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Review

Intrinsic self-sensing concrete and structures: A review

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ABSTRACT

Intrinsic self-sensing concrete (ISSC) refers to a structural material that can monitor itself without the need of embedded, attached or remote sensors. By measuring electrical resistance of the ISSC, the stress, strain, crack and damage can be in situ monitored. Compared with conventional structural materials which require additional sensors for monitoring or detection, the ISSC is advantageous in its high sensitivity, good mechanical property, natural compatibility, identical lifespan with concrete and easy installation and maintenance. The ISSC can be used for structural health monitoring, traffic detection and border/military security. In this paper, we systematically introduce research progress of the ISSC, with attentions to its compositions, fabrication methods, sensing signal testing methods, sensing properties and generation mechanism, and structural applications. Future challenges in the development and applications of the ISSC are also discussed.

Contents

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1. Introduction

Concrete is the second most used resource in the world after water [1]. Most of infrastructures around the world are built with concrete. However, due to the degeneration of concrete materials, complex interaction between concrete materials and their service environment, absence of advanced design and condition assessment tools and timely maintenance, many concrete structures are in a state of utter disrepair, and significant efforts are needed to render the failing infrastructures back to a serviceable and safe state. Intrinsic self-sensing concrete (ISSC) is an ideal engineering material for addressing this issue. This smart material can help us develop intelligent infrastructure integrated with sensing and health monitoring abilities, thus improving serviceability, safety, reliability and durability of the infrastructures. ISSC provides a new approach for maintaining sustainable development in concrete materials and structures [2,3].

The ISSC (also called self-monitoring, intrinsically smart, piezoresistive or pressure-sensitive concrete) is fabricated through incorporating some functional fillers such as carbon fiber(CF), carbon nanotube(CNT), and nickel powder(NP) into conventional concrete to increase its ability to sense the strain, stress, crack or damage in itself while maintaining or even improving its mechanical properties and durability. The functional fillers are dispersed in concrete matrix to form an extensive conductive network inside concrete composite. As this composite is deformed or stressed under external force or environmental action, the conductive network inside is changed, which affects its electrical behaviors. Strain (or deformation), stress (or external force), crack and damage under static and dynamic conditions can therefore be detected through measuring the electrical properties of the composite. The ISSC has both structural and sensing functions, so it replaces the need for additional sensors. It not only has potential in the field of structural health monitoring and condition evaluation for concrete structures, but also can be used for traffic detection, corrosion monitoring of rebar, military and border security, structural vibration control and so on [4–7].

The intrinsic self-sensing behavior of concrete was firstly investigated in 1992 [8]. Since then, much research work has been done on sensing properties, sensing mechanism and structural application of ISSC with different functional fillers, such as CF, steel fiber (SF), graphite powder (GP), steel slag (SS), NP, carbon nanofiber (CNF), hybrid iron containing conductive functional aggregate and CF [9–30]. In the past two decades, much effort has been made toward the advancement of ISSC, and many innovative achievements have been gained in both development and application of ISSC. The scope of this paper is to provide a systematical review on the main progress and advances in design, fabrication, measurement, characterization, sensing properties and generation mechanism, and structural applications of ISSC. Future challenges for continued development and deployment of ISSC and structures are also discussed.

2. Compositions of ISSC

The ISSC, having a highly complex structure, is a multi-phase, multi-scale and multi-component composite in nature. At the macroscopic level, the ISSC may be considered to be a two-phase material, consisting of functional fillers dispersed in a concrete matrix as shown in Fig. 1. The filler phase distributes in the concrete matrix phase to form conductive network. The concrete matrix phase, composed of mineral aggregates glued together with a binder, supports the functional fillers and holds them in place. Here the binder of concrete can be cement, asphalt or even polymer [31–37].

At the microscopic level, there is a third phase in the ISSC, which is composed of the interfaces between fillers and concrete matrix and between fillers [38]. Since the fillers are mainly in micro-scale or nano-scale, the potential filler–matrix and filler–filler interface areas are enormous. These interfaces affect the quality of the electrical contact between fillers and concrete matrix and between fillers, thereby affecting the conductive network and the electrical conductivity of ISSC. Therefore, they will have a great influence on the sensing behavior of ISSC. Some researchers have proved this and modified the sensing properties of ISSC by changing the interface between fillers and matrix [20,39–41].