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Case study

Self-monitoring application of conductive asphalt concrete under indirect tensile deformation

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ABSTRACT

Conductive asphalt concrete has excellent self-monitoring abilities for internal damage and attractive application prospects. By studying the resistance and strain changes under indirect tensile deformation, three distinct stages of output resistivity changes are observed during the destruction of the specimen. In the initial loading stages, contact between the mixture particles tightens because the specimen under loading forms a more conductive path, and the resistivity decreases significantly. In the second stage, asphalt concrete deforms smoothly; small changes in the interior of the asphalt concrete also correspond to small changes in resistivity. In the final stage, because of the progressive development of cracks in asphalt concrete, the specimens are destroyed, and the conductive paths are also seriously damaged, significantly increasing resistivity. This change in the resistivity value exceeds 50%. Conductive asphalt concrete also has a good self-monitoring ability regarding the strain caused by the applied stress. The unit strain corresponding to changes in resistivity is greater when graphite content is lower. CT (Computer Tomography)identification can confirm that changes in resistivity are caused by material changes in the interior due to fatigue failure. The decrease or increase in resistivity is the result of a decrease or increase in the internal porosity of the material.

1. Introduction

Conductive asphalt concrete can be prepared by adding a conductive material such as graphite powder, carbon fibre, or blast furnace carbon black to ordinary asphalt concrete. The conductive properties are thus changed; resistance can decrease from $10^{13}\,\Omega$ to $10^{2}\,\Omega$ or even less (Wen and Chung, 2004, 2005; Wu et al., 2002, 2003, 2005; Liu and Wu, 2010; 2011a,b). This modified conductive concrete also has superior smart characteristics (Liu et al., 2008, 2009; Wu et al., 2003) and road performance and is used in roads, bridges or airport runways; the material is expected to self-monitor stress, strain and defects.

Self-monitoring asphalt concrete is a structural material that does not require implantation or addition of sensors and has the following advantages:

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1) The embedding of sensors and resulting performance degradation can be avoided.
2) The material self-monitors its structure at a low cost.
3) Accuracy and timeliness.
4) Stable performance and high durability.

In addition, asphalt concrete strain self-monitoring can be applied in weighing (strain-stress correspondence) and confirming the overloading of vehicles, traffic monitoring and structural vibration control (strain correspondence to vibration) (Liu and Wu, 2008). Previous reports showed that (Liu et al., 2009a,b; Liu and Wu, 2011a,b) conductive asphalt composites containing graphite powder can monitor cycle load strain under uniaxial compression.

There are several indoor fatigue tests for asphalt mixtures. Currently, the most widely used methods are the simple bending test, support bending test, uniaxial test, indirect tensile test, triaxial test, fracture mechanics testing and rutting test. According to the SHRP, comparing the advantages and disadvantages of the fatigue test method (Superpave Mix Design, 1996; AASHTO, 2015), the repeated bending and indirect tensile tests are better comprehensive evaluations and have been widely adopted. However, beam specimens are difficult to produce and are influenced by unstable factors, and the test methods are complex and produce widely varying results. In contrast, cylindrical specimens are more conveniently produced, and the test methods are simple and easily performed; therefore, this paper introduces the self-monitoring applications of conductive asphalt concrete to the indirect tensile test through changes in resistance of the strain and fatigue damage of the material.

Damage mechanics (Li and Zhang, 2003) is a new discipline established in the 1980s that focuses on the occurrence and development of microscopic defects, microcracks, and micropore points (which, taken collectively, are injurious) before the appearance of macroscopic cracks. Asphalt concrete is a complex heterogeneous composite whose damage mechanism is the basis of the study of asphalt concrete damage. Determination of the law between internal damage and the variation of resistivity is the foundation of damaging self-monitoring conductive asphalt concrete. This method is an effective way to study injury and damage accumulation through analysis of the interior of asphalt concrete.

CT (computer tomography) technology displays high-resolution digital images of different densities of information at a specified level in computer image reconstruction. In the process of X-ray penetration of substances, the intensity decay is exponential. The density of the material is evidenced by the X-ray attenuation coefficient, which differs for different substances. When an X-ray penetrates a detected object, the light intensity is defined as follows:

$$I = I_0 \exp(-\mu_m \rho_x) ,$$

where I_0 is the light intensity of X-rays before penetrating the object; I is the light intensity of X-rays after penetrating the object; μ_m is the detected mass absorption coefficient per unit, which is only related to the wavelength of the incident X-ray under normal circumstances; x is the penetration length of the incident X-ray; and ρ is the material density. Therefore, the following equation for the X-ray absorption coefficient is more convenient:

$$\mu = \mu_m \rho \mathrm{cm}^{-1} .$$

For water, ρ = 1.0; thus, for its absorption coefficient, $\mu_w = \mu_m$.

The CT number is the CT quantitative description; the CT numbers of air, water and ice are defined as −1000, 0 and −100. The X-ray absorption coefficient can be converted to the CT number by the following relationship:

$$\mathrm{CT}_{\mathrm{number}} = \frac{\mu - \mu_w}{\mu_w} \times 1000 ,$$

where μ_w is the X-ray absorption coefficient for water. A complete set of CT images can be obtained because brightness is proportional to the CT number. The differences and changes in material composition and damage can be detected by the CT number and CT images.

Table 1
Materials and properties descriptions.

Materials	Descriptions
Asphalt binder (AH-70)	Asphalt with a penetration of 65 (0. mm at 25 °C, 100 g and 5 s), ductility of 167.3 cm (at 5 °C) and softening point of 45.4 °C
Graphite	Its particle size <150 μm, carbon content 98.9%, ash content 0.2%, iron content 0.03% by weight, the electrical resistivity 10^{-4} Ω cm
Carbon fiber	Its tensile strength 1.68 GPa, tensile modulus 752 GPa, fiber diameter 10 μm, and average filament length 5 mm, the electrical resistivity 10^{-3} Ω cm
Aggregate	A crashed basalt mineral, with a density of 2.93 g/cm^3 and the maximal size of 19 mm, their electrical resistivity was more than 10^{14} Ω cm. Limestone powders were applied as the mineral filler, with a density of 2.830 g/cm^3 and major chemical compounds: CaO content 51.5% and SiO_2 content 1.76%. The passed percentage on sieve was 100%, 97.3% and 83.7 % for the sieve openings 0.3 mm, 0.15 mm and 0.07 5mm, respectively