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Laboratory investigation of the durability of a new smart geosynthetic material

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HIGHLIGHTS

- A new smart geosynthetic named sensor-enabled geobelt (SEGB) was developed.
- The effects of three degradation tests on the durability of SEGB were investigated.
- Mechanical properties and tensoresistivity of SEGB after degradation were evaluated.
- The degradation mechanism of SEGB was analyzed.

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ABSTRACT

The durability of geosynthetics is important for their service life, transportation and long-term storage. This paper presents the effects of three accelerating degradation tests (thermal oxidation, UV radiation and corrosion) on the mechanical properties and tensoresistivity of a new smart geosynthetic material called sensor-enabled geobelt (SEGB), which is made by high-density polyethylene (HDPE) filled with carbon black (CB). Three characteristics obtained by two tensile tests with different loading speeds are considered to evaluate the durability of the SEGB: tensile strength, elongation at break and electrical resistance. The results show that the tensile strength and elongation at break decrease to different degrees. It indicates that the mechanical properties of the SEGB deteriorate after the three degradation tests. And the electrical resistance displays a sharp increase trend after the strain exceeds a certain number. That means the sensitivity of tensoresistivity improves. Furthermore, the degradation mechanism of the SEGB in the three degradation tests is demonstrated. And it indicates that the chain reactions trigger the change of these mechanical properties and the tensoresistivity of the SEGB.

1. Introduction

Geosynthetics is the generic term for a series of sheets or fibroid materials that are primarily applied in geotechnical and environmental engineering [1,2]. And the geosynthetics can appear in multiple forms such as geogrids, geotextiles, geomembranes, geomeshes, geosynthetic clay liners, geomats and geonets. Basically, all of these geosynthetics are made of polymers. After decades of material science development, the polymer used in geosynthetics production has been converted from the original polyamide (PA) to various types such as polypropylene (PP), polyethylene (PE) and polyethylene terephthalate (PET) [3]. Benefiting from the advantages of these polymer materials, most geosynthetics are stable, strong, light, widely available, easy to transport and cost-competitive against other alternatives. Therefore, the emergence and prosperity of geosynthetics in civil engineering are nothing short of remarkable.

Most often, geosynthetics are extensively used in civil engineering projects for reinforcement applications. Examples include the stabilization of highway slopes and embankments [4,5], reinforcement of foundations [6–8], and reinforcement of paved roads to mitigate cracking and rutting [9]. As geosynthetic-reinforced structures become more globally widespread, it becomes increasingly vital to ensure that these structures are safe and offer a satisfactory level of serviceability through health monitoring and timely measures to prevent catastrophic failures. One of the most important aspects of health monitoring in geosynthetic structures is to monitor the geosynthetic strain during the service life and extreme (e.g., seismic) events. Therefore, many attempts to measure soil strains and in-soil reinforcement strains include the use of digital imagery, X-rays, tomographic techniques and fiber optic cable

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[10–16]. However, the limited monitoring scope of these techniques renders them impractical for field-scale structures. Consequently, smart geosynthetic materials that are made from conductive polymer composites are attempted for use in monitoring areas. Existing research shows that using carbon black as filler can make the polymer composite conductive [17–19], and its conductivity certainly changes with pressure, tension, temperature, etc. Therefore, the smart geosynthetics made from this type of material have great potential in the monitoring of numerous fields of engineering [20].

Hatami et al. proposed a new concept called the sensor-enabled geogrid (SEGG) to add a self-sensing function to conventional geosynthetics by adding a critical concentration of CB to the polymers [21]. This function affords geosynthetics a unique and significant characteristic, by which their tensile strain can be more conveniently measured than the conventional monitoring methods. However, an important unsolved problem remains in the referenced SEGG studies: the strain-conductivity response of SEGG materials with multiple ribs is complex, and the accuracy of the measurement results cannot be fully ensured [22]. Therefore, to ensure the measurement accuracy, a new smart geosynthetic named sensor-enabled geobelt (SEGB) was developed by the authors [23]. The SEGB of high-density polyethylene (HDPE) filled with carbon black (CB) was fabricated in both industry and laboratory. A series of in-isolation tests or in-soil tests was performed to study its mechanical properties and tensoresistivity performance.

In addition to being used as reinforcements, SEGBs are also used in other fields such as landfills, deep foundations, and waste disposal. The environment of these engineering applications is extremely complex and often accompanied by high temperature, high heat, radiation, and acidic/alkaline liquids. These aspects have raised the requirements for the durability of SEGBs. In addition, SEGBs are expected to have favorable durability during the service life, transportation and long-term storage. However, durability studies of SEGB or SEGG remain scarce. In contrast, the studies on the durability of polymer materials have more results. For example, several long-term durability tests of polyolefin geotextiles were compared with the oxidative resistance of HDPE by Mueller [24]. The results show that the lifetime of the HDPE is essentially determined by the slow loss of stabilizers, and the mechanical property degradation strongly depended on the oxidation conditions. Lodi found that only the ultraviolet part of light was harmful to the geosynthetic materials, and each material was sensitive to a particular wavelength [25]. The main reactions in the degradation of HDPE during long-term aging were presented by Kriston and Mitroka [26,27]. Zanasi demonstrated a series of suitable accelerated aging methods of HDPE [28]. These studies add great value to the durability study of SEGB from content to method.

Therefore, to evaluate the durability performance of SEGB, three experiments were performed to explore the effects of adverse conditions (thermal oxidation, ultraviolet radiation and acid/alkaline corrosion) on the mechanical properties and tensoresistivity of the SEGB.

2. Fabrication and features of SEGBs

2.1. Materials and production processes of SEGBs

Two types of raw materials were used to make SEGBs: virgin polymer using a high-density polyethylene (HDPE) and a conductive masterbatch using super conductive carbon black (masterbatch of CB). Because the components of the super conductive carbon black and their contents were disclosed by the supplying companies, the filler content of the CB-filled SEGB specimen in this paper was the mixing ratio of the conductive masterbatch to the virgin polymer (HDPE) instead of the actual content. Table 1 shows three parameters of the HDPE.

First, the masterbatch of CB was manually mixed with HDPE until the polymer beads appeared to be evenly distributed in the mix. Then, the mixture was extruded using a twin-screw extruder with a mixing section. All polymer pellets in the batch should be preheated and completely and uniformly melted. The temperatures in the working zones of the extruder were set to 180 °C, 185 °C, 190 °C, 200 °C, 213 °C, and 205 °C. The compounding procedure began after reaching the target temperature, and the mixture was melted in the working zones. The compounding procedures began after reaching the target temperatures, and the pellets melted in the working zones. Once extruded, the samples were compression-molded.

2.2. Determination of the percolation region

As the filler, the content of carbon black significantly affects the conductivity of the SEGB. Therefore, the optimal mixing ratio of black carbon and HDPE is important to find before the production of SEGBs. This optimal mixing ratio can be derived from the percolation theory [19,21], and the percolation phenomenon is shown in Fig. 1. Specifically, first, a batch of samples with different carbon black contents should be made. Then, a variation curve of the surface resistivity with the CB content can be certain based on a test. Finally, the carbon black content at the sharp turning point of resistance is the optimal value. The test is as follows:

The CB and HDPE mixture was poured into a prepared steel mold and pressed for 10 min at 180 °C. Then, the mold is put into the laboratory plate vulcanizing press machine to cool under a 24 MPa compressive stress [19,21]. The specimen with the dimensions of 160 mm × 110 mm × 4 mm is obtained.

The specimen and stick conductive tapes are cleaned on the measuring points, and the surface resistance can be measured with a FLUKE insulation tester. The surface resistivity is defined as follows:

$$\rho_s = R_s \frac{l}{d} \tag{1}$$

where ρ_s is the surface resistivity; R_s is the surface resistance; d is the electrode distance perpendicular to the two conductive adhesive tapes; l is the electrode length.

Fig. 2 shows the variation curve of the surface resistivity with the CB content. At the point of 47.5%, the surface resistivity has a sharp decrease. Hence, the optimum CB content value was 47.5%. The SEGBs in this paper were produced based on this CB content.

2.3. Mechanical properties of SEGBs

The tensile strength and elongation at break are two extremely important mechanical indices. Specifically, the elongation at break refers to the ratio of the sample length after breakage to its original length. Both tensile strength and elongation at break can be obtained through tensile test I.

Tensile test I was strictly performed according to the Plastics-Determination of tensile properties [29]. Fig. 3 shows the dimensions (160 mm × 15 mm × 1.7 mm) of the SEGB specimen in tensile test I. Tensile test I was performed on a universal testing

Table 1
Physical properties of HDPE.

Density (kg/m^3)	Tensile strength (MPa)	Elongation at break (%)
0.954	26	500