Tribology International 101 (2016) 122–130

Contents lists available at ScienceDirect

Tribology International

journal homepage: www.elsevier.com/locate/triboint

Improving the friction and abrasion properties of nitrile rubber hybrid with hollow glass beads

Yanbao Guo [a,b,*], Zhiqiang Cao [a], Deguo Wang [a], Shuhai Liu [a,b]

[a] *College of Mechanical and Transportation Engineering, China University of Petroleum, Beijing 102249, China*
[b] *Laboratory of Tribology and Surface Engineering, China University of Petroleum, Beijing 102249, China*

ARTICLE INFO

Article history:
Received 27 January 2016
Received in revised form
15 April 2016
Accepted 17 April 2016
Available online 22 April 2016

Keywords:
Nitrile rubber
Hollow glass beads
Friction
Abrasion

ABSTRACT

This paper presents the results of an investigation into the effects of hollow glass beads (HGB) fillers on the tribological behaviors of nitrile rubber (NBR). Properties like tensile strength, fracture energy and glass transition temperature were studied. The tribological tests show that the HGB hybrid into rubber matrix can reduce the friction coefficient of NBR and enhance its anti-wear ability. The fracture energy and interfacial strength investigation indicated that the HGB filler have a good interfacial action and can enhance the anti-wear behaviors of original rubber. Furthermore, the greater apparent effective aspect ratio of filler could improve the interfacial strength and benefit to the enhancement of anti-wear behaviors of polymer.

1. Introduction

Nitrile rubber (NBR) is widely used as sealing and wear-resistant parts of polymer material due to its excellent physical properties, outstanding resistance to water and oil [1,2]. However, the abrasion of NBR is still unavoidable when the seal assemblies are used under rough conditions, especially in the movement systems. Such as screw pump, filtration, and separation equipment for petroleum production [3,4]. 60–80% of failures are caused for the wear of rubber, which leading to enormous economic loss [5]. Many studies have been carried out to investigate the abrasion behaviors of NBR including the operating conditions, its structure factors, and so on [4,6,7]. Cao et al. [8] studied cross-linked heterogeneity of NBR effects on the abrasion behaviors. Guo et al. [9] prepared bimodal nitrile butadiene rubber and tested its tribological properties. The results indicated that the form and density of the network structure can be controlled from elastomeric networks to thermosetting resin networks. And the tribological tests shown that common elastomers cannot simultaneously reduce friction and wear of rubber, whereas, the bimodal elastomer [10] can efficiently solve this problem.

In addition, as rubber application demand compounds with high performance, many new rubber composites with improved properties are developed. Many types of filler are playing more and more important roles in reinforcing polymer and reducing its cost due to the limit of oil resources and the urgent demand of environmental protection [11]. Thus, the development of filler/polymer composites has attracted increasing attention. Gatos [12] investigated the aspect ratio of layered silicate platelets on the mechanical and oxygen permeation properties of hydrogenated nitrile rubber/organophilic layered silicate nanocomposites. Tian et al. [11] prepared fibrillar silicate/rubber composites. Surface modification of fibrillar silicate could improve the dispersion of fibrillar silicate and enhance the interfacial adhesion between fibrillar silicate and rubber. Glass bead is a kind of small solid spherical particle with smooth surface. Polymers filled with glass beads have less interface stress, good mechanical properties. Hollow glass beads (HGB) consist of outer stiff glass and inner inert gas, which results in a number of unique properties, such as light weight, low thermal conductivity, low dielectric constant, and so on. Precisely because of these properties, HGB has been used in the fabrication of polymer composite materials for different applications [13]. Recently, the researchers investigated the effect of the filler content, morphology, and surface treatment on the mechanical properties of glass beads filled polymer composites, such as polyethylene (PE) [14], polypropylene (PP) [15], epoxy [16,17], syntactic foams [18] and so on. Generally, when the HGB content is low, the composite referred as HGB modified polymer [19]. The hybrid HGB could reinforce the mechanical properties of polymer. Therefore, the hollow glass beads can be used as a good kind of fillers in rubber, plastics, and coating materials for production of light and special products [20].

---

[*] Corresponding author at: College of Mechanical and Transportation Engineering, China University of Petroleum, Beijing 102249, China.
E-mail address: gyb@cup.edu.cn (Y. Guo).

http://dx.doi.org/10.1016/j.triboint.2016.04.022
0301-679X/© 2016 Elsevier Ltd. All rights reserved.

In this study, different specimens of NBR hybrid with HGB were prepared by blending HGB into nitrile rubber according to a certain proportion of formula through two-roller mill and sulfuration process. The samples were characterized by universal test machine, DMA and DSC. Friction and abrasion behaviors of NBR hybrid with HGB have been investigated by a ball-on-flat tribometer. At the same time, the microstructural features of the composites and wear surface were analyzed by scanning electron microscope (SEM).

2. Experiments

2.1. Materials and specimen preparation

The nitrile rubber (N215SL, acrylonitrile content of 48%) was purchased from JSR Corporation, Japan. Sulfur (99.5% purity) was supplied by Kezhan Chemical Company (China) as the curing agent. The hollow glass beads (HGB) were supplied by Shanghai huijing Sub-Nanoseale New Material Co., Ltd. Three styles of HGB with different size of average diameter 120 μm, 75 μm and 18 μm, the micro-morphology of the three styles HGB are shown in Fig. 1. The shell thickness parameter was provided by the HGB supplier. It is about 8–10% of the whole diameter, it can be easily seen from the broken SEM image of the hollow glass bead as shown in Fig. 2. The rubber vulcanization accelerator (N-Cyclohexy-2-benzothiazole sulfonamide, CBS; Tetramethyl thiuram disulfide, TMTD), Zinc oxide (ZnO) and other ingredients were obtained as commercial grade chemicals and used without further treatment. The formula of specimens is shown in Table 1. Furthermore, unfilled NBR specimen was also prepared for contrast tests according with the formula in Table 1. The NBR vulcanizates were well prepared with two-roll laboratory mill and then cured in hydraulic press under a pressure of 20 MPa at 155 °C. The optimal cure time was determined by a moving die rheometer (GoTech-M2000A, China).

2.2. Experimental apparatus and measurements

The uniaxial tensile behaviors of rubber specimens were tested by a universal test machine (WDTII-20, China) according to the ISO 37: 2011. In this study, the crosshead displacement rate was set at 50 mm/min, and the initial separation distance between two clamp holders was 36 mm. Five different samples were measured to obtain an average value. Furthermore, the unnicked angle tearing test was conducted using the same universal test machine with a speed of 5 mm/min to determine the fracture energy (G_c) of specimens which could be calculated as following [21].

$$G_c = \frac{2F}{t} \tag{1}$$

where F is the tear force and t is the thickness of test piece.

The dynamic mechanics analysis (DMA) of NBR specimens was investigated by dynamic mechanical thermal analysis apparatus (NETZSCH, DMA242C, Germany) under stretch mode. The dynamic tensile modulus was tested under frequency of 1 Hz with the temperature rise rate of 3 °C/min from −60 °C to 30 °C.

The differential scanning calorimetry (DSC) was carried out by a DSC instrument (NETZSCH, 204F1, Germany) with the test temperature rise rate of 10 °C/min from −60 to 30 °C. The glass transition temperature (T_g) can be determined from the DSC result.

The friction and abrasion experiments were carried out using a ball-on-flat tribometer (HT600, China) operating in ambient air (open air) which is shown in Fig. 3. A steel ball (GCr15, quenching and tempering treatment, the hardness is about 58–62 HRC) with diameter of 5 mm was the counterpart sliding against NBR specimen. The surface roughness of steel ball is around 0.8 μm. The NBR samples were vulcanized into 70 mm long, 40 mm wide and 2 mm thick. And it was bonded on the steel disc during curing process. The tribological experiment was conducted at a speed of 0.37 m/s and a constant load of 3.5 N, which lasted for 3 h. All the steel balls were ultrasonically cleaned in acetone and then thoroughly dried and all the tests were conducted at room temperature (20 ± 2 °C) and a relative humidity of 25%. During the friction experiments, the friction force and coefficient were monitored continuously by strain gauges. The specific weight wear rate (R_w) was calculated

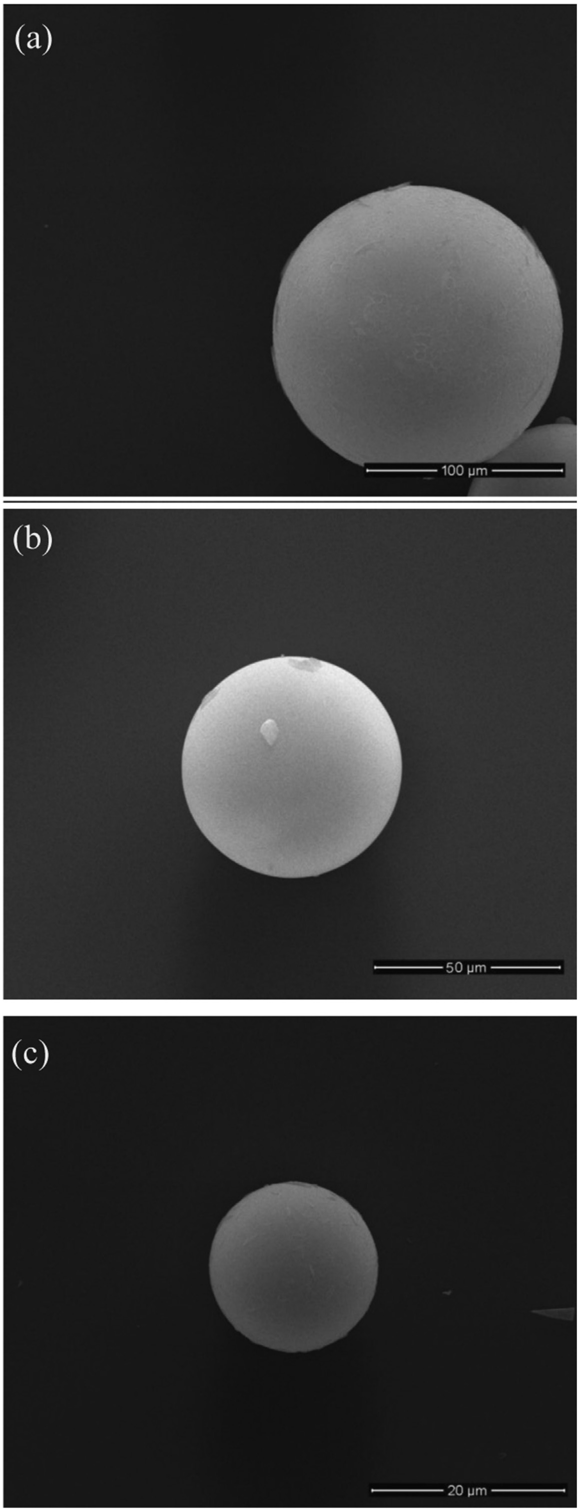

Fig. 1. SEM images of hybrid particulates for (a) HGB120, (b) HGB75 and (c) HGB18.