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Nondestructive evaluation on dispersion of steel fibers in UHPC using THz electromagnetic waves

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HIGHLIGHTS

- Dispersibility of the steel fiber in UHPC is destructively evaluated like coring.
- THz waves can be used as a new test method for detecting steel fiber in UHPC.
- Dispersibility of steel fiber is quantitatively evaluated using THz 3D images.
- This technology can be used as automated NDT method for enhanced quality control.

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ABSTRACT

Ultra-high performance concrete (UHPC), which has better mechanical properties and durability than reinforced concrete, can greatly reduce the weight of structures due to its high strength and reliability. So, it is very effective for the construction of high-rise buildings and long-span bridges. The mix design for UHPC is not only composed of traditional materials (i.e. cement, sand, and aggregate) but also includes binder and admixture. Moreover, steel fiber is necessary to improve ductility. Since the tensile strength of UHPC depends greatly on the direction of the steel fiber, it is important to confirm the dispersibility and orientation of the steel fiber. However, verification of the dispersibility of the steel fiber after curing is indirectly performed through destructive methods like strength tests through coring. Thus, for a better method of dispersibility confirmation, a more effective dispersion analysis technique is required. In this study, the dispersibility of steel fiber in UHPC was evaluated through tomography of UHPC using THz electromagnetic waves. These waves have both infrared straightness and microwave penetrability. Three UHPC specimens were fabricated with steel fiber and were tested with THz electromagnetic wave spectroscopy by experimentally scanning the specimen. From the experimental results, it was possible to obtain a 3D image of the steel fiber arrangement inside the specimen through scanning of the specimen. Also, through image analysis, the dispersibility of the steel fiber in each specimen was numerically derived. For the future, it is expected that the dispersion analysis technology proposed in this study will be applied as an automated nondestructive testing method for enhanced quality control.

1. Introduction

Recently, the importance of structural health has been greatly amplified for such reasons as the increase in the collapse of large-scale infrastructure around the world and the deterioration of aged facilities with long-time use. For these reasons, to improve safety of structures in various areas, seismic design techniques to minimize the earthquake damage to structures and ultra-high performance concrete (UHPC) that incorporates advanced materials (i.e. nanomaterials, composites, binders, and admixtures) to overcome the limitations of conventional reinforced concrete structures have been actively developed [1,2].

More specifically, high strength concrete has been developed to improve and enhance performance. In the conventional method, which is divided into aspects of concrete and steel, new concept construction materials (i.e. nano and composite materials) have been developed and used for high reliability, and strength development has also improved [3,4]. Concrete using nano-silica-based concrete was developed to reduce weight and to allow strength similar to that of current concrete.[5] Carbon-based

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nano-materials (i.e. carbon nanotubes [6] and graphene oxide [7]), which are used to fill cavities in concrete, are expected to provide high reliability and strength. Additionally, carbon-based concrete has been extended to allow multifunctional construction by adding a smart sensing function to the structure [8–10]. On the other hand, studies on increasing the strength of concrete have reported higher compressive strength than that of conventional concrete, achieved by combining specific binders and admixtures [11]. Especially, UHPC has been found to perform well, with a compressive strength of 150 MPa or more. UHPC improves structural performance aspects like ductility through mixing with other materials such as steel fiber [12–14]. Since defects of concrete can be caused by improper distribution of steel fibers, it is important to ensure the dispersion and direction of steel fibers, so as to guarantee uniform compressive strength [15,16]. If the dispersibility and orientation of the steel fiber are not uniform, the steel fiber can act as a defect in the structure, resulting in a decrease of strength. The dispersion of steel fiber depends on the mixing time and the speed of the manufacturing process. After fabrication, the dispersibility of steel fiber is estimated by the destructive method through specimen sampling. This analysis measures the strength and internal defects of the test specimen through fracture tests, such as compressive strength testing and coring. However, in the industrial field, there is a limit to the applicability of the conventional method, which is based on destructive methodology: a new nondestructive method is required to be developed for advanced methodology of dispersibility confirmation.

In cases of conventional nondestructive testing, such as radiation and ultrasonic testing, techniques are widely applied to estimate structural health through defect measurement of cracks in the concrete. However, because nondestructive testing is basically dependent on the proficiency of the inspectors, a sensor-based

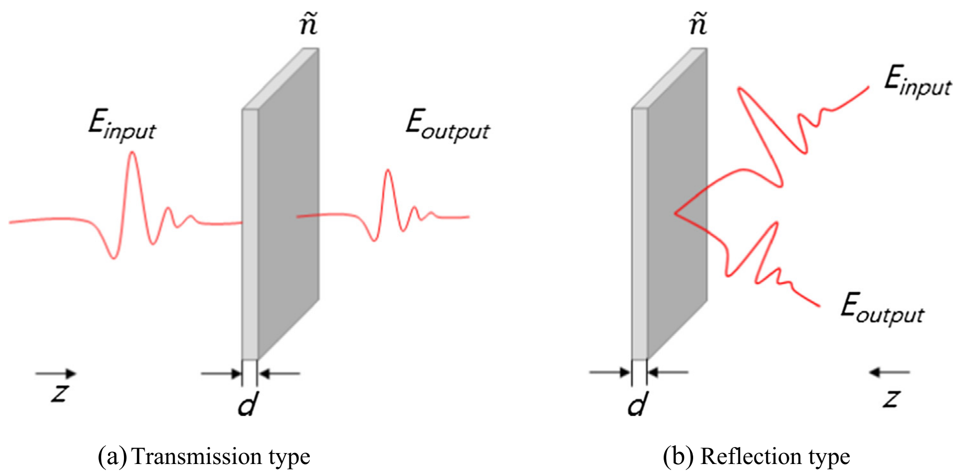

Fig. 1. Transmission and reflection of THz electromagnetic wave through a medium with complex refractive index.

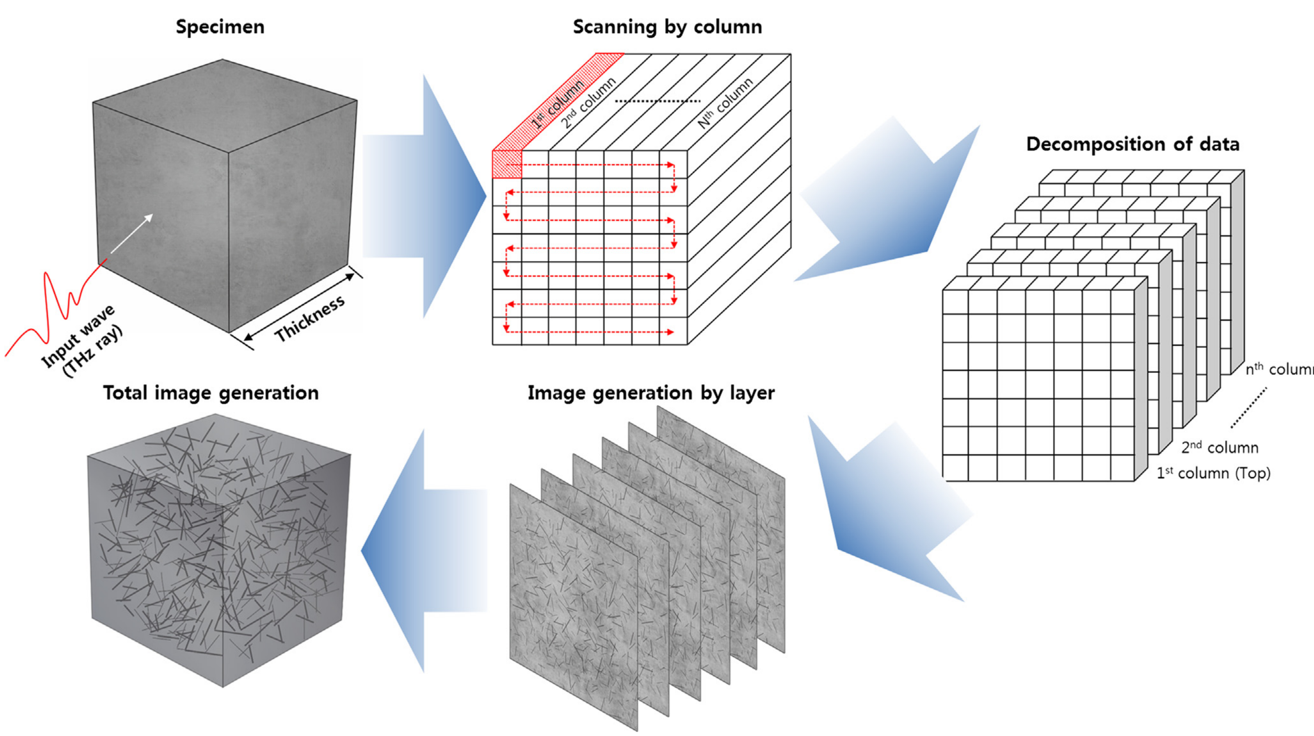

Fig. 2. Principle of tomography for 3D imaging.