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Influence of Nano-Silica on the properties of recycled aggregate concrete

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HIGHLIGHTS

- Colloidal Nano-Silica is used as partial replacement of cement for production of concrete mixes.
- Recycled aggregate concrete has inferior mechanical properties as compared to that of control concrete.
- Recycled aggregate concrete with 3% Nano-Silica has compressive strength similar to that of natural aggregate concrete.
- Improvement in tensile strength of recycled aggregate concrete is observed with the incorporation of Nano-Silica.
- Non-Destructive parameters are also enhanced with addition of Nano-Silica.

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ABSTRACT

The present work addresses the effect of incorporation of colloidal Nano-Silica on the behavior of concrete containing 100% recycled coarse aggregate. In this study, concrete mixes containing both natural and recycled aggregate are produced by replacing a fraction of Portland cement 0.75%, 1.5% and 3% of colloidal Nano-Silica respectively. The results of experimental investigation depicts that compressive strength, tensile strength and Non-Destructive parameters are enhanced due to addition of NS. Moreover, the study reveals that the characteristics of recycled aggregate concrete resembles with that of natural aggregate concrete with the addition of little amount (3%) of Nano-Silica.

1. Introduction

Concrete, being most extensively used construction material is primarily responsible for depletion of natural resources since its main constituent materials such as aggregates are drawn from nature, therefore, several countries are facing acute shortage of natural aggregates. Simultaneously, huge amount of waste concrete is produced due to demolition of aged concrete structures and sufficient number landfills are not available for dumping such waste materials. In recent decades, these waste concrete are collected and are crushed to produce aggregates and these aggregates are effectively used as novel construction materials in several countries. Therefore, utilization of recycled aggregates (RAs) as a replacement of natural aggregate (NA) is a solution to a number of problems faced by civilization: preservation of natural resources, lessening the costs of waste treatment prior to disposal, and reduction of pollution [1]. However, the main problem in using these recycled aggregates is the attached mortar that distinguishes these aggregates from natural aggregate. Earlier works confirmed that RA had some inferior properties like low density, more water absorption and reduction in quality and durability due to the mortar that remains attached to NA [2]. Several studies were found in literature regarding the application of aggregates produced from waste concrete and those were reported in the previous review works done by Nixon [3] and Hansen [4,5]. The characteristics of parent source concrete had influence in determining the properties of the fresh concrete produced with the recycled aggregates for instance water absorption of RCA increased with an increase in strength of parent concrete from which the aggregates are produced [6]. The behavior of the RAC containing aggregates from various field sources was investigated and reduction of mechanical properties and micro-structural compared to NAC was reported [7]. Previous study confirmed that there was no significant change in compressive strength (CS) of recycled aggregate concrete (RAC)

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when the replacement of aggregates was within 30% and reduction of CS was observed beyond this limit [8]. However, elastic modulus of concrete containing 30% of recycled aggregates was found to be 15% lower than that of NAC [9]. Kwan et al. [10] recommended that target strength could be achieved using recycled aggregates up to 80% with accepted mechanical and durable properties. Moreover, concrete having strength 80 MPa or more than that could be produced using recycled aggregates, however mechanical properties of the concrete is inferior to the natural aggregate concrete (NAC). Moreover, the use of recycled fine aggregate (RFA) was not recommended in place of natural sand since it had an adverse effect on workability and strength of concrete [11]. The development of compressive strength (CS) of both RAC and NAC were maintaining similar trend but strength development was little faster in case of NAC during first seven days and 10% reduction of 28 days CS was reported [12]. The durability properties like creep and shrinkage of RAC increased with replacement of NA with RA due to the inferior properties of aggregates [13].

1.1. Influence of two stage mixing and supplementary cementitious materials

To improve the properties of RAC, researchers adopted two-stage mixing approach and improvement in strength and durability was reported [14]. Detailed and quantitative analysis of Scanning Electron Microscopy (SEM) images and nano-indentation confirmed that the proposed two-stage mixing approach strengthened the interfacial transition zone (ITZ), hence it was an effective method for enhancement of mechanical and durability characteristics of RAC [15,16]. Tam and Tam [17] brought further modification in two-stage mixing approach methods by addition of silica fume (SF) into certain percentages of recycled aggregate (RA) in the pre-mix procedure, which was named as two-stage mixing approach(silica fume) (TSMAs). The other proposed technique was the addition of SF and proportional amounts of cement into certain percentages of RA in the first mix, named as two-stage mixing approach(silica fume and cement) (TSMAsc). The weak areas of the RA were filled by silica fume and proportional cement content, which created a stronger interfacial layer around aggregate, and hence the compressive strength of the concrete was improved. In addition to above mixing techniques, addition of supplementary cementitious materials are another significant method of improvement of properties of RAC. The incorporation of fly ash (FA) in RAC significantly improved the resistance to chloride ingress and resistance to sulfate erosion the long-term resistance to carbonation [18]. The CS of RAC could be improved with incorporation of SF and FA as a fine aggregate replacement and it was observed that the pore structure of RAC is improved, and particularly the volume of macro-pores was reduced due to addition of fly ash [19]. Brendt [20] adopted different proportion of FA and blast furnace slag (BFC) in RAC and concluded that the concrete with 50% BFC had produced best results in terms of strength characteristics among all combinations. However, addition of fly ash in RAC decreased elastic modulus, increased the coefficient of permeability and chloride diffusion coefficient, although the values remained satisfactory for durable concrete. In addition to above, pulverized fuel ash (PFA) and ground granulated blast furnace slag (GGBS) were used to enhance the concrete properties: the long-term strength development, the resistance to chloride permeability and resistance to chloride-induced corrosion [21]. Li et al. [22] investigated the effect of a new mixing technique-coating with pozzolanic powder: Fly ash (FA), SF, blast furnace slag (BS) or their combination on the workability, strength and microstructure. The outcome the study was that a dense ITZ structure along with satisfying workability and strength could be achieved with this new mixing technique-coating with pozzolanic powder. Kong et al. [23] conducted similar type of study by adopting a triple mixing method (TM) to further enhance ITZ and thus properties of the RAC by surface-coating of pozzalanic materials, such as fly ash, slag and silica fume. The outcome of the experimental investigation revealed that the compressive strength and chloride ions penetration resistance of the RAC could be further enhanced by using TM as compared to that by using two-stage mixing approach.

1.2. Application of nano-materials

Currently, the applications of nanotechnology have been gaining popularity in different fields of science and technology [24]. The developments of new materials with new functions or improvements in the properties of existing materials using nanotechnology are new areas of interest in civil engineering [25]. The use of nano-particles in cement based products was increasing day by day as these particles are effective in filling the voids of the C–H–S, enhancing the rate of hydrations by acting as nucleation centers and reducing the size of $Ca(OH)_2$ crystal [26]. Among existing nano-particles, Nano-silica (NS) is efficiently applied in the field of cement and concrete for enhancing the properties of concrete. The use of NS was preferred in place of previously used pozzolanic material SF because the pozzolanic activity of the NS was more than SF at early days due to the higher of rate of consumption of $Ca(OH)_2$ crystals [27]. NS was quite effective in improving the mechanical properties and the microstructure of high-strength cement pastes even in low concentration and this improvement of paste behavior is attributed to the fact that increasing packing among particles [28]. However, the addition of NS to paste and mortar reduced the mix workability, due to immediate reaction between the NS and the cement paste, with development of gels characterized by high water retention capacities [29]. The incorporation of NS enhanced the CS and tensile strength of mortar due to the increased pozzolanic action and filling effect. Moreover, incorporation of NS improved the microstructure of cement mortar [30]. Other studies comprising of addition of NS in mortar were produced similar type of observations [31–33]. Moreover, the fire resistance of high strength fly ash mortar could be improved with addition of NS [34]. The use of colloidal NS in place of dry powder form in concrete was preferred as it was more dispersive in nature and reduced segregation compared to dry powder form of NS [35]. In addition to above, the addition of colloidal NS accelerated the cement hydration largely in the early age with a reduction in low-stiffness C–S–H gel and an increase in high-stiffness C–S–H gel [36].

The application of NS in concrete was proven to be beneficial in enhancing compressive strength (CS) along with reduction of porosity due to fact that the addition of NS led to significant consumption of portlandite (CH) in the pozzolanic reaction, hence making concrete strong and dense [37]. Moreover, the permeability of concrete was also improved with addition of NS due to the removal of minute pores present in cement mortar matrix and ITZ [38]. Hosseini et al [39] confirmed that the replacing cement by 3% of NS of in the concrete made with 100% recycled aggregate produces strength more that of concrete made with natural aggregates. Moreover, microstructure became dense, uniform and even extremely small voids had been omitted due to the filling of small particles of NS in those voids. However, it was proved that higher dosage of the NS affected workability due to dispersion problems and conglomeration of particles.

The critical observations from the detailed literature review are follows:

- The properties of recycled aggregates are inferior to natural aggregates due to the adhered mortar present in them.