Construction and Building Materials 163 (2018) 482–495

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Effect of aggressive chemicals on durability and microstructure properties of concrete containing crushed new concrete aggregate and non-traditional supplementary cementitious materials

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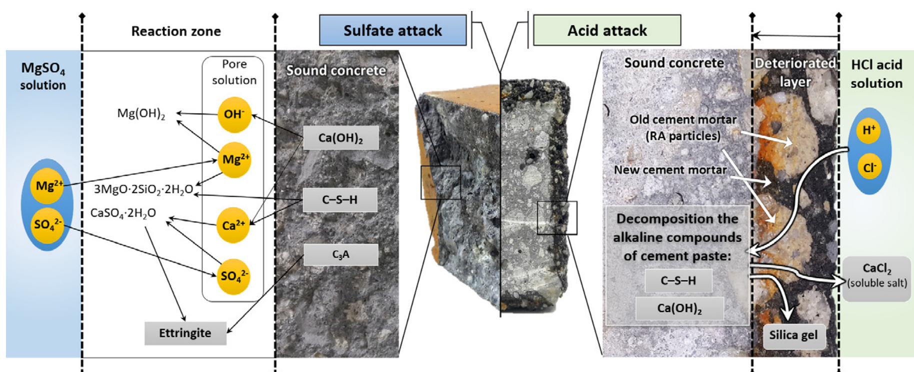
HIGHLIGHTS

- RHA, POFA and POCP were used as SCMs in concrete made of RA.
- The deterioration depth caused by acid was 2–4 times less for SCMs-based concrete.
- Less propagation of micro-cracks observed for SCMs-based concrete attacked by sulfate.
- The chemical compositions of concrete mixture is a significant factor affecting its performance.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 15 August 2017
Received in revised form 9 December 2017
Accepted 12 December 2017

Keywords:
Concrete durability
Microstructure
Supplementary cementitious materials
Acid attack
Sulfate attack

ABSTRACT

The increasing awareness and usage of traditional supplementary cementitious materials (SCMs) in concrete have pressured the construction industry to look for alternatives to overcome the concerns over their plentiful availability in the future. This research illustrates the performance of recycled aggregate concrete prepared with the incorporation of available industrial by-products, namely rice husk ash (RHA), palm oil fuel ash (POFA) and palm oil clinker powder (POCP) as alternatives for traditional SCMs. The effect of hydrochloric (HCl) acid and magnesium sulfate ($MgSO_4$) attack was evaluated by measuring the change in mass, compressive strength and microstructural analysis. The results revealed that the incorporation of RHA, POFA and POCP up to 30% minimizes concrete deterioration and loss in compressive strength when the specimens were exposed to HCl solution. In addition, the scanning electron microscopy image showed less propagation of micro-cracks caused by expansive ettringite in the case of $MgSO_4$ attack. Further, the X-ray diffraction analysis indicated that RHA is more effective as pozzolanic additive than POFA and POCP. Overall, the RA-based concrete had significant enhancement in its performance against acid and sulfate attacks using alternative SCMs from industrial by-products.

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https://doi.org/10.1016/j.conbuildmat.2017.12.106
0950-0618/

lower calcium content than 100% OPC-based concrete (Table 6 and Fig. 22). The decomposition of cement matrix attacked by acid is primarily due to the release of calcium from the hydration products and, only at very low pH values, due to the release of aluminium and iron [57]. Bassuoni and Nehdi (2007) [59] revealed that the C–S–H structure with high CaO/SiO_2 ratio is more vulnerable to acid attacks, and on the contrary, the decomposition of C–S–H with low CaO/SiO_2 ratio occurs at slower rate. Additionally, Chatveera and Lertwattanaruk (2011) [22] concluded that the chemical composition and the CaO/SiO_2 ratio in concrete mixture are important factors for evaluating the effect of acid attacks. Consequently, the C–S–H that produced with low CaO/SiO_2 ratio is less susceptible to decompose (release of calcium), since it has a crystalline structure with low amounts of calcium. These observations also support the results of this study, where the superior performance was recorded for concretes containing low CaO/SiO_2 ratios (refer to Table 6, Figs. 14 and 16).

3.7.3. Effect of chemical composition on sulfate attack

The position of concrete mixture on the $CaO–Al_2O_3–SiO_2$ ternary diagram could be useful to determine its sulfate resistance. For instance, if the concrete mixture falls within the gehlenite region as shown in Fig. 22, it typically has a low resistance against sulfate attacks [60]. This could be related to the high C_3A content in this region, where C_3A is considered as the reactive compound responsible for ettringite formation. However, the results of this study showed that the SCM-based concretes have lower CaO content than that of RAC, and thus, the resulting content of reactive C_3A will be reduced. Therefore, in this ternary diagram, one would expect to see a shift of the SCM-based concrete mixtures away from the gehlenite region. Donatello et al. (2013) [41] revealed that the CaO content of pastes incorporating high volume fly ash is much lower as a direct consequence of the lower OPC content and higher fly ash content. They stated that the substantially higher C_3A content in the OPC paste made it more susceptible to sulfate attacks.

4. Conclusions

This investigation mainly focused to observe the effect of SCMs incorporation on recycled concrete composite under acid and sulfate attacks from the aspects of microstructure and durability characteristics. Based on the experimental program conducted, the following conclusions can be drawn:

1. The obtained strength and durability of concrete made of 100% RA were lower than that containing crushed granite aggregate. However, RAC still possessed sufficient compressive strength of 35.8 MPa or about 79% of the same concrete containing crushed granite aggregate.
2. The utilization of RHA, POFA and POCP to replace cement at levels of up to 30% is feasible, since the designed strength of 30 MPa was achieved after 90 days of water curing.
3. The capillary water absorption (sorptivity) of RA-based concrete was decreased significantly after long curing period of 90 days using RHA, POFA and POCP at replacement levels of up to 30%, 20% and 10%, respectively. The effect of the aforementioned SCMs on the sorptivity was via the formation of additional C–S–H gel, which has the potential of blocking existing micro-voids and refining pore structure.
4. After exposure to HCl acid solution, the RA-based concrete containing RHA, POFA and POCP showed superior performance against deterioration, mass loss and strength loss due to low amount of $Ca(OH)_2$, which is very weak in resisting acid attack.
5. The SEM images showed that the incorporation of RHA, POFA and POCP was able to minimize the deterioration of RA-based concrete exposed to $MgSO_4$ solution due to the formation of dense microstructure that inhibits the ingress of sulfate ions and reduces the formation of expansive ettringite, which in turn leads to less propagation of micro-cracks.
6. The XRD results showed that incorporation of SiO_2-rich SCMs decreased the amount of portlandite and formed more C–S–H. Moreover, the XRD analysis indicated that RHA is more effective as pozzolanic additive than POFA and POCP, where RHA-based samples showed the lowest trace of portlandite.
7. The proportion of chemical compositions in concrete mixture is a significant factor affecting the performance of concrete attacked by aggressive chemicals. SCM-based concrete with SiO_2-rich content is characterized by lower calcium content than 100% OPC-based concrete. Thus, the hydration products are less susceptible to decompose (release of calcium) when exposed to acid. In addition, the content of reactive C_3A will be reduced, where the latter is considered as reactive compound responsible for the formation of ettringite.

Acknowledgement

The authors are grateful to University of Malaya for the financial support through the University of Malaya Research Project-RP037A-15AET ‘‘Enhancement of Concrete Properties Made from Local Waste Materials Using Nano Particles”.

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