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Scratch behavior of the aged hydrogenated nitrile butadiene rubber

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ABSTRACT

The objective of this work was to study the scratch behavior of the aged hydrogenated nitrile butadiene rubber (HNBR) including its scratch damage modes and their corresponding mechanism. A home-made device was used to perform the scratch testing on the virgin and thermal-aged HNBR substrates with a progressively increasing depth. The scratch resistance of HNBR declined dramatically with the increase of the aging time. The surface topography and damage modes of the scratched HNBR samples were investigated. Two types of scratch damage mode, i.e. the flake peeling and the helical-form damage were observed and both exhibited the characteristics of tearing. Specimens of two different geometries were used to measure the effects of aging time on tear strength of HNBR. It was found that there was a strong correlation between the strength data from two types of tear tests with the scratch damage modes. This finding provides a valuable guidance for improving the scratch resistance of the rubber materials and prolonging their service life.

1. Introduction

During the daily use of rubber components over a wide range of applications such as tires, seals and vibration absorbers etc. [1], the surface scratch due to the relative movement with other counterparts not only seriously decreases the esthetics, but also degrades the material performance and eventually shortens the service life of the rubber products. Moreover, the scratch performance of rubber materials can be tremendously worsened by the inevitable aging caused by the harsh service environment and complex loading conditions [2–4]. Therefore, the study of the scratch behavior of the aged rubber is of great importance for engineering applications.

Different from the investigation on the rubber wear, which focuses on the wear volume loss during a repeated abrasion [5–9], the research on rubber scratch, a single pass with a point contact, discusses the evolution and mechanism of the scratch damage [10]. The scratch behavior has been intensively studied on a wide range of plastic polymers such as polycarbonate [10,11], polymethyl methacrylate [12], polypropylene [13], thermoplastic polyolefin [10,14] and polymer-based composites [15–17], but not much attention has been given to rubbers. Schallamach investigated the single pass friction behavior of natural rubber using a stainless steel needle and found that the tensile stress in the substrate behind the needle produced lateral tears of the rubber across the sliding trace [18–20]. Briscoe found that the decreased cone angle of the scratch tip led to a more severe scratch damage of the rubber substrate and the bulk material tearing was accounted for the damage [21]. Low indicated that the scratch velocity could aggravated the scratch damage of styrene butadiene rubber, neoprene and ethylene propylene diene monomer rubber while the carbon black reinforcement could improve their scratch resistance [22]. The correlation between the material properties and possible scratch damage modes of rubbers was not fully investigated. Moreover, little work has been conducted to study the scratch behavior of the aged rubbers.

In this work, the scratch tests with a progressive increasing scratch depth were carried out on the virgin and thermal aged HNBR using a home-made scratch device. The surface morphology of the scratched HNBR was investigated to identify the scratch damage modes. Then two types of tear strength were measured for the samples with different aging time. The correlation between different scratch damage modes and tear strengths was established. This study could help the material researchers to better understand the scratch behavior of rubbers and thus to improve its overall scratch resistance.

2. Experiment

2.1. Material and thermal aging experiments

The HNBR plates (Kaidi Northwest Rubber Co. Ltd.) were 90% saturated, containing 50% acrylonitrile content and reinforced

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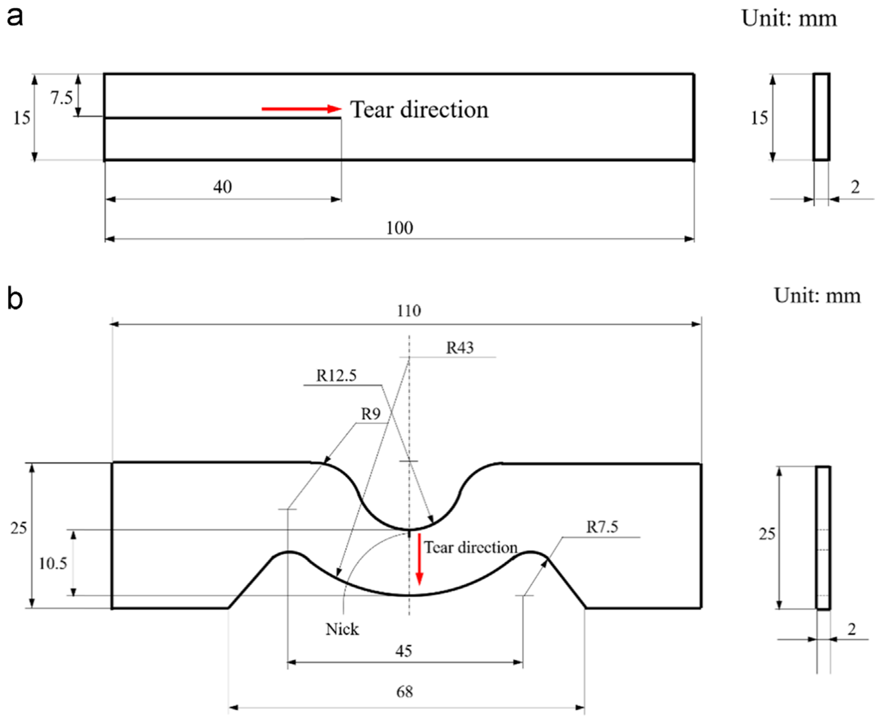

Fig. 1. Shape and size of the tear specimens of HNBR. (a) Type T (b) Type B.

with 30 phr hydrated silica. All the samples were thermally aged at a moderate temperature, i.e. 90 °C (about 120 °C higher than the Tg of HNBR), in an environment chamber (WG03, INBORN) referencing the literatures [23,24]. After reaching the prescribed aging time, the samples were removed from the chamber and air cooled to the ambient temperature. Then, they were stabilized in air for more than 16 h.

2.2. *Tear tests*

An electronic universal testing machine (AGS-J, SHIMADZU) was utilized to measure the tear strengths of the HNBR at room temperature (about 25 °C). Two types of tear specimen, type T (Fig. 1(a)) and type B (Fig. 1(b)), were selected following ASTM D624-00 (2012) since they represented two different fracture modes in nature, i.e. type T tear for mode III fracture and type B tear for mode I fracture respectively. The tear tests were carried out under a loading rate of 500mm/min for type T and 50 mm/min for type B tearing respectively according to ASTM D624-00 (2012). Then the values of the tear strengths were calculated and the average value from five repeated tests was recorded.

2.3. *Scratch tests and post-scratch analysis*

The scratch tests were performed under the ambient temperature using a home-made scratch device, which is schematically illustrated in Fig. 2. The scratch test unit comprises of a servo motor that drives the scratch tip moving tangentially with a prescribed speed. The increasing scratch depth is controlled with the help of another servo motor. The rigidity of the apparatus is enough to prevent the possible vibrations during scratch. To avoid its arching in front of the tip during scratching, the rubber sample was glued on an epoxy plate and then the plate was well clamped on the test stage. A conical stainless steel indenter (half cone angle: 22.5°) with a spherical tip (diameter (d): ≈ 0.1 mm) was used in this work. A progressive increasing scratch depth (D) from 0 to 1.5 mm was adopted. The scratch length was 100 mm and the scratch speed was kept constant at 25 mm/s. The formation of the scratch damages has been in-situ observed with a high-speed video (Photron FASTCAM Mini UX50). Three duplicated scratch tests were carried out under each aging condition. The surface topography of the scratched sample was characterized using a super depth digital microscope (VHX-1000, Keyence). The good resolution (600 × 600 dpi) images of the scratches were obtained using an optical scanner (LiDE 210, Canon).

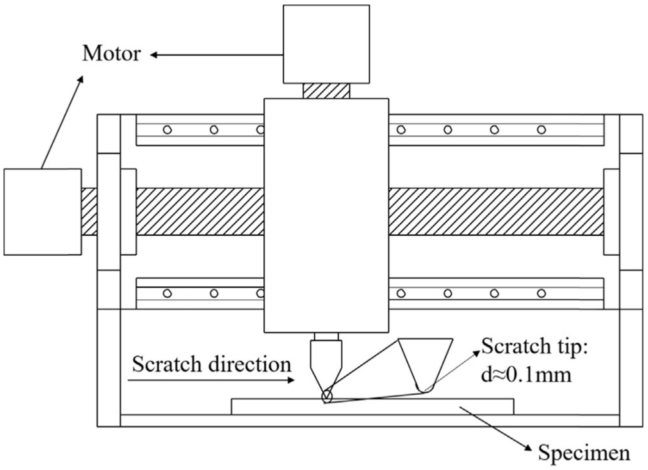

Fig. 2. Schematic illustration of the home-made scratch device.

3. Results and discussion

3.1. *Aging effect on the scratch behavior*

The scratch damage images of the HNBRs at different aging time under a linearly increased scratch depth are exhibited in Fig. 3. It is clear that the longer the aging time is, the more severe the scratch damage is. Only a minor scratch is visible for the virgin specimen even at the latest stage of the scratch process. However,