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Performance enhancement of Structures by Nano-Reinforced Concrete

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Introduction

The most widely used material in infrastructure projects for construction is concrete. On correct design and construction concrete based structures exhibit durability and good mechanical properties. However, many structures are subject to frequent repair and maintenance (R&M), which is expensive and leads to a great environmental cost and disruption for the public (Gardner et al., 2018, AlTabbaa and Paine, 2018). Mechanical strength of concrete is mainly contributed by the hardened cement paste. During the cement hydration process, the formation of calcium silicate hydrate (C-S-H) gel acts as adhesive and offers the original mechanical strength of concrete. Therefore, the shape and density of the C-S-H gel plays key roles in determining the mechanical properties of the concrete. Seeking a method that can significantly improve the strength of hardened cement paste through regulation of its microstructure is certainly worth considering.

To be able to regulate the microstructure of cement paste, reinforcing materials need to possess some properties including intrinsically high strength, large surface areas, good dispersability in water, and the ability of forming chemical bonds with the C-S-H gel. Traditional materials are hard to fulfill such requirements. In the present era, nanotechnology offers promising alternatives in practically all conceivable fields; construction industry not being spared either. With the development of nanotechnology, many nanomaterials have been synthesized, such as silica nanoparticles (Slane et al, 2014), carbon nanotubes (CNTs) (Stynoski et al., 2015) and graphene(Pan et al., 2016). The primary reason for this proposition is to examine the plausibility of functionalized Graphene for similarity with concrete hydrates and support steel. Graphene, a 2-dimensional structure that comprises of a single layer of carbon atoms arranged in a hexagonal lattice (Geim and Novoselov, 2007). Graphene's properties include a very high intrinsic strength (130 GPa), a Young's modulus of 1 TPa, very high thermal and electrical conductivity, as well as complete impermeability to any gases (Novoselov et al., 2012). Inspired by its special structure and superior application properties, Graphene, as the reinforcing material, was utilized to refine the microstructure of cement in this project.

Literature Studies

Devasena and Karthikeyan (2015) investigated strength properties of graphene oxide concrete. They added Graphene oxide to the concrete in three mix proportions. Graphene oxide content were varied by 0.05%, 0.1%, 0.2% of cement content. All the specimens were cured for the period of 7, 14 & 28 days before crushing. Tests were performed at the age of 7, 14 & 28 days. Test results indicated that the inclusion of graphene oxide in concrete enhanced the compressive, split tensile and flexural strength.

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Dimov et al., (2018) used Functionalized grapheme (FG) commercially available graphene nanoplatelets of industrial grade (IG) and ultrathin graphite (UTGr) flakes to study their effect on various properties of reinforced concrete composites. They found grapheme concrete composites' strength increased up to 146% in the compressive and 79.5% in the flexural strength, whilst at the same time an enhanced electrical and thermal performance is found. A surprising decrease in water permeability by nearly 400% compared to normal concrete making this novel composite material ideally suitable for constructions in areas subject to flooding.

Papanikolaou et al., (2019) performed a survey on the use of graphene reinforced concrete for self sensing applications and found that there was improvement in tensile/flexural strength and the development of a self-sensing mechanism were the main future opportunities of grapheme concrete composites.

Mohammad Shareef and co-workers (2017) studied the compressive and split tensile strengths of M25 concrete by replacing cement with 1% and 2% graphene oxide. The testing was performed at 28days, 56days and 90 days of curing. The results demonstrated the compressive strength and split strength of concrete increased for 2%GO content when compared with control sample at various duration of days.

Experimental Details

Fabrication of Water-Dispersed Graphene: Graphite fine powder was procured from Supelco, Sigma Aldrich having density 2.2 g/cm^3 at 20 °C. The high-shear exfoliation of graphene in water is extremely efficient for the fabrication of graphene-reinforced concrete as it can substitute water directly in the concrete mixture and it is industrially scalable (Dimov et al., 2018). We used sodium cholate surfactant functionalized graphene (FG) prepared from graphite dispersed in water using high-shear blending. The suspension was decanted and the heavy excess graphite discarded, the dispersion was filtered through a mixed cellulose hydrophilic Millipore(R) membrane with 1 µm pore size. The graphene was incorporated into concrete by mixing the water-based graphene dispersions with ordinary Portland cement (OPC) Grade 53, fine dry sand, and 10 mm coarse aggregate.

Compressive Strength: Various solutions with different concentrations (5%, 10%, 15% and 20%) of FG in water were investigated in order to optimize the performance of the graphene-reinforced concrete. Subsequently, cubes of concrete were prepared, cured, and tested for their compressive strength according to standards regulating the architectural and engineering designs. A metallic split mould of inner diameter 38 and 76 mm length was used to prepare samples on optimum moisture content and were compacted from both the ends to achieve a uniform compacted sample. Testing procedure, calculation and other guidelines were followed as given in Indian standard IS 2720 (Part XI, 2006). Specifically, the fresh concrete mix was poured in standard 10 × 10 × 10 cm steel molds, removed after 24 h and kept in a water tank to cure. One of the key mechanical properties of concrete is the evolution of compressive strength over time. Therefore, we have tested the cubes after intervals of curing time ranging between 7 and 28 d, in order to extract the early age and later age strength values. The graphene-reinforced concrete samples were compared with standard concrete. To this end, a control sample group was produced following the same procedure, but with replacing the graphene water solution with tap water. These measurements ensure that the concrete samples investigated in this work comply with the test batches used for casting at construction sites that are prepared in accordance with engineering designs.

Results are awaited as the experimental part is under investigation. It is expected that graphene-enabled nano-engineered multifunctional concrete composites will display an unprecedented range of enhanced properties compared to standard concrete. There should be significant increase in compressive strength and decrease in water permeability of Graphene reinforced concrete.

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