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Sustainability on durability of self compacting concrete from C&D waste by improving porosity and hydrated compounds: A microstructural investigation

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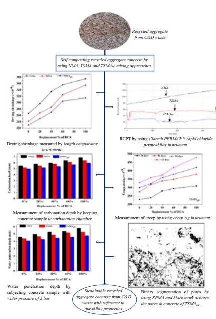
HIGHLIGHTS

- Sustainable concrete from C&D wastes with reference to durability properties.
- Modified two stage mixing approach ($TSMA_{sfc}$) by using silica-fume and fly-ash.
- Improvement of microstructures by adopting modified two stage mixing approach ($TSMA_{sfc}$).
- Quantitative microstructural investigation for measuring porosity and hydrated compounds.

GRAPHICAL ABSTRACT



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ABSTRACT

This research article is on establishment of sustainability with reference to the durability properties of self compacted recycled aggregate concrete (SCRAC) by improving porosity and hydrated compounds in concrete. Partial replacement of fly ash by silica fume and virgin concrete aggregate (VCA) by recycled concrete aggregate (RCA) are taken for preparing the SCRAC by adopting suitable mix design method along with proposed two stage mixing approach ($TSMA_{sfc}$). This two stage mixing approach makes significant improvement in durability properties as the slurry of cement and silica fume fills the pores and cracks and makes interfacial transition zones (ITZs) stronger. Microstructure analysis using the electron probe micro analyser (EPMA) is carried out to justify the reason of improvement of durability properties of SCRAC. Image analysis of backscattered secondary electron (BSE) images are carried out for the quantitative analysis of different compounds (C-S-H, UH, CH and pores) at the ITZ. Image analysis and EPMA analysis confirmed that the ITZ gets stronger by adopting two stage mixing approaches.

1. Introduction

In the recent years, due to growth of population and rapid urbanization, the demand on construction industry for infrastructural development has increased substantially. In the view of providing minimum maintenance, economy and increased life, it is anticipated to provide sustainable materials for construction. Further, modernisation of old construction leads to generate huge construction and demolition (C&D) waste. These C&D activities contains major amount of wastes from concrete. These concrete wastes can be recycled and can be used as aggregates. As, 70–75% of the concrete contains aggregate, recycling the demolition waste concrete can solve the issue of disposal problem, reduces the cost of concrete production and also solve the environmental impact because of aggregate production. This waste concrete can be used as recycled concrete aggregates (RCA) by breaking

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mechanically into small pieces using jaw crusher. The small sized concrete wastes will be then screened using sieves of standard sizes and separated into different sizes which is used for preparing recycled aggregate concrete (RAC). The sustainability of concrete production using such recycled aggregates can be further increased by producing self compacting concrete (SCC). The properties of the recycled aggregate concrete can be optimized for the better performance by producing the self compacting concrete with the use of admixtures like fly ash, silica fume and superplasticizer. The advantage of producing SCC lies in its ability to flow in its own weight without any need of compaction or vibration. Extensive research work [1–9] suggested that the RCA can be used for constructing new structures as experimental results presented that with proper mixing approaches and addition of admixtures, the RCA can attain the desired strength for both normally vibrated concrete as well as self compacting concrete.

Xuan et al. [10] evaluated mechanical properties and durability properties of RAC prepared with non-carbonated and carbonated RCA in terms of recycled aggregate concrete (RAC). It was indicated that the incorporation of the carbonated RCA in RAC helps to reduce the water absorption and permeability of RAC. Zhu et al. [11] investigated the durability properties of RCA using silane based water repellent agents. It was found that the durability properties of recycled aggregate concrete can be improved by using integral silane treatment, but using this treatment compressive strength was reduced. Kou and Poon [12] concluded that to overcome the lower quality of recycled aggregate, class F fly ash was used in the concrete mix design. Rao et al. [13] found that with the replacement of coarse natural aggregate (NA) by RCA, the water absorption capacity of concrete gradually increased. The water absorption capacity of RCA is 3.5 times higher than NA. Zega and Di Miao [14] concluded that the replacement of 20% and 30% by volume of fine NA with fine RCA the carbonation depth was similar of normal aggregate concrete (NAC) and RAC. Limbachiya [15] noted that by replacing 30% of VCA by RCA, the creep strain was almost equal for 30 MPa of design strength. Evangelista and De Brito [16] observed that the water absorption capacity of concrete was 16% and 46% higher than that of conventional concrete with the replacement of 30% and 100% of fine RCA, respectively.

Manzi et al. [17] investigated the shrinkage and creep behavior of self-compacting concrete prepared with recycled coarse and fine concrete aggregates. Results highlighted that the self-compacting characteristics, shrinkage and creep behavior are maintained when recycled aggregates are utilized, and their good quality improves mechanical properties. Matias et al. [18] studied the effects of superplasticizer on the durability properties (shrinkage, water absorption by immersion and by capillarity, carbonation and chloride penetration resistance) of RAC. It was reported that by introducing superplasticizer, the properties of durability were enhanced. Gonzalez-Corominas and Etxeberria [19] observed that the lower quality of the RCA aggregates with higher replacement ratios has the effect of producing the highest drying shrinkage value. Somna et al. [20] conducted experimental investigation on various mechanical properties of RAC. Cement was replaced with ground fly ash (GFA) and ground bagasse ash (GBA) by various percentages (20%, 35%, and 50%). It was concluded that with 20% replacement of cement by GFA and GBA, durability properties of RAC were highly effective. Limbachiya et al. [21] noted a marginal difference in resistance to chloride ingress with the replacement of 30% of coarse natural aggregate by RCA. Significant improvement in resistance to chloride ingress was observed of RCA by replacing 30% ordinary portland cement (OPC) by fly ash.

Many researchers [22–28] have done extensive work to enhance the mechanical and durability properties of concrete by using different mixing approaches. Liang et al. [24] proposed two mixing method i.e., mortar mixing approach (MMA) and sand enveloped mixing approach (SEMA) to improve the harden properties of RAC. Li et al. [25] developed a new technique in which the surface of RCA was coated with pozzolanic powder (fly-ash, silica fume and blast furnace slag) which results in better quality of RCA. It was concluded that the compressive and flexural strength of RAC were improved after using new technique compared to normal mixing. The combination of silica fume and fly-ash enhances the strength of RAC which is due to the higher packing density. Tam et al. [27] proposed a new mixing approach i.e., the two stage mixing approach (TSMA) and they observed that TSMA resulted better compressive strength than that of normal mixing approach (NMA). Tam and Tam [29] further developed TSMA with the use of silica fume and cement at premix stage for the improvement of mechanical properties and microstructure of RAC. It was found that the addition of silica fume and cement at premix stage improves the interfacial transition zone (ITZ) around the aggregate and resulting increase in the strength of RAC. Tam and Tam [30] evaluated the durability properties in terms of deformation (shrinkage and creep) and permeability (water, air and chloride permeability) of recycled aggregate concrete. It was concluded that after adopting TSMA, the durability properties of RAC were enhanced than that of normal mixing approach (NMA).

Researchers [1,31–37] have made the efforts to study the cement hydration products, loose paste and interfacial transition zone (ITZ) of concrete using electron probe micro analyser (EPMA) and scanning electron microscopy (SEM) technique with the acquisition of backscattered secondary electron (BSE) images. Doods et al. [38] investigated the electrical resistivity, water absorption by capillary action and SEM analysis of RAC to determine the effects on concrete microstructure and durability properties. It was observed that the presence of RCA has negative effect on microstructure and water ingress of structural concrete. Mukharjee and Barai [39] evaluated the compressive strength and characteristics of the ITZ of concrete containing RCA and nano-silica. They observed that the full replacement of NCA with RCA has significant effect on compressive strength and ITZ characteristics of concrete. It was also mentioned that the compressive strength and microstructures of RAC was improved with the incorporation of nano-silica.

From the literature review, it was noticed that the two stage mixing approach results significant improvement in properties of RCA for normally vibrated concrete (NVC). In this context, there is a significant research gap about determination of microstructural changes and enhancement in durability properties of self compacting recycled aggregate concrete (SCRAC) due to two stage mixing approach. Recently, the present research group presented the work on microstructural changes and improvement in mechanical properties because of modified mixing approach in Rajhans et al. [1]. Microstructure and Wavelength dispersive X-ray spectroscopy (WDS) analysis were performed for justifying the improvement in mechanical properties of SCRAC. However, the previous study [1] did not focus about durability properties. In this context, present experimental investigation is an effort for improving the durability properties of SCRAC prepared with proposed two stage mixing approach and is justified through microstructural investigations in ITZ. Image analysis is also carried out for quantitative analysis of different components (C-S-H, CH, UH and pores) at ITZ.

2. Experimental details

2.1. Materials used

2.1.1. Cementitious material

Ordinary Portland cement of grade 43, class F fly ash and silica fume were used in the concrete mixture. Class F fly ash was taken