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Electromagnetic quality control of steel fiber concrete

Hashem Al-Mattarneh

Civil Engineering Department, Faculty of Engineering, Najran University, 11001 Najran, Saudi Arabia

HIGHLIGHTS

- An electromagnetic sensor was proposed to evaluate and test steel fiber concrete.
- The fiber contents, dispersions and orientations were evaluated by dielectric means.
- The mean measured dielectric properties can be used to determine the fiber content.
- Variations in the point to point dielectric are related to the fiber dispersion.
- Variation in the dielectric at different angles indicates the fiber orientation.

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ABSTRACT

Introducing steel fiber to concrete materials enhances the performance of concrete structures in terms of their flexural strength, impact load resistance and limited crack propagation. The fiber concrete performance depends on the fiber content, dispersion and orientation. No standard method is currently available to evaluate these three parameters, especially in situ. This paper describes the feasibility of using a surface electromagnetic sensor as nondestructive radio wave test system to determine the concentration, dispersion and orientation of steel fibers in the concrete. The system needs to contact the concrete material and requires only one face of the concrete material for testing. The surface electromagnetic sensor can slide on the fiber concrete surface and measure the dielectric properties at various locations to assess the fiber distribution. In addition, the sensor can rotate to polarize the electric field to various angles and evaluate the fiber orientation. The mean and standard deviation of the measured dielectric properties increase with increasing fiber content and fiber dispersion. The results indicate that the dielectric properties are maximal when the fiber is oriented in the direction of the electric field and minimal when perpendicular. A simple linear model was established to determine the fiber content and flexural strength from the measured electromagnetic properties.

1. Introduction

Concrete is the most commonly used construction material. Massive quantities of various concrete types are used annually. The increasing demand for this material and the extensive need for concrete with higher performance properties has encouraged many researchers to investigate methods to improve its mechanical properties. One such method is to use fiber concrete. Fiber concrete is made by introducing fibers, generally steel and polypropylene, directly to the concrete mixture [1,2].

The inclusion of even small amounts of fibers in concrete mixtures [3] effectively improves the engineering performance of structural and non-structural concrete, including the flexural strength, tensile strength, fatigue, impact strength, toughness, load bearing capacity, durability, and resistance to both fire and abrasion [4–7]. This extra performance comes from fibers in cracks effectively bridging and transferring any loads to un-cracked parts of the concrete matrix, which prevents crack propagation [8–10]. Additionally, fiber concrete is conventionally used to overcome the tension weakness of concrete especially high-strength concrete [1,9].

The fiber efficacy in the concrete depends on many factors, such as the fiber properties (fiber type, length, and shape), content, and distribution [9–13]. The fiber distribution in the concrete matrix, especially the orientation, significantly affects its performance [3,14,15]. The efficiency was found to decrease 70% for randomly oriented fibers relative to totally aligned fibers [16]; the efficacy depended on the number of effective fiber oriented with the principal stress [17]. The fiber orientation in the matrix is influenced by parameters such as the fiber geometry, concrete flow characteristics,

E-mail addresses: drhashem2010@yahoo.com, hmalmattarneh@nu.edu.sa

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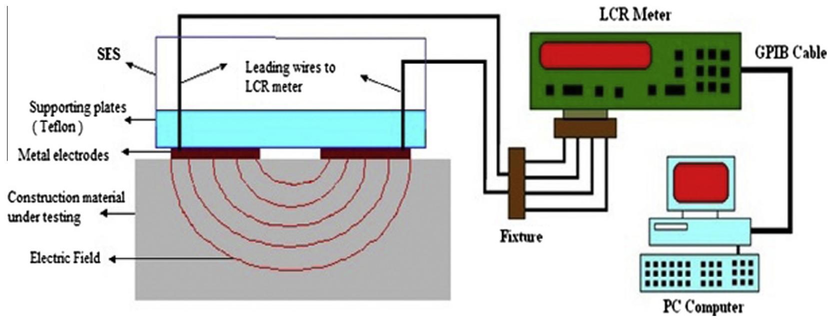
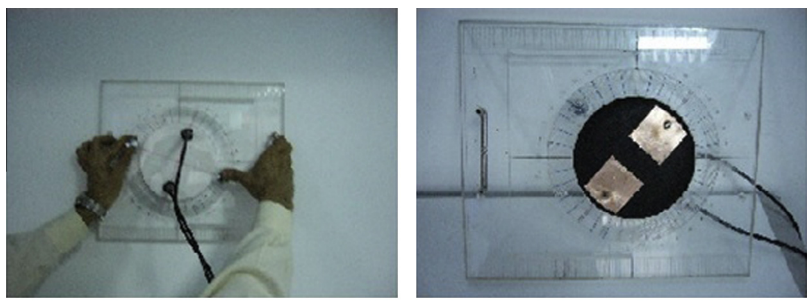


Fig. 1. Schematic diagram and design of the SES setup.



(a) Front-View of SES (b) Back-View of SES

Fig. 2. Detail descriptions of the SES.

mean of the compaction and casting method, concrete or framework geometry and fine to coarse aggregate ratio [18–22].

Several methods have been developed to predict the fiber content and/or orientation in the concrete matrix; these methods may be classified as either destructive or nondestructive and are based on either direct or indirect measurements. The majority of direct destructive techniques, such as crushing concrete samples and manually counting the fiber content and orientation [23,24], and indirect techniques used to calculate orientation parameters, such as mechanical testing [25,11], image analysis [26,27], X-ray analysis [28,29], and CT scans [30,31], are both costly and time consuming and ill-suited for use at the site. These methods also require special sample preparation and a specific sample size. For nondestructive tests, electromagnetic techniques have received considerable attention in recent years.

Electromagnetic techniques enable the rapid, easy and economic measurement of the fiber orientation. These techniques can be used on large-scale samples; therefore, bulk effects could be assessed. Furthermore, these methods allow for the virtually continuous monitoring of samples from the initial viscous state to setting and long-term hardening. Electrical resistivity measurements [31], inductive coils [32], alternating-current impedance spectroscopy [33], electromagnetic coaxial transmission lines, and waveguide antenna are example electromagnetic techniques [34].

This research, describes the feasibility of using a surface electromagnetic sensor (SES) as a nondestructive radio wave test system to determine the concentration, dispersion and orientation of steel fibers in concrete. This system must be contact the concrete material during testing and only requires one concrete face. This method proved to be highly reliable for in situ testing. Different parameters, such as concrete mixture, concrete curing age, fiber concentration, fiber distribution and fiber orientation, are detailed. The influence of these parameters on the measured dielectric properties of the fiber concrete was analyzed.

2. Electromagnetic Theory

2.1. Dielectric properties

Every material has a unique set of electromagnetic properties that affects the way it interacts with electric and magnetic fields

Table 1
Mix proportions and strength properties for steel fiber concrete.

Steel fiber concrete mix	Cement (kg/m^3)	Water (l/m^3)	Fine aggregate (kg/m^3)	Course aggregate (kg/m^3)	28-days Compressive strength (N/mm^2)	28-days Flexural strength (N/mm^2)
G50 0 kg/m^3	360	180	722	1098	35.6	3.18
G50S10 10 kg/m^3	360	180	722	1096	37.0	3.49
G50S20 20 kg/m^3	360	180	722	1094	36.0	3.55
G50S30 30 kg/m^3	360	180	722	1092	33.9	3.87