ABSTRACT

The present work deals with the development of self-compacting concrete (SCC) containing rice husk ash (RHA), metakaolin (MK), and their combination (1:1 ratio). Several research studies have reported on the performance of RHA and MK blended SCC. However, very limited information is available on the permeability, acid, sulfate, and corrosion resistance characteristics of RHA, MK, and their combination blended SCC.

The objective of the present investigation was to evaluate RHA and MK as supplementary cementitious materials (in both binary and ternary systems) in terms of fresh, strength, water permeability, chloride ion permeability, acid (sulfuric and hydrochloric), magnesium sulfate, and corrosion resistance properties in blended cement SCC and to identify the optimal level of replacement of ordinary Portland cement (OPC) with RHA, MK, or RHA+MK. The blended cements were prepared by replacing OPC with RHA, MK, or RHA+MK (5–40%) in dry conditions. To that end, experiments were carried out in three phases, according to standard testing procedures.

In the first phase, the chemical composition, physical properties, and characterization of RHA, MK, and their combination were carried out. Tests of strength and the water permeability properties of the blended mortars were also evaluated. In the second phase, studies on the blended SCC specimens were conducted. RHA, MK, and RHA+MK SCC mixes and a
normal SCC mix were prepared with a constant water-to-binder ratio of 0.55 for a design mix. The tests conducted included fresh state properties, compressive strength, splitting tensile strength, ultrasonic pulse velocity, dynamic modulus of elasticity, water absorption, coefficient of water absorption, and sorptivity. In the third phase, the chloride, acid, sulfate, and corrosion resistance properties of the RHA, MK, and RHA+MK blended SCC were assessed.

This particular RHA consisted of 87.89% silica, and MK consists of 51.80% silica, mainly in amorphous form. The average specific surface area of RHA and MK were 36.47(BETs) and 2350 m$^2$/kg (Blain’s) respectively. The loss on ignition value of RHA and MK were 4.36 and 0.34% respectively. The density, specific gravity, and mean grain size of both RHA and MK are lower than those of OPC. Water required for standard consistency increased linearly with both RHA and MK content. The initial and the final setting time measured up to 30% RHA, 30% MK, and 40% RHA+MK were found to be within the permissible limits.

The test results obtained for the fresh properties showed that the slump flow and blocking ratio (L-box test) decreased with the addition of RHA and MK content. V-Funnel times increased with increasing the replacement levels of the RHA and MK content in OPC. All of the mixes exhibited satisfactory fresh state properties (according to the criteria established by EFNARC and previous studies), except for the 30% RHA, 30% MK, and 20% RHA +20% MK mixes.

Compressive strength, ultrasonic pulse velocity, and dynamic modulus of elasticity increased with RHA content up to 15%, MK content up
to 20%, and RHA+MK content up to 30% replacement level of normal SCC. Scanning electron microscopy with EDAX analysis on RHA, MK, and RHA+MK blended SCC revealed that reactions between silica present in RHA and MK and extra lime in OPC took place and yielded calcium silicate hydrate (C-S-H) (I) gel, giving it a denser structure. The development of strength in blended SCC is primarily attributed to the C-S-H (I) gel component.

Coefficient of water absorption, sorptivity, and chloride permeability were found to be enhanced in RHA, MK, and RHA+MK blended SCC compared with normal SCC. Improvement in the impermeability characteristics of the RHA and MK SCC specimens is attributed to the fineness and reactivity of the RHA and MK used. The chloride permeation in terms of total electrical charge passed was considerably reduced (more than 40%) in the RHA and MK blended SCC due to pore refinement and pozzolanic reaction in the blended SCC.

The results from the specimens exposed to 5% sulfuric acid ($\text{H}_2\text{SO}_4$) showed that the SCC blended with RHA and RHA+MK was the most resistant against sulfuric acid attack, compared to the SCC blended with MK. Unexpectedly, the MK blended SCC showed a negative effect on sulfuric acid resistance behavior. The results of the blended SCC specimens exposed to 5% hydrochloric acid (HCl) solutions show that the lowest weight losses were obtained at the replacement levels of 20% RHA, 20% MK, and 15% RHA+15% MK. When the magnesium sulfate attack of the blended SCC was considered, the lowest weight losses were observed in 10% RHA, 20% MK, and 10% RHA+10% MK blended SCC. However, the weight losses of all
the blended mixtures were lower than that of the unblended SCC (NSCC-100% OPC). When considering the impressed voltage technique results, 15% RHA, 25% MK, and 30% RHA+MK blended SCC was found to have the maximum levels of replacement for the superior corrosion resisting characteristics of SCC.

Another interesting observation resulting from this study was the linear or polynomial relationships that exist among fresh, mechanical, water absorption, water sorptivity, and chloride penetration properties. The correlation between silica ratio (SR) and weight loss due to sulfuric and hydrochloric acid was also evaluated, and the results showed that the SR is perfectly correlated with weight loss due to the sulfuric acid attack of the blended SCC.

The test results conclusively established that percentages as high as 20%, 10%, and 30% by weight of OPC can be optimally replaced with RHA, MK, and RHA+MK, respectively, without any adverse effect on fresh, strength, and permeability properties, and acid (sulfuric and hydrochloric), magnesium sulfate, and the corrosion resistance of steel in SCC.