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RESEARCH ARTICLE

Enhanced self-healing of micro-cracks in concrete using graphene oxide encapsulated sodium alginate microcapsules: microstructure, elemental, and oxide composition analysis

N Divyah[1] · M Devasena[2]

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Abstract
In contemporary practice, cracked concrete is commonly healed through the application of specific cementitious materials. However, challenges persist in accurately detecting the cracks and effectively treating them. As a result, significant research attention has been devoted to concrete imbued with self-healing properties.Factors such as shrinkage during drying, temperature changes, and chemical reactions can lead to the creation of microcracks. Self-healing microcracks provide a novel solution to the problem of cracks in concrete buildings. The notion entails the ability of concrete to autonomously repair or close minor cracks that may form gradually. This study specifically examines the integration of microbeads containing healing agents into the mortar mix, despite the existence of other self-healing processes. Upon the occurrence of a crack, these microbeads break, therefore releasing the healing chemicals that subsequently react to close the crack effectively. The study employed Graphene Oxide (GO) and Graphene Oxide (GO) encapsulated with Sodium Alginate (SA) as the healing agents. The study determines that the combination of SA and GO has a self-healing effect and a pore-filling effect, which results in the densification of the pore structure and filling of pre-existing micro fractures. The scanning electron microscopy (SEM) study showed a decrease in pre-existing cracks and an enhanced resistance to the development of new cracks. The energy exhibited by Calcium (Ca), Silicon (Si), and Oxygen (O) was 25, 21, and 9.5 cps/eV, respectively, in the combination of GO and SA, in comparison to the other mix.

Keywords Graphene oxide · Sodium alginate · Self-healing · Micro cracks

1 Introduction

One of the major issues in building construction is the formation of micro-cracks which can cause progressive deterioration and degradation of structures as a result of water or carbon dioxide infiltration [1]. A minor crack experiences autogenous healing when water particles seep through cracks, and hydrate the unreacted cementitious particles causing expansion of the cement and filling up the crack. It becomes imperative to establish an alternative technique when cracks are greater in width.The propagation of micro-cracks in addition to inherent micropores can be combated with the incorporation of suitable nanomaterials into cement [2]. The cementitious materials thus formed are robust and used for high-performance applications in the construction industry. Graphene Oxide (GO), a derivative from graphene is one such nanomaterial with two-dimensional single-layer carbon with hydroxyl (-OH), epoxy (C-O-C) and carboxyl groups (-COOH) on its surface exhibiting excellent hydrophilicity, dispersity, large specific surface area and mechanical properties [3, 4].

Homogeneous dispersion of GO reduces porosity, and and thereby enhances the mechanical properties of cementitious materials [5]. However, homogenous dispersion of GO within the cement matrix remains a challenge as GO tends

✉ M Devasena
cto-gscoe@iitpkd.ac.in

N Divyah
divyah991@gmail.com

1 Department of Civil Engineering, PSG Institute of Technology and Applied Research, Coimbatore, Tamil Nadu, India

2 Global Sanitation Centre of Excellence, Indian Institute of Technology Palakkad, Palakkad, Kerala, India

to aggregate with Vanderwal interaction between graphene layers [6]. GO dispersion methods include ultrasonic dispersion [7], compounding with mineral admixtures such asSilica Fumes (SF) and Fly Ash (FA) [8], Ground Granulated Blast Furnace Slag (GGBS) [9]; usage of surfactants such as Gum Arabic and Sodium Dodecyl Sulphate (SDS) [10]. Recently, studies have reported that polymers are effective matrices for homogenous nanoparticle dispersion and immobilization among which polysaccharides such as alginate, pectin, starch, cellulose and chitosan with remarkable functionality and properties are extensively used [11, 12].

Sodium Alginate (SA) is a linear copolymer of β-D- 7 mannuronic acids (M) and α-L-guluronic acids (G) linked together with 1→4 linkages [13]. SA is non-toxic, environmentally benign, renewable, cost effective, rich in hydroxyl and carboxyl groups and therefore readily crosslinks with polyvalent ions such as Barium (Ba^{2+}), Calcium (Ca^{2+}) and Iron (Fe^{3+}) [14]. When added to concrete, although autogenous healing of microcracks takes place, much more wider cracks at inaccessible points require an internal solution such as enhanced self-healing with super absorbent polysaccharides (SAP) which comes with limitations. SAP release the entrapped moisture leading to further cement hydration, and CSH gel formation leaving air-filled macropores. This can be overcome by the use of nanoparticles such as graphene oxide which acts as a nucleation site for hydration of cementitious matrix. The pore-filling nature of graphene oxide due to its nano size in conjunction with sodium alginate acts as an effective self-healing and self-sealing agent as shown in Fig. 1.

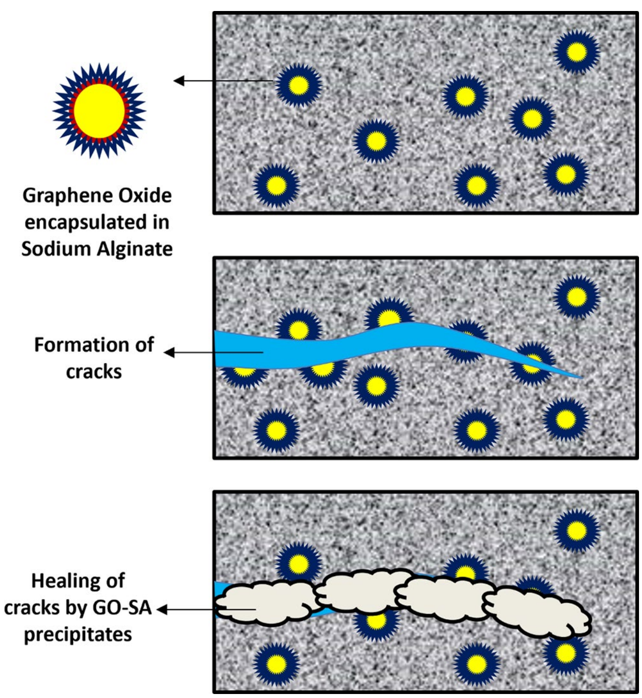

Fig. 1 Chemistry of crack healing

During the release of water entrained within SA, GO gets mobilized leading to dispersion and formation of nucleation sites for cement hydration where the pores get filled and the strength of concrete is not deteriorated. Upon release of water, the hydrogen bond facilitates the blending of GO and SA, and hence there is dispersion of GO and SA. The macro cracks are sealed by SA and the micro and nano cracks and the pores are healed by GO. This leads to an increase in the overall strength of cement mortar and concrete. The addition of GO-SA forms an interim solution for cracks at inaccessible joints within the concrete structures. Thermal stability and mechanical properties of SA improve upon GO addition. GO-SA composite beads are also widely used in applications such as pectinase immobilization [15]; metal/pollutant adsorption in wastewater treatment and photocatalysis [16, 17].

Sodium alginate encapsulation easily leaches out, which enhances the performance of concrete. Though graphene oxide is costly, even a small amount produces high-performance concrete that has increased mechanical properties and it can be economically synthesized from Hummers method. SA is easily available in seaweed. The addition of alginate encapsulated GO nanoparticles in concrete increases the durability of the concrete by self-healing property, preventing cracks and providing better quality. The microstructural study is conducted through SEM analysis and EDX tests. This is the first-ever report of the incorporation of GO-SA composite microbead as reinforcement into cement mortars. This study is aimed to investigate the microscopic, elemental and oxide composition of standard mortar, GO incorporated mortar and GO-SA composite microbead incorporated cement mortar.

The research employs a cost-effective method for producing GO, making the technology more viable for practical applications. The addition of GO-SA composite microbeads to the concrete imparts self-healing capabilities, which could potentially address a major difficulty in maintaining concrete infrastructure. The study extends its scope beyond mere conceptual illustration. Using Scanning Electron Microscope (SEM) analysis and Energy Dispersive X-ray Spectroscopy (EDX) tests, the study provides a scientific understanding of the reinforced mortar's microstructural and elemental composition, verifying the technique. Overall, this study addresses a significant need in concrete maintenance by introducing a unique and potentially cost-effective way for producing self-healing concrete incorporated with GO-SA composite microbead. This suggests more possibilities for investigation and innovation in the field of concrete technology.