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Effect of basalt fiber surface silane coupling agent coating on fiber-reinforced asphalt: From macro-mechanical performance to micro-interfacial mechanism

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HIGHLIGHTS

- SCA reduces hydrophilicity to enhance BF water damage resistance and compatibility with asphalt.
- SCA makes BF surface become rough to enhance chemical bonding and mechanical occlusion effect.
- Better adhesion and force-transmitting between BF and asphalt helps to gain stronger interaction.
- SCA heightens low and high temperature mechanical performances of fiber-reinforced asphalt.

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ABSTRACT

The main goal of our work was to study mechanism of interfacial adhesion between basalt fiber and asphalt. Solution of silane coupling agent (2.5 wt%, KH-550) was used to modify fiber surface. Modified fibers were then used for fiber-reinforced asphalt fabrication with different fiber concentrations (0.5, 1.0 and 1.5 wt%). Samples were analyzed by DMA, DSR, EDS, ESEM, ACAM and FTIR. Treatment with KH-550 resulted in fibers with rough surface and weak hydrophilicity. It also increased surface area of fibers, improved their compatibility with asphalt and enhanced their chemical bonding with asphalt, all of which resulted in overall increase of mechanical performance of asphalt. Our research provides foundation for fiber surface modification for applications in road pavement engineering.

1. Introduction

In recent years, China has experienced very rapid development of traffic and transportation industry. However, asphalt on roads often lacks needed rutting resistance, which accumulates early damages and shortens pavement service life. Thus, it is important to figure out how to enhance road performance and extend pavement's life.

Modern binder theory believes that regular asphalt mixture has a multistage spatial network structure, which consists of asphalt binder, aggregates and air. Asphalt binder is the most important component of this mixture. Variety of fibers and fillers can be dispersed in asphalt binder. Dispersed fibers reinforce asphalt on different levels blocking crack formation propagation, thus preventing or minimizing rutting deformation. Therefore, researchers and pavement engineers studied and developed methods of adding fiber stabilizers into asphalt.

Basalt fibers (BFs) are eco-friendly mineral fibers, which attract lots of attention from researchers and constructors because of their excellent stability, as well as corrosion, combustion and high temperature resistances. BFs are found applications in variety of engineering fields such as aerospace and in different materials, such as polymer matrix composites, plastics and cements [1–6]. Lignin fibers (LFs) were frequently used in the past in road engineering. LFs tend to carbonize and shrink when agitated at high temperature during asphalt preparation and construction. In contrast to LFs, BFs maintain their shape and function during the same high temperature procedures. A lot of research was conducted showing that high surface area of BFs enhances and stabilizes asphalt. BFs provide multiple reinforcing and bridging functionalities and help asphalt mixtures to withstand high temperature and minimize shearing deformation, and low temperature cracking, and, at the

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same time, significantly improve fatigue failure, water damage and freezing/thawing cycle resistances [7–11]. However, BFs are not soluble and melt at extremely high temperatures. They also tend to segregate in asphalt mixtures and integrate poorly. Thus, it is necessary to enhance the adhesion between BFs and asphalt and achieve their better dispersion. There are relatively few studies on disadvantages of BFs because of their prominent physical and chemical properties. BFs are reported to enhance performance of different matrices, however, bonding between BFs and matrix material are frequently poor due to the interfacial incompatibility [12].

Typically, BFs are machined and their surface is mechanically roughened. Rough surface helps to improve interaction and adhesion with the matrix, yet, even with roughened surface, is still difficult to achieve good interfacial bonding strength. Moreover, mechanical BF surface modification needs sophisticated equipment and strict procedure control, both of which significantly increase the total costs. Thus, a more efficient method for BF surface modification is needed. Chemical modification of fiber surface could enhance interaction of fiber with the matrix material, improve BF wettability and even create chemical bonds with the matrix. We believe that formation of stronger interface between BFs and the matrix should help the material to withstand damages due to the drastic temperature changes and other harsh environment, eventually improving performance of fiber-reinforced materials.

Silane coupling agent (SCA) is an organic compound with two polar groups which is of great importance to bond materials with different type and performance, improve the interfacial condition and bonds with variety of materials (such as glass fibers, adhesives, coatings, textiles, fillers) and improve interaction between the matrix and silane-functionalized compound by forming molecular "bridges" [13–15]. Coupling mechanism of inorganic substrate by silane is shown in Fig. 1. Despite of widespread usage of SCA, there are only few studies reported on SCA applications in asphalts. SCA was used to modify the surface of basalt aggregates, fillers and nano-particles to improve resistance of ultraviolet aging and moisture damage [16–19].

In this paper, we used SCA to modify BF surface to gain modified BF (MBF) and promote interaction between fibers and asphalt to improve cohesion of fiber-reinforced asphalt (FRA). We compared performance of a typical asphalt matrix (AM) with BF-reinforced asphalt (BFRA) as well as with MBF-reinforced asphalt (MBFRA). This present work has a significant value and could be an important reference of mineral fiber surface modification for road engineering.

2. Materials, procedures and methodologies

2.1. Raw materials

Traditionally, asphalt binder is composed of asphalt matrix, fine powder and fiber. Considering of tackifying and thickening effect of powder, as well as if too much powder is blended in asphalt, the asphalt self-adhesive performance would decline and fiber reinforcement may be weakened, consequently, research focuses on influences of SCA on BF and asphalt without regard for powder. Raw materials are: (a) 6 mm short-cut BF; (b) γ-ammonia propyl triethoxysilane KH-550 ($H_2NCH_2CH_2CH_2Si(OC_2H_5)_3$) as SCA; (c) 70$^{\#}$ road asphalt. The main technical indices of BF, SCA and AM are presented in Tables 1, 2 and 3, respectively. In all our experiments we used the same type of AM and fibers and the only difference was fiber treatment with SCA.

2.2. Modification of BF surface

SCA solution should be prepared first and then using this solution to immerse BF for surface modification. Procedure of treating BF surface with SCA are as follows: (a) ethanol solution is prepared by dissolving absolute ethanol in distilled water with 3:7 ratio at room temperature; (b) 2.5 wt% of KH-550 is added into above

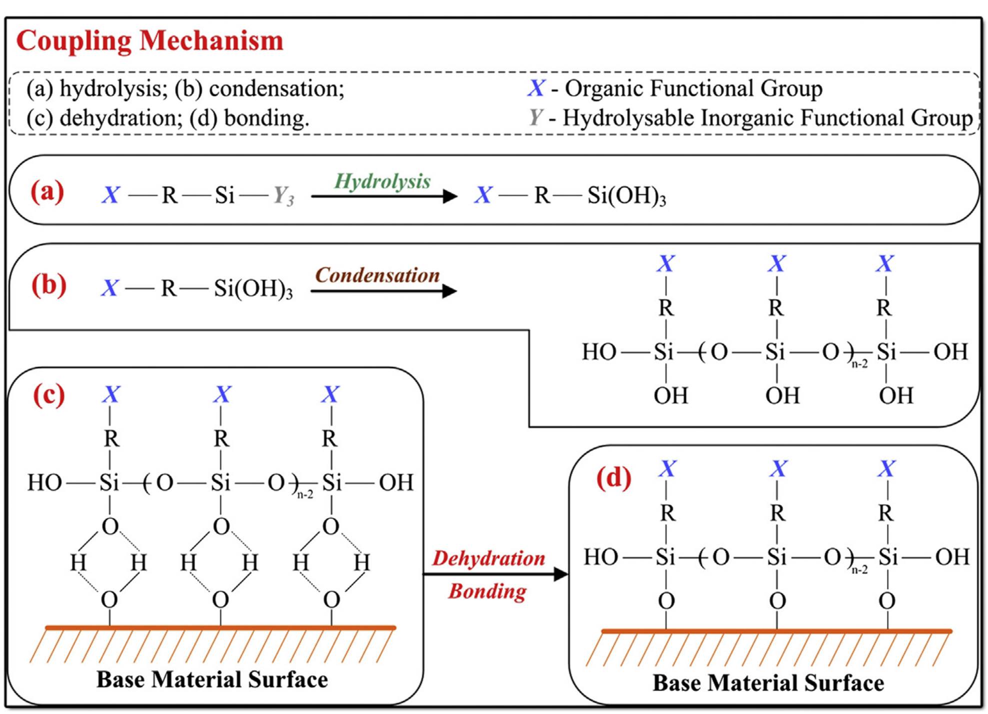

Fig. 1. Coupling mechanisms of common silane coupling agent.