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MECHANICAL PROPERTIES AND DURABILITY OF MORTAR WITH RICE HUSK ASH CALCINED AT LOW TEMPERATURE

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Abstract

In past studies, rice husk ash (RHA) calcined at 1000 °C or higher was found active. They can be alkali-activated or induce pozzolanic reactions in cement hydrates. However, calcination at high temperature consumes much energy. In addition, most RHA is produced at an open-aired site. The burning temperature cannot be so high even in a power plant. In view of these issues, this study explores the mechanical properties and durability of mortar in the presence of RHA produced at low temperature. During the experiments, the rice husk was calcined under different temperature (400-1000 °C). Results showed that the properties of the RHA met the requirements in ASTM C618. Then, the mortar was prepared at w/c of 0.6, the cement in mortar was replaced by RHA by 5%-20% by volume, and the compressive strengths of the mortar were conducted. The 10% was found the optimum. Specimens with RHA calcined under 800 had higher strengths higher than those with RHA calcined at 1000 °C. However, the specimens with RHA calcined at 400 °C had the highest compressive strength at all ages possibly due to high remaining carbon content which absorbed water and reduced the w/c. Further results also showed that the shrinkage did not change significantly with the calcining temperature and dosage of the RHA, but the expansion due to alkali-silica reaction was effectively inhibited at 10%. RHA calcined by 400 °C had the best inhibition on expansion due to alkali-silica reaction (ASR) than that calcined by 800 °C or 1000 °C.

Keywords:

Rice husk ash, Calcining temperature, Shrinkage, Alkali-silica reaction, Compressive strength

1 INTRODUCTION

Portland cement is widely used in civil engineering. However, much carbon dioxide is released during the manufacture and aggravates the global warming. With the consideration of the environmental sustainability and the cost reduction for the cement productions, many past studies focused on reducing the cement dosages in concrete by admixtures. On the other hand, the rice is stable food in most Asian countries, but its husks are largely produced annually and occupy much space as a waste. Therefore, to resolve this issue, some rice husks are used for fertilizers or soil improvements. But, such utilizations only deal with small amounts of waste husks. It is necessary to develop new ways of treating rice husks.

Rice husk is composed of 50% cellulose, 25-30% lignin, and 15-20% silicon [Siddique 2008]. After burning, the cellulose and lignin were away, leaving ashes containing silica and minor elements. Rice husk ash (RHA) is a good pozzolanic material like silica fume and can be used in concrete. Since the RHA has great specific surface area and porous microstructure, the pozzolanic effect is increased by the fineness [Mehta 1978]. It was suggested that the replacement of RHA for the Portland cement in concrete was 10-20% to improve the properties of concrete [Ismail 1996]. It was found that the early strength of concrete was increased, but the long-term strengths depended on the calcining conditions of the RHA [Rodríguez de Sensale, G. 2006]. It is likely calcining temperature influences the RHA compositions. The X-ray diffraction analyses showed that the elemental oxides in the RHA was changed by the calcining temperature [Hwang 1989]. Some studies showed that the amorphous silica appeared at calcining temperature of 500 °C, 680 °C sustaining for 1 min. or more, or 900 °C sustaining less than 1 hr. [Mehta 1978, Yeoh et al. 1979, Zain et al. 2001] further showed that the silica was almost amorphous at calcining temperature of 900 °C [Zain et al. 2001]. The crystalline silica existed at calcining temperature of 1000 °C.

In view of the need for waste reduction and utilizing the pozzolanic properties of RHA, this study further explores the influences of RHA on the properties of mortar. In contrast to the past studies, lower temperature and open-air calcination were applied to simulate the most burning conditions in the field.

2 MATERIALS AND METHODS

2.1 Materials

This study used Type I Portland cement in accordance to ASTM C150 and the fine aggregates crushed from the river stones. The calcined RHA was produced from the japonica rice grown in I-Lan County, Taiwan. After the calcination, the ashes were ground using a ball miller. The particle size distribution is shown in Fig. 1. The ashes had average size in diameter at D_{50}=5.57 μm for 400 °C, D_{50}=4.67 μm for 800 °C, and D_{50}=4.31 μm for 400 °C, all of which were smaller than the Portland cement.

Tab. 1: Mix design for the mortar specimens (unit: kg/m3)

RHA replacement	Cement	Water	Fine aggregates	RHA	Superplasticizer (%)
0%	358	243	1717	0	0.25
5%	340	243	1717	13	0.25
10%	323	243	1717	25	0.25
20%	287	243	1717	51	0.25

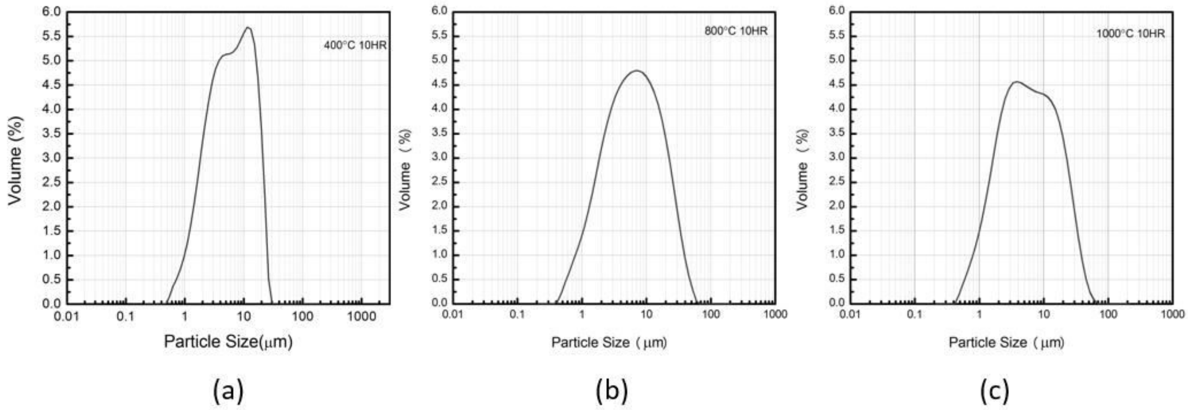

Fig. 1: Particle size distribution of RHA calcined at (a) 400 °C, (b) 800 °C, and (c) 1000 °C.

2.2 Methods

The ashes were prepared using an open-aired furnace, in which burning temperature in chamber was maintained at 400, 800, or 1000 °C and the burning time was controlled at 10 hours. The properties of ash were determined by the X-ray fluoresce (XRF) and X-ray diffraction (XRD). In mortar specimens, portions of cements were replaced by the ashes by 0-20%. Cubic specimens of 50 mm×50 mm×50 mm were prepared for the compressive strength tests. The mix design is shown in Tab. 1. The specimens were cured in saturated lime water until the time of tests. Prismatic specimens of 50 mm×50 mm× 260 mm were prepared for the shrinkage tests in accordance to ASTM C596 and accelerated alkali-silica reaction (ASR) tests in accordance to ASTM C1260. The water-cement ratio of the specimens in the shrinkage and ASR tests were maintained at 0.6.

3 RESULTS AND DISCUSSION

3.1 Effect of calcining temperature

XRD patterns in Fig. 2 showed high peaks at around 22° and 23° in 2θ, which corresponded to the phase of SiO_2, in RHA specimens calcined at 400 °C, 800 °C, and 1000 °C for 10 hours. However, the patterns of RHA calcined at 400 °C showed a great portion of amorphous phases. It appears that there were lots of unburned residues, such as lignin, and cellulose. These residues were not welled detected by XRD. At high calcining temperature, the residues were vaporized so the crystalline silica dominated.

3.2 Compressive strengths

RHA calcined at 800 °C

The compressive strengths of the mortar specimens with RHA calcined at 800 °C are shown in Fig. 3(a). It was found that the 28-day compressive strengths of the specimens with replacements of 5% and 10% were lower than those of the plain. In the long term, the compressive strengths were gradually increased and close to those of the plain, suggesting the occurrence of the pozzolanic effects. However, in specimens with replacement of 20%, the compressive strengths were always low. It is likely that the pozzolanic effect by the RHA could not compensate the loss of strength due to the reduction of cement.

RHA calcined at 1000 °C

The compressive strengths of the mortar specimens with RHA calcined at 1000 °C are shown in Fig. 3(b). It was found that the 28-day compressive strengths of the specimens with replacements were also lower than those of the plain. Although the long-term strengths were increased, they were still lower than the plain. When compared with those with RHA calcined at 800 °C, the compressive strengths of the specimens with RHA calcined at 1000 °C were slight slower, suggesting that the presence of the crystalline SiO_2 did not improve the compressive strengths. It is likely that the amorphous silica were more active so the hydration was increased. In summary, it is presumed that the 10% is the optimum replacement for the mortar specimens with RHA, but the reduction in early strength could not be recovered in the long term.

RHA calcined at 400 °C

The compressive strengths of the mortar specimens with RHA calcined at 400 °C are shown in Fig. 3(c). In contrast to the results of the specimens with RHA calcined at 800 °C and 1000 °C, it was found that the 28-day compressive strengths of the specimens with all replacements were higher than those of the plain. Such high strengths were unusual. It is quite likely that the RHA calcined at 400 °C remained lots of organic matters, which absorbed water and reduced the w/c.

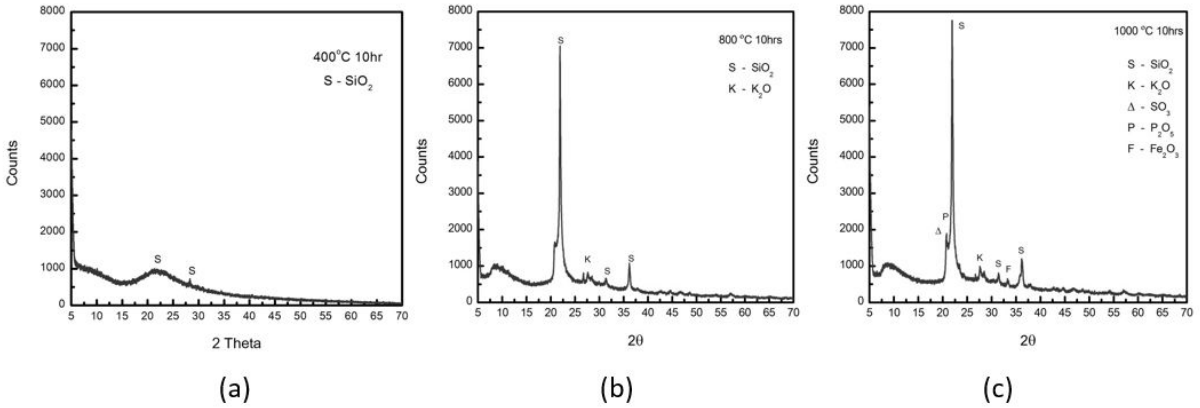

Fig. 2: XRD patterns of RHA calcined at (a) 400 °C, (b) 800 °C, and (c) 1000 °C

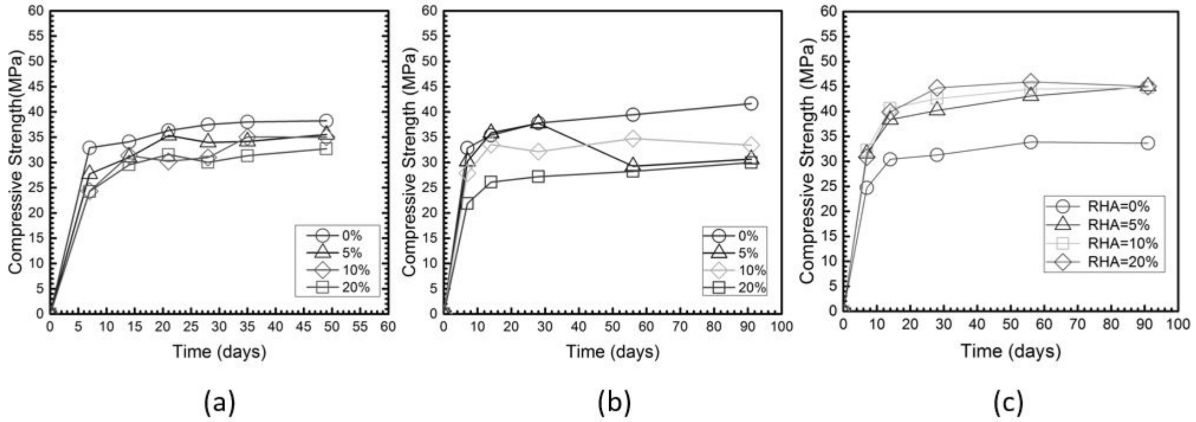

Fig. 3: Compressive strengths of mortar specimens with RHA calcined at (a) 800 °C, (b) 1000 °C, and (c) 400 °C

3.3 Shrinkage

The results of shrinkage tests are shown in Figs. 4 and 5. With specimens calcined at 800 °C, the lengths were not changed apparently during the first day of water curing. The major shrinkage occurred during the air-curing. When the RHA replacement reached 20%, the shrinkage was only 0.1%, close to the plain. Such results suggested that the RHA did not change the shrinkage of the mortar but reduce the consumption of cement.

With the specimens calcined at 1000 °C, the shrinkage was increased until 60 days. The shrinkage of the plain specimen was 0.04% without noticing differences from those with 5% or 10% RHA replacement. The specimen with 20% RHA replacement had shrinkage as little as 0.035%, implying that the shrinkage in mortar was not influenced by the RHA even at replacement of 20%.

3.4 Alkali-silica reaction

RHA calcined at 800 °C

The results are shown in Fig. 5(a). In all specimens, the expansion increases as the immersing time increases. When compared with the plain specimens, the expansions were reduced by the RHA replacements. At age of 21 days, the expansion of the plain specimen was 0.85%, 0.55% in those with 5% replacement, 0.1% in those with 10% replacement, and only 0.02% in those with 20% replacement. Such results suggested that the ASR expansion was effectively inhibited by 10% replacement, which reduced the expansion by 88%. With 20% RHA replacement, the ASR expansions were mostly inhibited.

RHA calcined at 1000 °C

The results are shown in Fig. 6(a). The expansion was 0.7% in those specimens with 5% replacement, 0.12% in those with 5% replacement, and only 0.03% in those with 20% replacement. Again, the RHA calcined at 1000 °C effectively inhibited the ASR expansion.

RHA calcined at 400 °C

Since both RHA's calcined at 800 °C and 1000 °C showed great inhibition on ASR expansion at replacement of 20%, the effect of RHA calcined at 400 °C on the ASR expansion was tested at replacement of 20%. Results are shown in Fig. 6(b). Most of the ASR expansions were reduced, similar to the behaviors of the specimens with RHA's calcined at 800 °C and 1000 °C.

In summary, calcined RHA's inhibited the ASR expansion and such inhibition was associated with the amount of replacement and calcining temperature. The expansion was reduced as the replacement was increased because cement was decreased and the RHA was not as highly alkaline as the cement. So, the ASR expansion was reduced. On the other hand, the inhibition was more by RHA calcined at lower temperature. At 5% replacement, the RHA calcined at 800 °C reduced the expansion more than that calcined at 1000 °C by 10%. At 10% replacement, the RHA calcined at 800 °C reduced the expansion more by 0.7%. At 20% replacement, the RHA calcined at 400# reduced the expansion the most. Such results suggested that the compositions of the calcined RHA can be an issue. RHA calcined at lower temperature may have much residue carbon so as to reduce the w/c in mortar. In addition, the crystalline silica was less, which prevented from ASR.

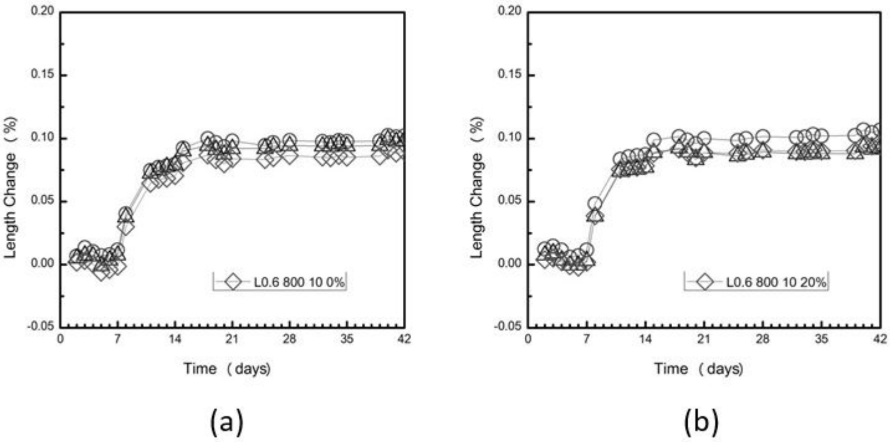

Fig. 4: Length changes of mortar specimens with RHA calcined at 800 °C at replacement of (a) 0%, and (b) 20%

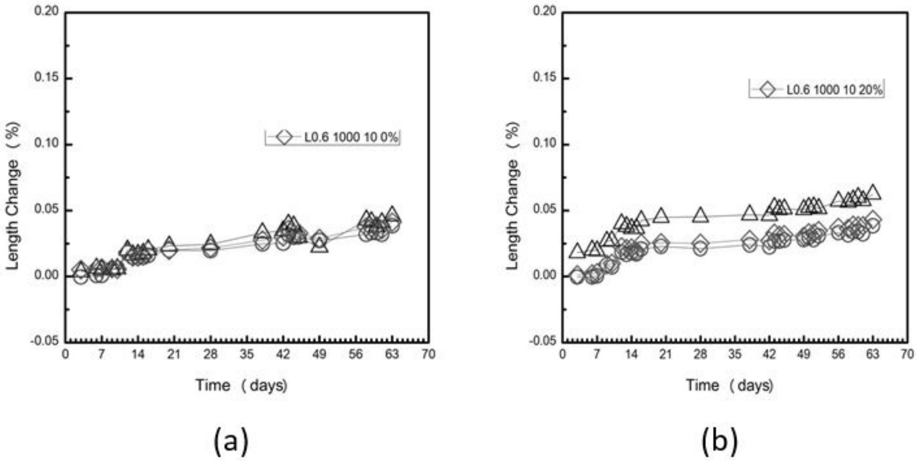

Fig. 5: Length changes of mortar specimens with RHA calcined at 1000 °C at replacement of (a) 0%, and (b) 20%

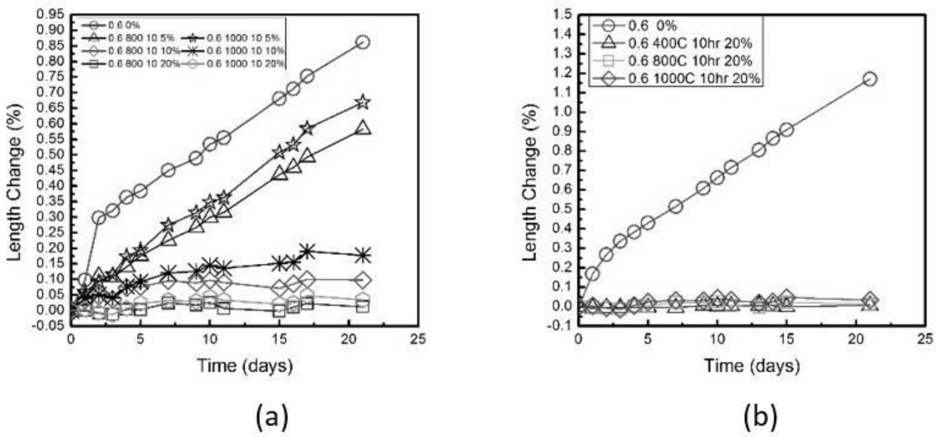

Fig. 6: ASR expansions inhibited by RHA calcined at (a) 800 °C and 1000 °C, and (b) 400#, 800 °C, and 1000 °C at 20% replacement

4 CONCLUSION

This study explores the mechanical properties and durability of mortar with cement partially replaced by the RHA. The results were summarized as follows:

1. The compressive strengths of the mortar specimens with RHA calcined at 800 °C or 1000 °C had similar strength reduction at early age. In the long-term, the compressive strengths of the specimens with RHA calcined at 800 °C were close or even higher than those in the plain specimens.
2. When the replacements were 5% or 10%, the shrinkages of mortar were not influenced by the RHA calcined by 800 °C or 1000 °C. But, the shrinkage was effectively reduced by 20% replacement.
3. The RHA significantly inhibited the ASR expansion, which were generally reduced by 35.3% at 5% replacement, 88% at 10% replacement, and 99% at 20% replacement. The inhibition was related to the calcining temperature of RHA. The highest inhibition was in the presence of RHA calcined at 400 °C, and the lowest was in the presence of RHA calcined at 1000 °C.

5 ACKNOWLEDGEMENT

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