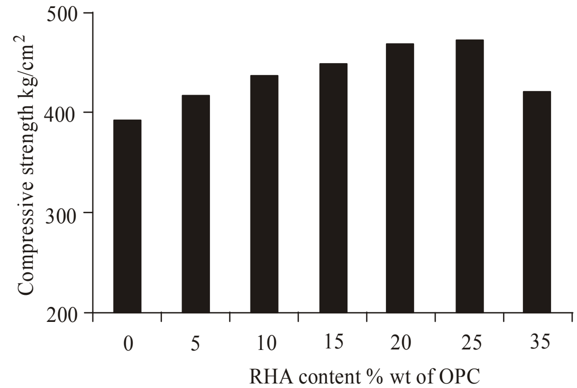

Fig. 1: Compressive strength of RHA mortar after 56 days of curing (Abdelalim *et al*., 2002)

RHA mortar tends to achieve higher compressive strength and decrease of permeability due to the reduction of porosity, calcium hydroxide content and width of interfacial zone between the paste and the aggregate (Zhang *et al*., 1996).

However, for RHA mortar with w/c of 0.55, the compressive strength at 5% RHA replacement is higher than other percentage of RHA replacement. On the other hands, RHA mortar with w/c of 0.5 shows the higher compressive strength at 20% RHA replacement compared to other percentage of replacement (Anwar, 2011).

The incorporation of RHA in 1:4 mortars resulted in higher compressive strength than control mortar. Anwar (2011) found that at 5% RHA replacement, 0.5 w/c RHA mortar has higher compressive strength than control mortar and it has the highest compressive strength compared to the other 0.5 w/c RHA mortars. The compressive strength for 0.5 w/c RHA mortars is decreasing after 5% RHA replacement. On the other hands, 0.55 w/c RHA mortar with 20% RHA replacement has the highest compressive strength compared to control mortar and other 0.55 w/c RHA mortars.

Incorporation of pozzolan such as fly ash and RHA in mortar mixtures reduces the average pore size and cause an extensive pore refinement in the matrix and in the interface layer (Chindraprasirt *et al*., 2005; Rodriguez, 2006). The water permeability of hardened mortar reduces throughout the hydration progress (Naji Givi *et al*., 2010). Saraswathy and Ha-Won (2007) reported that the coefficient of water absorption of RHA concrete at all levels was less than control concrete due to the micro-filling and pozzolanic effect of RHA in cement mixtures.

Anwar (2011) found out that 0.55 w/c RHA mortars have lower IRS and water absorption value compared to 0.5 w/c RHA mortars for both binder to sand ratio of 1:3 and 1:4. He also stated that the water absorption increases as the RHA replacement increases might be due to amorphous form of silica in RHA which requires more water to complete hydration process with cement and sand to form C-S-H bond (Alireza *et al*., 2010).

IRS of mortars shows the amount of water sucked by the cubic mortar sample upon contact with mortar during laying. IRS affects the water tightness and durability of masonry as it can affect the bond strength between the brick and mortar. IRS must be limited to the specified limits as per standard so the optimum bond strength could be achieved. Thus, it is essential and important to measure IRS of mortar samples used in masonry construction. BS 3921 (1985) Appendix H specifies the test principle for measuring IRS of mortars by immersing the cubic sample in about 3 mm depth of water for duration of 1 min (BS 3921, 1985). Drysdale *et al*. (1994) established that bricks with IRS less than 0.25 kg/m^2.min can be considered as low suction bricks whilst bricks with IRS more than 1.5 kg/m^2.min can be regarded as high suction bricks. Bricks with IRS values between 0.25 to 1.5 kg/m^2.min have the capability to produce good bond strength when used with the appropriate mortar proportions.

Justification for study: The demand for a high quality sustainable material has increased and encouraged the researchers to find new alternatives. Rice husk from the rice production poses a major problem of disposal especially when open burning is no longer permitted due to the environmental issues. The usage of pozzolanic materials to reduce the carbon dioxide emitted per tonne of concrete produced are being investigated and utilized. A study by Wan *et al*. (2011) investigated the potential of using MIRHA in OPC mortar mixes. In it, the water-binder ratio was kept constant at 0.5. Control mortar without any replacement and 5, 10, 15, 20 and 25%, respectively of OPC replaced by MIRHA were studied with varied binder-sand ratio at 1:3, 1:4. 1:5 and 1:6. The compressive tests were conducted for the samples at 7 and 28 days. The result has revealed that, the MIRHA could be used in cement mortar due to its refined microstructures. In addition, the compressive test results were compared with three different standards: ASTM, MS and BS for bricks manufacturing. The results show the potential of using MIRHA in cement brick production. Amongst the cement replacement mixes, 20% MIRHA has shown highest compressive strength.

Objectives of present studies: The current study extends the work with two objectives namely:

Table 1: Mix proportion of RHA mortar (w/c = 0.50; binder: sand = 1:3)

RHA (%)	RHA (g)	Cement (g)	Sand (g)	Water (g)	Total mass (g)
0	0	66.667	200	33.333	300
5	3.333	63.333	200	33.333	300
10	6.667	60.000	200	33.333	300
15	10.000	56.667	200	33.333	300
20	13.333	53.333	200	33.333	300
25	16.667	50.000	200	33.333	300
30	20.000	46.667	200	33.333	300

- To obtain the optimum w/c and the optimum percentage of RHA and MIRHA as CRM in mortar and optimum c/s of RHA and MIRHA mortar
- To study the properties of IRS, water absorption and density of the RHA and MIRHA mortars

METHODOLOGY

The work was done as four undergraduate final year research (Yusoff, 2010; Haron, 2011; Alias, 2011; Anwar, 2011). For RHA and MIRHA mortar, the parameters were varied as follows. The w/c ratio of 0.50, 0.55, 0.6 and 0.65 were used and the RHA or MIRHA used were 0, 5, 10, 15, 20, 25 and 30% of OPC, respectively. The c/s proportions were 1:3 and 1:4. The mix proportions for 1:3 RHA mortar with w/c 0.5 is given in Table 1. The mix proportions in other cases are determined similarly. Compressive strengths of samples were evaluated at 7, 28 and 60 days using ASTM C109 (www.astm.org/Standards/C109.htm).

The water absorption and Initial Rate of Suction (IRS) of water of mortar bricks were also investigated. The Standard Test Method in ASTM C642 (1997) was used evaluate water absorption at 60 days. The IRS is evaluated at 60 days which determines the volume of water that mortar sample absorbs as per ASTM C1585 (2004). The particle size distribution of cement, RHA/MIRHA and sand was also evaluated.

RESULTS AND DISCUSSION

The results and discussion are divided into following sections.

Compressive strength: Figure 2 to 7 shows the comparison of compressive strength at 7, 28 and 60 days for the RHA mortars for 1:3 and 1:4 cement sand ratio, respectively.

RHA replacement: Figure 2 to 4 shows that shows that 7, 28 and 60 day, respectively compressive strength for 1:3 binder to sand ratio RHA mortars is lower compared to the control mortar for all w/c at all RHA replacement, except in case of the 60 day strength for w/c 0.6. The compressive strength results are seen to fluctuate for 0.5 and 0.55 w/c mortars. RHA at all replacement level does not give significant contribution towards the RHA mortars compressive strength. RHA mortar with 0.65 w/c at 5% RHA replacement shows the highest compressive strength at 7-day compared to other RHA mortars. This might happen due to the

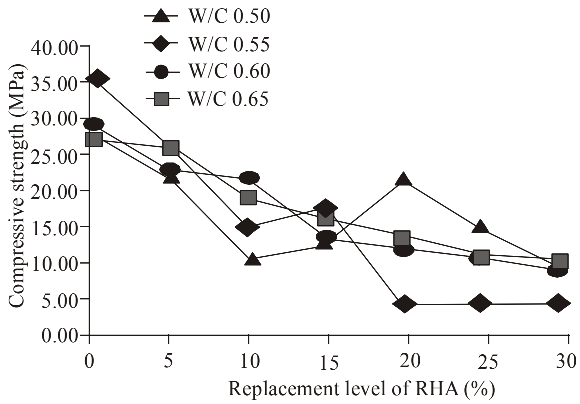

Fig. 2: 7-day comp. strength variation for 1:3 binder to sand ratio mortar of different W/C

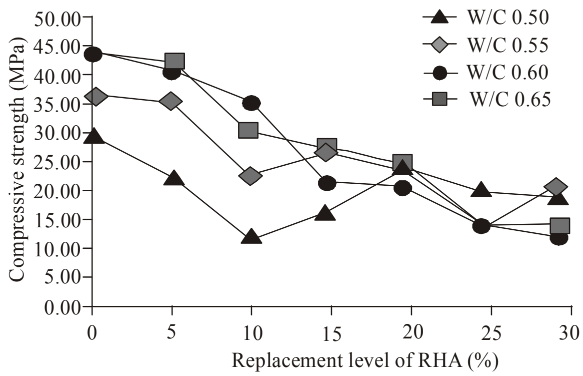

Fig. 3: 28 day comp. strength variation for 1:3 binder to sand ratio mortar of different W/C

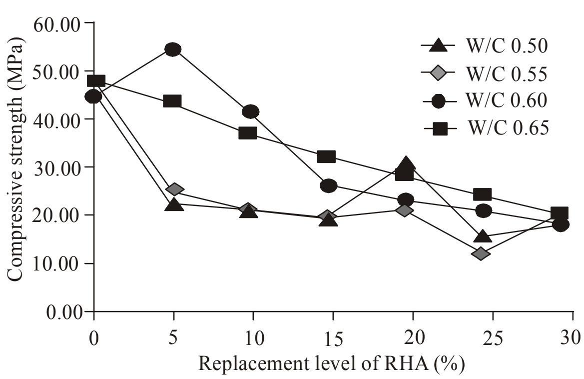

Fig. 4: 60-day comp. strength variation for 1:3 binder to sand ratio mortar of different W/C

sufficient water content in the mixture that contribute towards hydration process of cement and RHA which provide better pore refinement in the sample. Thus it contributes towards its high compressive strength compared to other RHA mortars. As 28-day results are used in design, it can be concluded that for 1:3 binder to sand ratio RHA mortars, the addition of RHA does not give any significant contribution to the compressive strength.

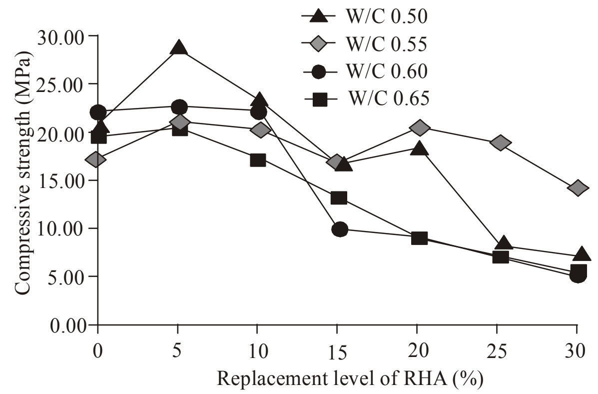

Fig. 5: 7-day comp. strength variation for 1:4 binder to sand ratio mortar of different W/C

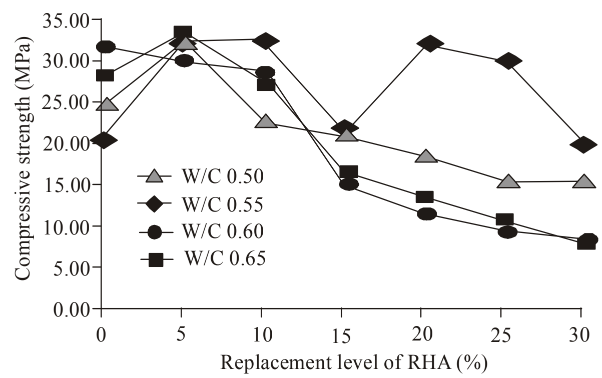

Fig. 6: 28 day comp. strength variation for 1:4 binder to sand ratio mortar of different W/C

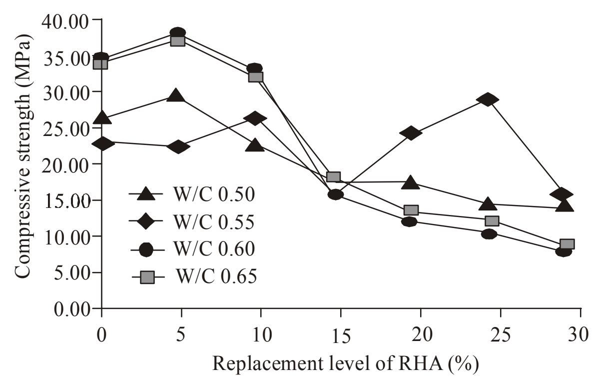

Fig. 7: 60-day comp. strength variation for 1:4 binder to sand ratio mortar of different W/C

Figure 5 to 7 shows that unlike 1:3 binder to sand RHA mortars, 1:4 RHA mortars show increase in compressive strength at 5% RHA replacement for all w/c. Figure 6 showing the 28-day compressive strength indicates that 0.6 w/c RHA mortars have lower compressive strength compared to control mortar. The maximum strength values are shown by w/c 0.50. 0.65 and 0.6 at 5% RHA replacement at 7, 28 and 60 days of

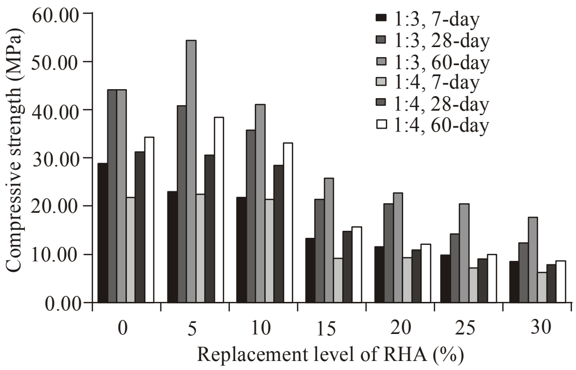

Fig. 8: Comp. strength variation for 0.60 W/C mortars at different days of water curing

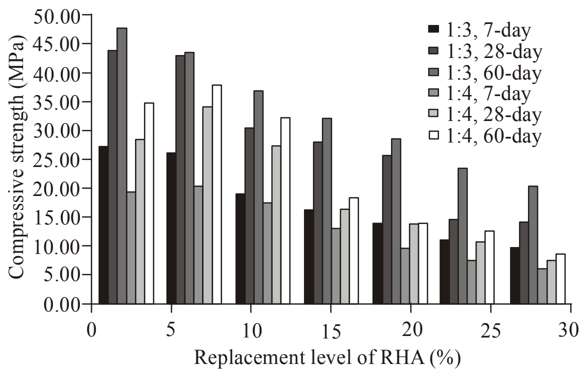

Fig. 9: Comp. strength variation for 0.65 W/C mortars at different days of water curing

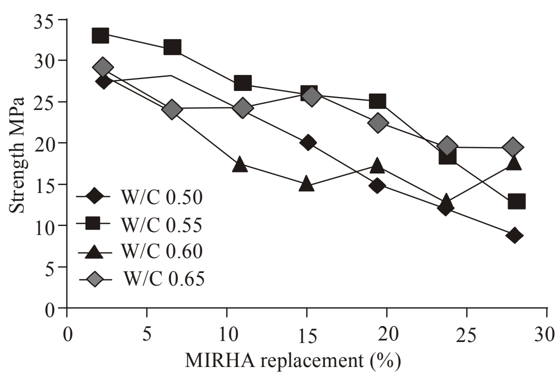

Fig. 10: 7-day compressive strength of 1:3 mortar

curing, respectively. The trend shown indicates that at 5% RHA replacement for 1:4 binder to sand ratio, the compressive strength is higher than respective control mortar except for 0.55 w/c RHA mortars.

At each age, the 1:3 mortars exhibit higher strength than 1:4 mortars, as expected.

The age wise strength development of the 0.6 and 0.65 w/c mortars are presented in Fig. 8 and 9 at different days of water curing. The compressive strength for all RHA mortars increases as the water curing period increases. The RHA mortars hardened due to hydration process that will only occur with the presence of water and at suitable range of temperature. The hydration process of cement and RHA is the chemical reaction between grains of both cement and RHA with water to form the cement gel. This process proceeds until all the cement and RHA reaches their maximum degree of hydration or until all the space available for the hydration product is filled by cement gel, whichever limit is reached first. All the samples are having proper hydration process over time as their compressive strength show increasing trend at 7, 28 and 60-days, respectively of water curing.

It can be observed that the compressive strength of RHA mortars with 1:3 binder to sand ratio is relatively higher than 1:4 binder to sand ratio at all RHA replacement for both w/c of 0.6 and 0.65. Both binders have smaller grain sizes which increase their capability to fill up the voids between the fines aggregate and increase the compressive strength. The compressive strength for most of RHA mortars decreases as the RHA replacement increases. This happened as RHA that is used in this research have coarser grain size than cement. Therefore, the incorporation of higher percentage of RHA in the mixtures caused the mortars to contain more voids which reduce their compressive strength. Although few RHA mortars do not have compressive strength greater than the control one, they still can be applied as construction materials according to requirements specified in the standard. As per BS 6073 (1981), RHA mortars that have compressive strength greater than 8 MPa can be used as bricks. Moreover, in accordance to BS 6717 (2001), RHA mortars that have compressive strength greater than 49 MPa can be used as pavement blocks. It was observed that the strength for mortar increases from 7 days to 28 days of curing, as expected. However, it should be noted that there were decreased value of compressive strength from 28 to 60 days of curing in most of the mixes. This phenomenon might be due to the fact that a rise in the curing temperature speeds up the chemical reactions of hydration which appears to form products of a poorer physical structure, probably more porous, so that a proportion of the pores will always remain unfilled (Ungsongkhun *et al*., 2009). It could be justified by Sung-Sik (2010) that the concrete or mortar system becomes weak because, if water is added, calcium silicate hydrate C-S-H gel moves gradually farther away and as a result van der Waals forces become weak. Additionally, the moisture can weaken the union of Si-O-Si when stresses are applied and thus weakening the mechanical interlocking between particles as it acts as a lubricant.

MIRHA replacement: Figure 10 to 12 show that the strength of the mortar seems to decrease as the content of MIRHA increases for higher w/c ratios and vice versa for lower w/c ratios. Increasing water ratio is seen to increase the strength. The compressive strength of mortar with w/c of 0.55 and 0.6 shows consistent higher strength for different MIRHA replacement. Cement to

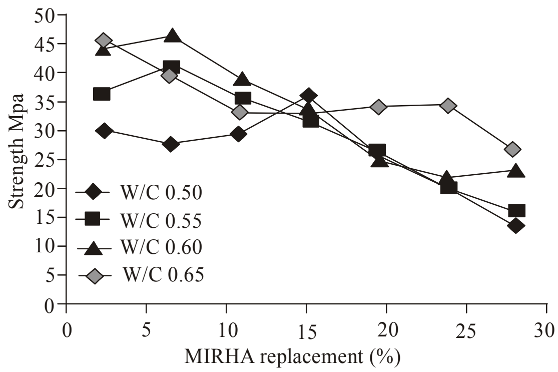

Fig. 11: 28-day compressive strength of 1:3 mortar

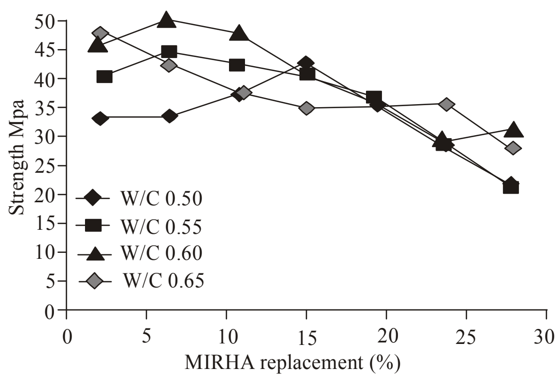

Fig. 12: 60-day compressive strength of 1:3 mortar

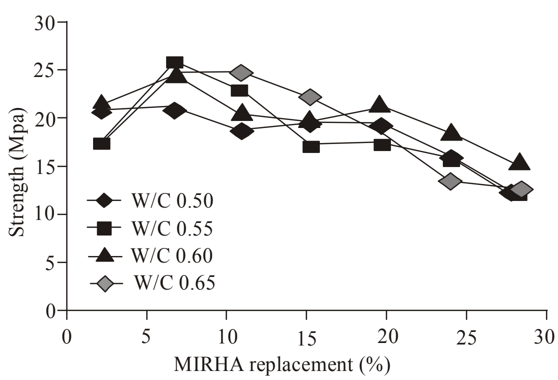

Fig. 13: 7-day compressive strength of 1:4 mortar

aggregate with ratio of 1:3 also has higher strength to 1:4. The 28-days compressive strength for 0.60 w/c mortar with 5% MIRHA replacement reached the highest strength compared to mortars of other water cement ratios. The trend of higher strength developed at 5% MIRHA replacement and decrease for higher MIRHA replacement is seen. This is follows the findings on MIRHA by Nuruddin *et al*. (2008). The 60-day compressive strengths for 1:3 MIRHA mortar shows maximum strength of 49.29 MPa at 5% MIRHA replacement. The decreasing trend of 0.65 w/c samples compared to 0.60 water cement samples indicates that

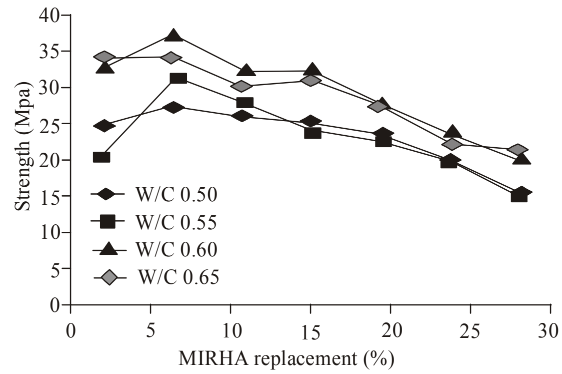

Fig. 14: 28-day compressive strength of 1:4 mortar

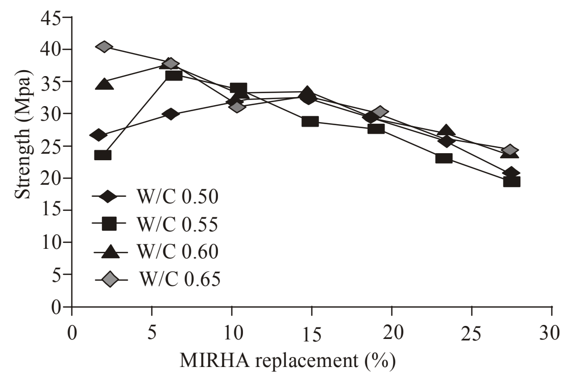

Fig. 15: 60-day compressive strength of 1:4 mortar

the optimum water cement ratio of MIRHA mortar for binder to sand ratio of 1:3 is 0.60. The figures indicate increasing trend of strength from 0.50 until 0.60 w/c and decrease at 0.65 water cement ratio. The highest strength of mortar could be between w/c 0.60 and 0.65. Figure 13 to 15 shows the compressive strength of 1:4 mortars; indicating highest compressive strength at 5% MIRHA replacement. The highest 7-days compressive strength for 1:4 mortar is with 5% MIRHA replacement and 0.55 w/c with value of 25.3 MPa. For 28-day compressive strength. Similar to 1:3 MIRHA mortar, the mortar with w/c 0.60 have the high strength for 28-days compressive strength test with the highest compressive strength test value of 37.14 MPa. The decreasing strength of mortar at w/c 0.65 can be seen in the graph. Therefore, it can be concluded that the optimum strength of mortar samples at 28-days is the mortar with 5% MIRHA replacement and w/c 0.60. Figure 15 shows the 60-days compressive strength for 1: MIRHA mortar. The optimum strength of mortar is shared between water cement ratio of 0.60 and 0.65 with the compressive strength value of 37.44 MPa. The result of 0.65 water cement ratio mortar is decreasing compared to the control mortar. This result can be interpret as the water cement ratio increase until it reaches the optimum value for MIRHA mortar, the excess water in the mortar will result to decrease of

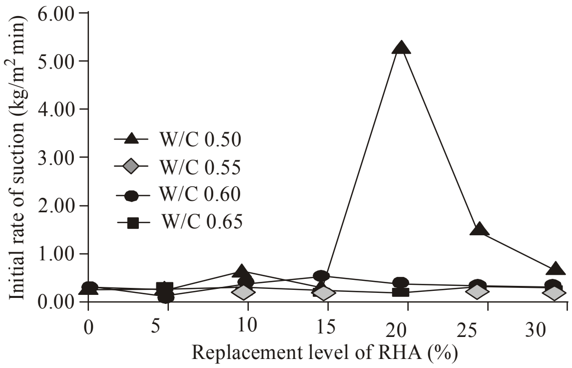

Fig. 16: IRS variation for 1:3 RHA mortar

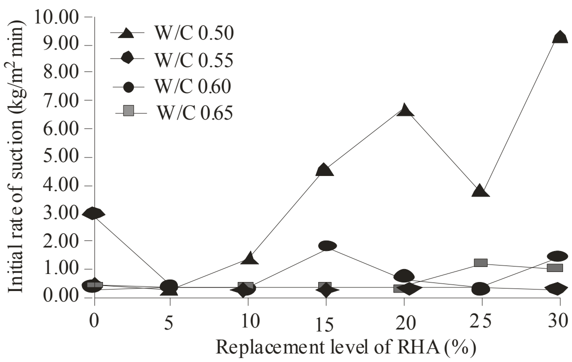

Fig. 17: IRS variation for 1:4 RHA mortar

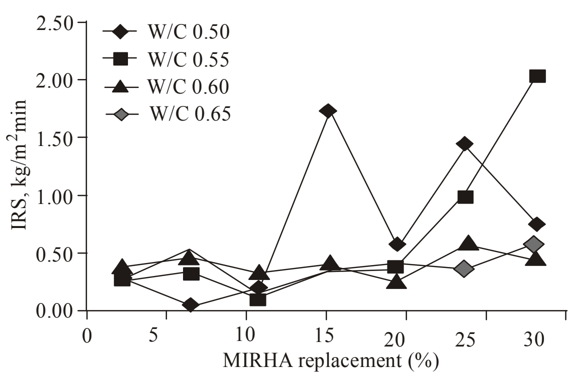

Fig. 18: IRS results of 1:3 MIRHA mortars

compressive strength of the mortar itself. Based on the result, generalization on higher water cement ratio the lower the strength of samples after the optimum water cement ratio of sample is obtained can be made. The strength of 1:3 w/c 0.5 MIRHA mortar keeps increase until 15%. W/c of 0.55 consistently have a higher strength compared to the 0.5 water ratio. Mortars with cement to aggregate ratio of 1:3 has higher strength compared to 1:4.

Initial rate of suction: Figure 16 to 19 shows the IRS values for 1:3 and 1:4 RHA and MIRHA mortars. The

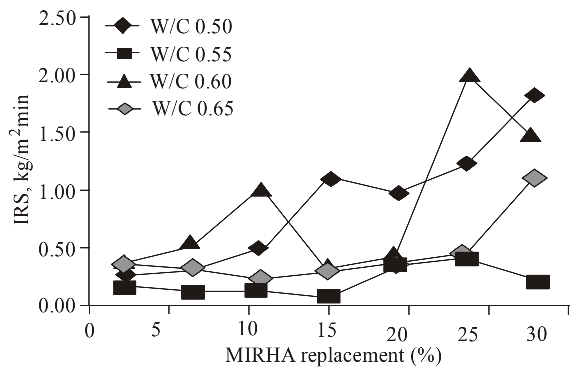

Fig. 19: IRS results of 1:4 MIRHA mortar

mortars in this investigation have a mean IRS within the specified limit of 0.25 to 1.5 kg/m^2.min which is ideal to be used as brick. Figure 16 shows that the IRS values for 1:3 RHA mortars with varied w/c are within the acceptable limit of 0.25 to 1.5 kg/m^2.min as specified in the standard. The 0.5 w/c mortar with 20% RHA replacement has IRS value that exceeds the acceptable limit. It shows that at this replacement level, the RHA mortar has a high capacity of initial suction that will affect the bonding strength between RHA bricks and mortar in construction. Figure 17 shows the that IRS values for 1:4 RHA mortars with various w/c are within the specified limit. However, 0.5 w/c RHA mortars have IRS values that exceeded the specified limit. This might happened due to porous surface of the samples. Lower w/c in the mixtures caused lower workability during the mixing as RHA absorbed more water quickly due to its high fineness. As workability decreases with increase in RHA replacement, the IRS values for 0.5 w/c mortars increases with the addition of RHA. Both 1:3 and 1:4 RHA mortars at various w/c have acceptable value of IRS. This represents the capability of these RHA mortars to be used as bricks as they contribute towards their bonding strength with the mortar. The appropriate bond strength can be achieved by these RHA bricks when they are used in the masonry construction. The low and high suction IRS values of RHA bricks will affect the bonding properties and thus, they are not suitable to be used as brick in the construction.

The IRS for 1:3 MIRHA mortar bricks ranged from 1.4 to 2.0 kg/min.m^2 indicating high suction property thus implying the necessity of wetting bricks before bricks layering (Ali, 2005). Based on the initial rates of suction for bricks, the mortar samples of 0.60 and 0.65 water cement ratio are all classified as low suction property which is good for application as bricks. From Fig. 19, the IRS of almost all samples was under the value 1.4 kg/min.m^2 which is acceptable. Based on observation during conducting the test, the surface of sample also affects the value of IRS. It was observed that, with the increase value of MIRHA replacement,

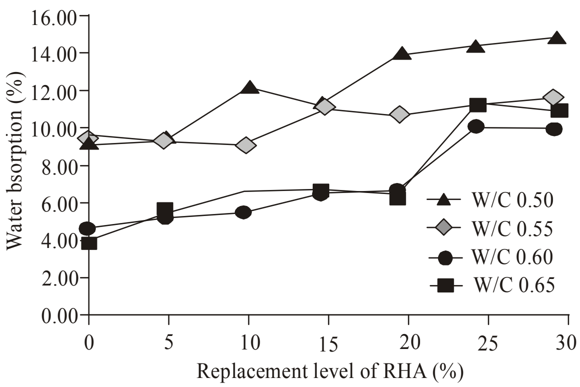

Fig. 20: 1:3 RHA mortar water absorption variations for different W/C

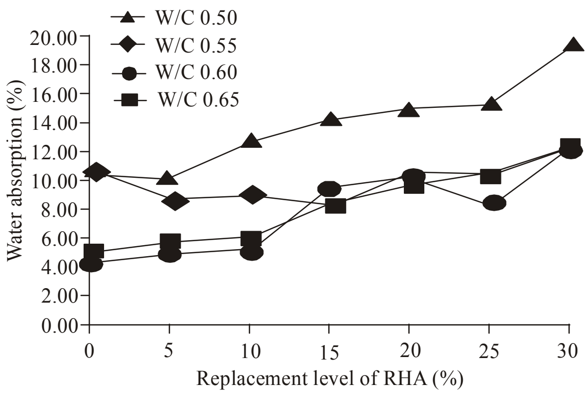

Fig. 21: 1:4 RHA mortar water absorption variations for different W/C

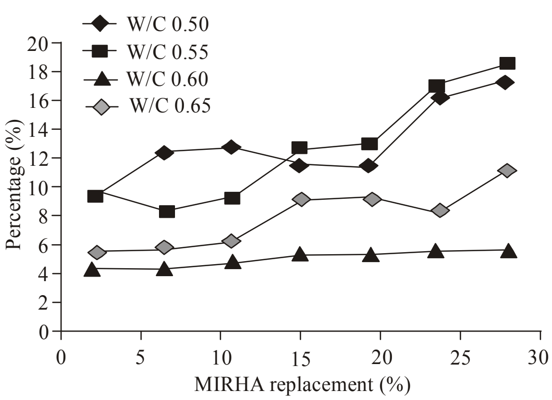

Fig. 22: 1:3 MIRHA mortars water absorption variations for different W/C

the workability of mixes become lower and effect casting process. Therefore, it is concluded higher the pores, the higher IRS value. For 0.65 w/c ratio samples, the workability of all mix during mixing were high for all samples which indicating high access of water in the samples. Less pores at the surface of samples 0.65 compared to samples 0.60 water cement ratio.

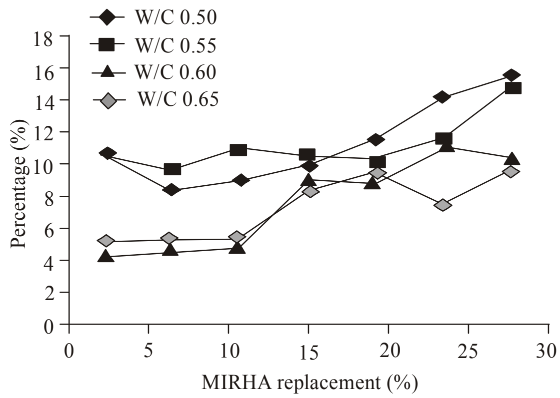

Fig. 23: 1:4 MIRHA mortars water absorption variations for different W/C

Furthermore, the workability of samples is very low due to the extra presence of sand and low amount of binders. Percentage of MIRHA in mortar affects the IRS rate because the higher amount of MIRHA, the higher the value of IRS. It may be one of the characteristic of MIRHA to absorb water faster in early minutes.

Water absorption: Figure 20 and 21 shows that water absorption values of most RHA mortars are higher than control mortar (0% replacement). This is due to the permeability of the RHA mortars. During the mixing of RHA mortars, the workability of RHA mixtures at same w/c was observed to decrease as the replacement level RHA increased. The lower workability of RHA mortars when the RHA replacement increases happened as RHA absorbs more water which resulted in mixtures that have lower workability. RHA used in this research has also coarser grain size than cement. The incorporation of RHA in the mixtures in higher percentage causes the final products to contain more voids and increase their permeability to liquid. The increment in permeability causes the RHA mortars to absorb more water when the replacement level of RHA increases.

Figure 22 and 23 shows the water absorption test results of 1:3 and 1:4 MIRHA mortars. The 1:3 MIRHA mortar of w/c 0.60 and 0.65 have less pores than samples with w/c 0.50 and 0.55. The reason of higher values of water absorption tests are due to pores in 1:3 MIRHA mortar of w/c 0.50 and 0.55. Less workability of samples during casting were the main reasons of pores. The mortar cubes are oven dried for more than 24 h, at temperature of 110°C and the water inside the samples have dried out. The pores inside the mortars depend on the water cement ratio of the mixes. Since 0.65 is higher than 0.60, the pores inside 0.65 water cement ratio sample are suppose to be higher. As the content of MIRHA in 1:4 mortars increases, the water absorption increases and may be up to 18%. Water absorption is higher in 0.55 W/C MIRHA mortars

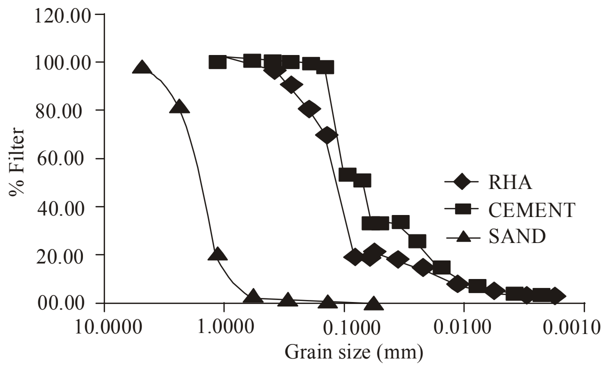

Fig. 24: Particle size distribution of RHA, cement and sand (Anwar, 2011)

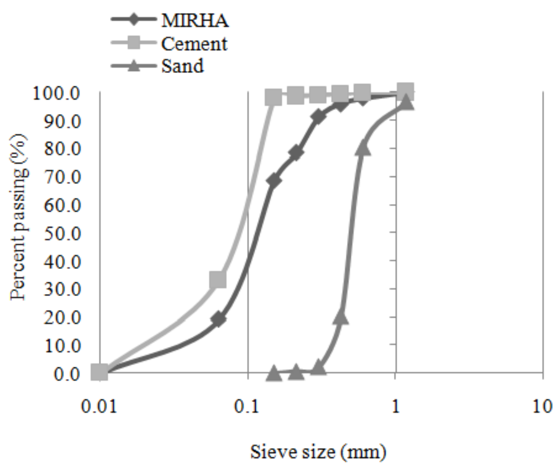

Fig. 25: Particle size distribution MIRHA, cement and sand

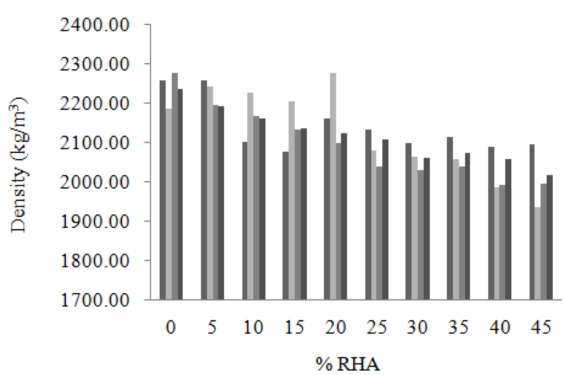

Fig. 26: Density of RHA mortars

compared to the 0.5 W/C ratio samples maybe because of the high amount of water content inside of the sample.

Partice size distribution: Figure 24 and 25 show the particle size distribution of materials used in RHA and MIRHA mortar respectively using sieve analysis and hydrometer tests. Cement is the finest material among all constituents of the mixture. RHA has coarser grain size but it is really close to cement. Sand is the coarsest material that is used in the experiment research. Previous researches show that substitution of pozzolans for part of the cement reduces permeability and porosity in mortar. The pozzolanic materials can contribute to the filling and segmentation of the capillary voids as they produce more identical products of hydration compared to cement alone. Thus, the incorporation of pozzolanic materials in the mortar mixtures will help producing dense and impermeable mortar and also more durable mortar. However, the use of coarser RHA than cement might cause these mortars to have higher permeability in porosity than the mortars that used finer RHA. The graphs also show that the water absorption is lower when the w/c is higher for both 1:3 and 1:4 RHA mortars. Higher w/c gives adequate water that helps the hydration of the pozzolanic materials. The precipitation of cement gel products during hydration process is greater in the presence of pozzolanic materials. This process helps to block the pores more effectively and thus reducing the permeability and porosity of the mortar. Thus, the RHA mortars with higher w/c tend to have lower water absorption value compared to RHA mortars with lower w/c. Sand has a larger particle sizes compared to MIRHA and cement while cement has the smallest particle sizes. At the bottom of each pan, the weight retained for MIRHA after passing the 0.063 mm is 29 g, weight retained for cement 49.4 g and sand has no particle that pass through the 0.063 mm.

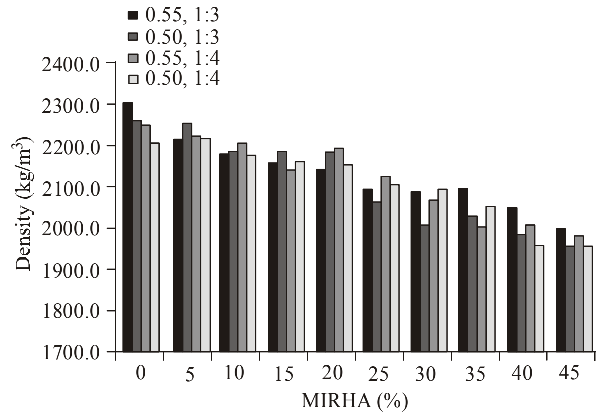

Fig. 27: Density of MIRHA mortars

The density also plays a part in relation to the strength of the mortar. Both strength and density show decrease with increase of RHA or MIRHA content in the mortar (Fig. 26 and 27).

CONCLUSION

The conclusions from the study addressing the stated objectives are presented below:

- The compressive strength of most RHA mortars decreased when the RHA replacement is increased. This is due to the coarser grain size of RHA than the cement which produced porous surface and more voids inside the mixtures. For 1:3 RHA mortars, the incorporation of RHA in varied w/c did not give significant contribution to the properties of the mortars. Based on 28-day results, all 1:3 RHA mortars have compressive strength lower than the respective control mortars. The addition of RHA in 1:4 mortars produced significantly results. At 5% RHA replacement, all samples have compressive strength higher than control mortars with 0.65 w/c RHA mortar having the highest compressive strength which is 37.23 MPa. However, 0.6 w/c RHA mortar recorded lower compressive strength than control mortar at all RHA replacement. Although several mortar mixtures did not have compressive strength higher than control mortar, they can still be used as bricks or pavement blocks according to several standards. MIRHA mortar with c:s ratio 1:3 consistently has higher strength than the ratio of 1:4. The strength of 1:3 MIRHA mortar at 7, 28 and 60 days, respectively shows variable performance with only w/c 0.55 and 0.6 showing increase in strength at 5% replacement. 1:4 MIRHA mortar consistently showed higher strength at 5% replacement for all w/c ratios.

- Most of the samples showed IRS between 0.25 to 1.5 kg/m^2.min which is within the acceptable limit. Mortars with IRS lower than 0.25 kg/m^2.min and greater than 1.5 kg/m^2.min are not suitable to be used as brick as their properties will affect the bonding strength between bricks and mortar. The IRS for 1:3 MIRHA mortar bricks ranged from 1.4 to 2.0 kg/min.m^2 indicating high suction property thus implying the necessity of wetting bricks before bricks layering. Based on the initial rates of suction for bricks, the mortar samples of 0.60 and 0.65 water cement ratio are all classified as low suction property which is good for application as bricks. The IRS of almost all samples in 1:4 MIRHA mortars were under the value 1.4 kg/min.m^2 which indicates acceptable value for IRS test; except for higher MIRHA replacement values. The percentage of MIRHA in mortar affects the IRS rate because the higher amount of MIRHA, the higher the value of IRS. It may be one of the characteristic of MIRHA to absorb water faster in early minutes.

Most of RHA mortars in this research have higher water absorption value compared to control mortar and the value increases when the RHA replacement is increased. This happened because the RHA is coarser than cement and its incorporation in the mortar mixtures produce more voids. Thus, when more RHA is added, more voids are produced which translate into higher permeability mortars. The addition of RHA into mortars also increases the water absorption due to the property of the pozzolanic material to absorb more water for hydration process. Thus, insufficient w/c will affect the mixing process which results in more voids in the samples. It can also be concluded that as the w/c increases, the water absorption decreases until it reaches the optimum w/c which is 0.6 in this case. 1:3 MIRHA mortar of w/c 0.60 and 0.65 have fewer pores than samples with w/c 0.50 and 0.55.

RHA has a larger particle sizes compared to cement while sand has the largest particle sizes. Sand has a larger particle sizes compared to MIRHA and cement while cement has the smallest particle sizes.

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