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The effect of Colloidal Nano-silica on workability, mechanical and durability properties of High Performance Concrete with Copper slag as partial fine aggregate

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HIGHLIGHTS

- Addition of Nanosilica in HPSC improves strength and durability properties.
- Early age strength is enhanced due to the use of nanosilica.
- Good correlation exists between compressive strength with splitting tensile strength and flexural strength.

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ABSTRACT

This study was conducted to investigate the effect of colloidal nanosilica on the properties of High Performance Concrete with copper slag as fine aggregate at a constant replacement level of 40%. Cement mortars and concrete mixes were produced by replacing Portland cement by colloidal nanosilica at 0.5%, 1%, 1.5%, 2%, 2.5% and 3%. Tests on workability, compressive strength, splitting tensile strength, flexural strength, rapid chloride penetration, water absorption, sorptivity and abrasion resistance were conducted on concrete mixes. The results indicate that the water demand increases due to the increase in the percentage of nanosilica owing to its high specific surface area. The amount of super plasticizer was adjusted in each mix to maintain a constant workability. The strength, penetration properties and resistance to abrasion of High Performance Slag Concrete (HPSC) were generally improved with the increment of nanosilica content in the concrete mix. The results denote that the colloidal Nanosilica act as a filler material that improves microstructure as well as an activator to promote Pozzolanic action. The addition of nanosilica enhances the strength characteristics up to 2% replacement level.

1. Introduction

High Performance Concrete (HPC) has been widely used throughout the world for the past three decades. The compressive strength of High Performance Concrete may vary between 20 MPa to 200 MPa. In addition to the strength requirements, workability and durability criteria play a vital role in the production of HPC. Therefore, it becomes necessary to use high quantity and quality materials to meet the above requirements. Also, the properties of the constituents of concrete namely cement, fine aggregate and coarse aggregate influence the properties of HPC. Aggregates constitute about 70%–80% of the volume of the concrete and hence there is a rapid increase in the consumption of natural aggregates throughout the world. This leads to the depletion of natural aggregates which affects the sustainable development.

Industrialization and population growth has led to the production of enormous waste materials and by-products that upon dumping or disposal of these materials causes environmental problems. Therefore, there is an urgent need to find and utilize alternative material for aggregates by utilizing the waste materials and by-products with little or no property modification which leads to a sustainable and greener environment along with the technical advantages.

To make HPC as an economical and ecological material, several mineral admixtures like silica fume, fly ash, metakaolin and rice husk ash are added or replaced with cement. There is an improvement in workability, mechanical and durability properties of HPC

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when the mineral admixtures are used as a partial substitute to Portland cement due to strengthening of interfacial transition zone. Nowadays, the use of nano materials in concrete is gaining more importance owing to its better properties in the fresh and hardened states of concrete due to their specific surface area. The materials used in nanosize are nano-SiO_2, nano-TiO_2, nano-Fe_2O_3, nano-Al_2O_3, carbon nanotubes/fibers. Among all the nanomaterials, nanosilica is the most widely used material in the cement and concrete to improve the performance, because of its pozzolanic reactivity besides the pore-filling effect. Due to the rapid development of infrastructure, it is necessary to develop a high strength, durable, sustainable and environment friendly cementitious composites [1]. Nanosilica is available in the form of compacted dry powder or colloidal suspension. Small amount of nanosilica, usually at 0–6% replacement is enough to enhance the properties of HPC. The addition of nanosilica accelerates the hydration process and also reacts with Calcium Hydroxide and produces more amounts of Calcium-Silicate-Hydrates thereby improving the mechanical properties. Concretes incorporated with nanosilica results in denser and compact microstructure with lesser amount of calcium hydroxide crystals [2–5,27]. Pozzolanic reactivity is found to be much higher and quicker in nanosilica added concrete up to 3% [3].

The incorporation of nanosilica in concrete resulted in higher compressive strength [2,6,7,24,35], increase in tensile strength and bending strength [7,8,35] and improvement in abrasive resistance than that of normal concrete to a considerable level. Also, the concrete becomes denser with improved durability properties. Researches on permeability characteristics of nanosilica concrete showed reduction in water absorption, capillary absorption and water permeability than normal concrete [4–6,8,18]. The addition of nanosilica in concrete with ground granulated blast furnace slag increased the rate of hydration and splitting tensile strength [9]. The addition of nanosilica in high volume fly ash and slag concrete reported reduction in the initial and final setting time of the concrete, the length of dormant period during hydration, Chloride ion penetration. Nanosilica addition improved the compressive strength due to acceleration of hydration [22,23]. Nanosilica addition in ceramic waste powder concrete improved the early age strength [10]. Addition of nanosilica improves the early age strength of fly ash cement mortar but rate of later age strength gain is slowed down [39]. High volume replacement of waste glass powder with cement in concrete is made possible by incorporating nanosilica [11]. Use of nanosilica in green-concrete mixtures, which is primarily made with the replacement of cement by waste materials overcomes the problem of low strength and delay in setting. Incorporation of Nanosilica in Recycled aggregate concrete resulted in improvement of compressive strength than conventional aggregate concrete [12]. Addition of nanosilica in oil well cement increases the strength and reduces the setting time [13].

The negative effects associated with sludge incorporation in terms of setting time and initial strength of sludge/fly ash mortars can be compensated by use of Nanosilica [19]. The addition of nanosilica was reported to an increase in strength of cement composites by 15–20% [20]. Also nanosilica particles improve the performance of sludge/clay mixtures in the tile production with reduction in water absorption and increase in abrasion and impact strength [21]. The improvement in mechanical and durability properties of concrete containing nanosilica is achieved due to its ultra fine particle size and its high specific surface area. The nanosilica particles fill the microscopic voids between cement, thus forming a dense structure. The calcium hydroxide produced during hydration reacts with nanosilica to form additional C-S-H gel [26]. Thus nanosilica act as centres of nucleation due to its high surface area, thus accelerating the hydration [26,27]. Also due to its high specific surface and high surface energies, increasing the amount of Nanosilica results in agglomeration thereby preventing uniform distribution of Nanosilica particles within the mortar. Thus the compressive strength improvement is decreased while increasing the amount of nanosilica content. Nano particles adsorb more Ca^{+2} ions and lower the concentration of calcium ions, thus accelerating the rate of dissolution of C_3S which increases the rate of hydration more effectively [32]. The bond between the cement paste and aggregate is also improved. Adding of Colloidal nanosilica is easier and efficient than adding powder nanosilica [41]. Nanotechnology has more potential in the field of construction and building materials which requires research in the field of nanotoxicity and care should be exercised while handling nano particles [25].

Most of the research focused on the study of properties of addition of nanosilica in cement pastes and mortars. Only a few researches carried out on determining the mechanical properties and permeability of the concrete with nanosilica. Many researchers reported different and contradictory optimum quantities of nanosilica along with some unusual effects which needs much concentration in the further research [2,7,14–17]. The optimum quantity of nanosilica must be arrived for each material individually.

Utilization of industrial wastes and by products is the major challenges faced today due to the disposal cost and potential pollution problem associated with it. The above problem can be reduced or even eliminated along with the achievement of resource conservation if it is efficiently used in the construction industry. Many slags have cementitious or pozzolanic properties which trigger the researchers to use it in cement or concrete. Copper slag is a by-product obtained during the matte smelting and refining of copper. Copper slag finds its use in abrasive tools for sand blasting, roofing granules, cutting tools, abrasives, tiles, glass, filling material in road base construction, railway ballast, asphalt pavements and cement and concrete industries [52,55]. Recently, many researches were carried out to study the possibilities of using waste materials and industrial by-products as partial/full replacement of cement/aggregates or as admixtures [54]. The use of copper slag as sand substitution in High Strength Concrete (HSC) improves strength and durability characteristics at same workability while super plasticizer is a very important ingredient in HSC made with copper slag in order to provide good workability and better consistency for the concrete matrix. The United Nations (UN) Basel Convention on the Transboundary Movement of Hazardous Wastes and their Disposal stated that copper slag is not a hazardous waste in the recent year after studying various researches conducted using copper slag. The use of copper slag in cement clinker production, and the effects of copper slag on the properties of Portland cement mortar and concrete in the form of cement replacement, coarse and fine aggregate have been investigated by many researchers [42,43–45,53,55]. Several works reported that the compressive and tensile strengths of concrete specimens made with copper slag as fine and coarse aggregates shows improvement than that of normal concrete [44–48].

Longer delay in the setting time is reported due to the decrease in the particle size of copper slag [46]. Bleeding and segregation is noticed in concrete containing more than 40% copper slag as fine aggregate replacement [44]. The above effect is due to glass like smooth surface of copper slag and the low moisture absorption [44,47]. The abrasion resistance of cement mortar containing copper slag as fine aggregate is increased [49]. For every tonne of copper produced, approximately 2.2–3 tonnes of slag were generated as per a scientific estimate. As per the survey in the year 2011, copper slag production was estimated around 33 tonnes all over the world. India is generating 6–6.5 tonnes of copper slag from the three copper industries [50,51]. M/s. Sterlite Industries, Tuticorin is producing 4,00,000 tonnes of copper every year from which approximately 8,00,000 tonnes of copper slag is generated every