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Properties of carbon nanotube reinforced cement composite synthesized using different types of surfactants

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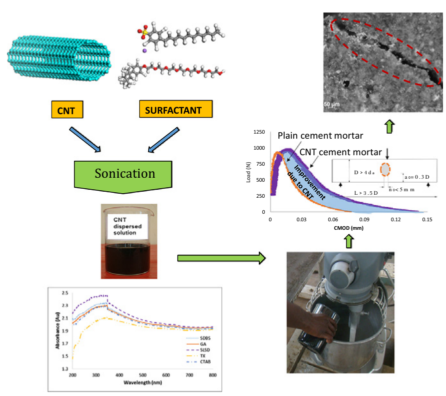
HIGHLIGHTS

- Identification of right sonication parameters for dispersing CNTs in solution.
- Synthesis of CNT-cement composite with different surfactants and dosage of CNTs.
- Evaluation of compressive, tensile and fracture properties of types of composite.
- Identification of optimum dosage of CNT and surfactant compatible with cement.
- Development of numerical scheme to determine size-independent fracture energy.

GRAPHICAL ABSTRACT



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ABSTRACT

Carbon nanotubes (CNTs) have proven to be the promising candidates to improve the tensile properties of cement composite. However, the properties depend upon the synthesis procedure which involves many parameters. In this study, investigations are carried out to determine the role of various sonication parameters, type of surfactant and dosage of CNT on compressive, tensile and fracture properties of CNT-cement composite. It is found that the CNT incorporated surfactant solution sonicated for a minimum of 1 h with the power of 70 W and the energy of 27 Ws/s provided the best dispersion. The dispersion capabilities of surfactants are found to be in the order of SLSD > SDB > GA > CTB > TX. It is also observed that the optimum dosage of CNT that can be incorporated into cement matrix is 0.06–0.1% by weight of cement. When CNTs are incorporated beyond that level, they cause detrimental effects to the cement matrix. Further, non-linear numerical scheme using loading-unloading history is proposed to determine the size-independent fracture energy of composite. The study demonstrates the role of synthesis procedure on the properties of CNT-cement composite and the procedure to numerically evaluate the performance of the composite.

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1. Introduction

Portland cement is one of the largest commodities consumed by mankind. Cementitious materials are, in general, very brittle and characterized by a very low tensile strength and strain capacity. This low tensile strength combined with brittle nature leads to

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sudden failure of structures without any warning. Hence, macroscopic steel reinforcing bars are added to provide tensile strength and ductility to cementitious materials. However, these steel reinforcing bars should be carefully placed in the tension dominant zones in order to improve the tensile strength and ductility.

Within the last few decades, researchers started using discrete macro- to microfibers to control crack growth in cementitious materials (e.g., cement paste, cement grout, concrete) ([1–3]). Unlike conventional reinforcing bars, which are specifically designed and placed in the tension dominant zone, these fibers are thin, short and distributed randomly throughout the member. The idea behind this transition to fiber reinforced concrete (FRC) is that the tensile strength is developed from many individual fibers rather than a few pieces of steel [1]. Therefore, the use of discrete fibers results in a more uniform distribution of stress within the matrix. Cementitious materials develop micro cracks with curing and these cracks propagate rapidly under applied stress. The fibers act as bridging members by holding the cracks together and dissipate the energy released at the crack tip. Thus, addition of fibers controls the development of cracks which, in turn, leads to improvement in post peak ductility performance, pre-crack tensile strength, fracture strength, toughness, flexural strength and fatigue performance.

Though FRC has all the properties desired for civil engineering community, there may be situations where even these microfibers are not desirable. For example, storage tanks of high sensitive materials like radioactive materials. Also, with the increased demands from infrastructure sector, specifically for high rise and special structures, there is a need to develop materials with higher elastic modulus, increased tensile properties in conjunction with smart properties. In such cases, cement based material has to be developed with specific and multiple requirements.

Carbon nanotubes (CNTs) are the next generation of fibres of length ranging from few nano-meters to micro-meters. CNTs are capable to be superior alternatives/complements to traditional fibers for the development of next generation high performance- and multifunctional- cement based materials. Owing to its smaller size, they help in bridging the cracks of much smaller size, i.e., few nano meters, thereby delaying the crack propagation and increasing the load carrying capacity [4]. CNTs have an average Young's modulus around 1 TPa, a tensile strength of 60 GPa, and an ultimate strain of 12%. Compared to steel, CNTs have a modulus of elasticity approximately 5 times higher, a tensile strength 100 times larger, can reach elastic strain capacities 60 times greater, and yet have a specific gravity only one sixth to that of steel [5]. Their excellent conductive properties can also be used to impart piezo-resistive properties into cementitious materials which can be used for sensing purposes [6]. These extraordinary properties makes CNT an ideal candidate to be used in cementitious composites.

As against the traditional microfibers, incorporating CNTs into cementitious matrix is quite challenging. One of the main challenges is the proper dispersion of CNTs into cement matrix, partly due to their high hydrophobicity and partly due to their strong self-attraction caused by high van der Waals forces. This higher attraction causes the CNTs to be more prone to agglomeration (bundling). In order to effectively and efficiently utilize CNTs into cement matrix, they must be separated into individual fibres and uniformly distributed in the cement matrix. CNTs are incorporated into cementitious matrix using various methods such as chemical vapour deposition [7], plasma process [8], using bridging agents [9], etc. In broader sense, there are two commonly employed methods to disperse CNTs into cement matrix, viz., covalent and non-covalent functionalization. In covalent method, chemical bonds are created between CNTs and the matrix. However, this method is prone to deteriorate the intrinsic properties of CNTs and may even cause structural defects [10]. The non-covalent method of functionalization involves wrapping of surfactants on the surface of CNTs and thereby, preventing them to get agglomerated. This method is advantageous since it preserves the intrinsic structure and properties of CNTs [11]. Hence, in this study, noncovalent functionalization of CNT is done with the help of surfactant and ultrasonic agitation.

However, choosing the right surfactant and proper sonication parameters are very crucial. Surfactants that are good in dispersing CNTs may not be compatible with cement matrix. It is reported that few surfactants may retard or prevent hydration, entrap air in the matrix, or undergo reactions with water-reducing admixtures which result in re-agglomeration ([12,13]). Also, if sonication energy is low, it may not properly disperse CNTs; if it is high, it may damage CNTs. Hence, it becomes important to choose the right type of surfactant that not only disperses CNTs properly but also compatible with cementitious composites and right sonication parameters in order to effectively and efficiently incorporate CNTs into cement matrix.

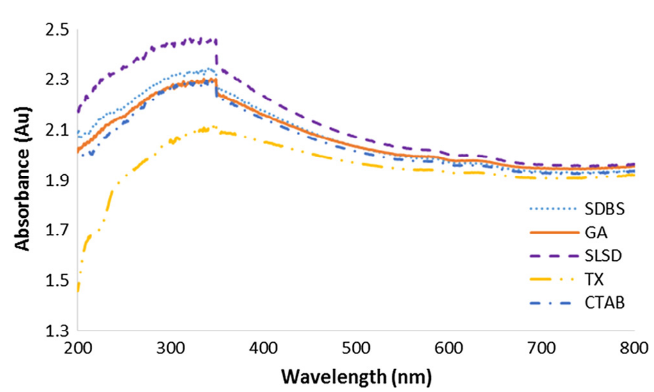

Fig. 2. UV-Vis absorbance characteristics of CNT solutions dispersed in different surfactant solutions.

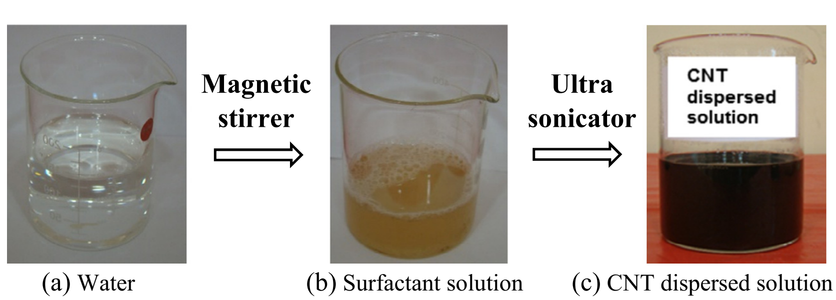

Fig. 1. Preparation of CNT-water surfactant solution.

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