Effects of Surface Treatments on Mechanical Properties of Continuous Basalt Fibre Cords and Their Adhesion with Rubber Matrix

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(Received December 16, 2015; Revised May 18, 2016; Accepted May 21, 2016)

Abstract: To improve the mechanical properties and the adhesion to a natural rubber (NR)/styrene-butadiene rubber (SBR) matrix, continuous basalt fibre (CBF) cords with and without a silane coupling agent (3-aminopropyl)triethoxysilane (KH550) treatment were dipped into a typical resorcinol-formaldehyde-latex (RFL) system. The breaking force and elongation at break of the cords were tested using a universal testing machine. The adhesive properties were evaluated by both static mode and dynamic (fatigue) mode with H-shape cord-rubber samples. An elastomer testing system was employed to conduct the fatigue test, and the evolution of the adhesive properties between the CBF cord and the NR/SBR matrix was tracked. The interfacial fracture caused by H pull out and fatigue were both observed with a scanning electron microscope (SEM). The results of this investigation show that the RFL-dipping treatment can significantly improve the mechanical properties of the CBF cord and its adhesion to the NR/SBR matrix, and the pre-treatment of the CBF cord with KH550 can further improve the interfacial fatigue property.

Keywords: Continuous basalt fibre, Adhesion, Fatigue property, Mechanical properties, Surface treatment

Introduction

Recently, high-performance fibres have gained more and more attention as reinforcements for polymer-based composites from both industrial and academic worlds. Continuous basalt fibre (CBF), known as a type of natural mineral fibre, has been introduced into this field and has been studied [1] due to its excellent resistance to heat and cold, mechanical properties, chemical stability and relatively low cost. In addition, the increasing concern regarding environmental issues has also promoted the use of natural fibres [2,3]. With similar basic components but exhibiting a better performance, CBF is considered a serious competitor to glass fibre. New potential applications have been intensively investigated, though applications in the rubber industry, such as the use of CBF as a skeleton material, have seldom been mentioned.

In addition to the mechanical properties of a skeleton material, understanding the adhesion between the skeleton material and the rubber matrix is also very important [4]. The surface of CBF is smooth and lacks sufficiently reactive groups (except -OH), which leads to a relatively poor adhesion to the rubber matrix. So far, several types of surface treatment methods, such as acid or alkali etching, modification with silane coupling agents, surface coating, and plasma treatment, have been studied [5-8]. However, the previous work mainly focused on either the mechanical properties of CBF or the adhesion to thermoplastic/thermoset resin matrices, while little research was conducted on CBF/rubber composites. Actually, to improve the adhesion between a skeleton material, for example, nylon, polyester and aramid cords, and a rubber matrix, the resorcinol-formaldehyde-latex (RFL) system and its modified versions have been shown to be an effective solution, and RFL-dipped cords have been widely used in a series of rubber products, such as tires [4,9,10]. The structure of cured RFL has been viewed as a continuous resin phase with dispersed latex particles, and the morphology of RFL proposed is shown in Figure 1 [11-13]. During vulcanizing, the sulphur from the rubber matrix

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Figure 1. Proposed RFL morphology [13].
diffuses into the RFL layer, and sulphur cross-links form between the latex portion of RFL and the rubber matrix. Shirazi et al. [14] also reported that for a peroxide cured system, bonding happens between rubber and both the latex and resin parts of RFL. However, the effects of RFL dipping on the mechanical properties of CBF cord and its adhesion to a rubber matrix have not yet been studied.

An evaluation of the adhesive properties between CBF cord and the rubber matrix is also very important when considering the applicability of a CBF skeleton for rubber products. Normally, cord-rubber adhesion strength should be evaluated in both static and dynamic modes, considering the actual service conditions of rubber products. The H pull-out test is a type of standardized test method (ASTM D4776, GB/T 2942, etc.) and is usually employed to investigate the static adhesive property of raw materials to characterize the quality. For rubber products, the dynamic adhesive property is more important in determining the service life of an adhesive interface because under actual service conditions, rubber products normally experience periodic extensional and compressional forces. To date, there is no special standard for the testing of dynamic adhesive properties, but the fatigue test is a common approach to simulate the cyclic strain or stress an actual product might experience. Some studies have mentioned using the fatigue test on cord-rubber systems to estimate the dynamic adhesive properties for nylon, polyester and steel cord [15-19], and the fatigue resistance of the cord was also studied [20]. Jamshidi et al. [4] investigated the relationships between dynamic measurements and the static adhesion test, aiming to simplify the prediction of the durability of the system.

Based on a review of the literature, there is little information available on the applications of CBF as a skeleton material in rubber products, and the surface treatment method developed for rubber-based composites has not yet been mentioned. The present study was performed to focus on the effects of RFL dipping on the mechanical properties of CBF cords and their adhesion to a NR/SBR matrix. Aiming to further improve the adhesion, the use of a silane coupling agent (3-aminopropyl)triethoxysilane (KH550), which has been approved to be effective in improving the adhesion between basalt fibre and thermoset matrices [21-24], was also discussed as a pre-treatment that was applied to the CBF cords before RFL dipping, and the results were compared with those of directly RFL-dipped samples. An MTS Elastomer Test System (MTS) was employed to simulate displacement-control conditions and to record the evolution of interfacial adhesive properties; the interfacial fractures caused by fatigue were observed with SEM.

Experimental

Materials

CBF (BC11-200) was supplied by Sichuan Aerospace Tuoxin Industrial Co., Ltd., and CBF cord (200 tex/3) was produced by Shandong Tianhengfiber Co., Ltd. KH550 was purchased from Lvxun Chemical, Kunshan, China. The composition of the rubber compound used in this study is shown in Table 1. NR (SMR 10) was from Malaysia, and SBR (E53) was supplied by Sinopec Qilu Co., Ltd. ZnO was supplied by Zhenjiang Hakusui Chemical Co., Ltd. Stearic acid was supplied by Qingdao Kangan Rubber Technical Co., Ltd. Carbon black N330 and carbon black N660 were purchased from Kabote (China) Investment Co., Ltd. Polymerized 1,2-dihydro-2,2,4-trimethyl-quinoline (TMQ) was supplied by Sinopec Nanjing Chemical Industries Co., Ltd. Dibenzothiazole disulphide (MBTS) and tetramethyl thiruam disulphide (TMTD) were supplied by Puyang Willing Chemicals Co., Ltd. Aromatic oil (VIVATEC 500) was supplied by Hansen & Rosenthal Group. The adhesive agents RA (methylene donor) and RE (Acetaldehyde-resorcinol copolymer) were supplied by Wuxi Huasheng Rubber Technical Co., Ltd. Insoluble sulphur was supplied by China Sunsine Chemical Holdings Co., Ltd. The RFL (resorcinol-formaldehyde-latex) dipping system was supplied by Shandong Tianhengfiber Co., Ltd. Other reagents were commercially available and used as received.

Surface Treatments of CBF Cords

Desizing

To remove the sizing and any other dirt on the surface, CBF cords were desized by soaking in acetone for 50 min, then washed with distilled water, and dried in vacuo at 105°C for 30 min to obtain CBF-D.

Modification with KH550

A water/alcohol (1:1 mass ratio) solution containing 0.75 wt% KH550 was prepared, and it was left standing for 5 min. The desized CBF cords were soaked in the solution for 30 min at room temperature, and then the wetted cords