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Effect of abrasive size on friction and wear characteristics of nitrile butadiene rubber (NBR) in two-body abrasion

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ABSTRACT

Elastomeric seals are prone to failure caused by abrasion during sliding against rough surfaces. This study is devoted to investigate the two-body abrasion wear characteristics of NBR and effect of abrasive size on abrasive wear. The reciprocating abrasive wear tests were performed on a NBR pin against a SiC sandpaper, the abrasive sizes of SiC ranging from very large (200 μm) to small (2.5 μm). The morphologies of the NBR worn surface were examined using scanning electron microscopy and surface profilometry. In addition, the friction coefficients and wear rates were analyzed and compared. The results showed that abrasive size had a significant effect on the wear mechanical and tribological properties of the NBR. Overall, the wear mechanism of NBR transformed from abrasive wear to adhesive wear as the abrasive size decreasing. It is shown that for small abrasives, the friction coefficients decrease with the increasing abrasive size. However, for large abrasives, the reverse trend is observed. This difference is partially explained by the changes of wear mechanisms. The knowledge gained herein provides a better understanding of the rubber degradation and wear mechanism associated with abrasive sizes, and is useful to reduce sealant wear and lengthen their service life.

1. Introduction

Rubber has some extremely useful properties, such as the high Poisson ratio, large elongation-to-break and low Young's modulus, which make it suitable for many sealing applications in various equipment and appliances [1,2]. Rubber seals (especially dynamic seals) are critical and necessary components, which prevents the leakage of fluids from machine and contamination entering the machine. The rubber-moving components subjected to friction and wear can result in failure during the service life. Abrasive wear is a common type of wear mechanism which reduces the sealing ability and the service life of rubber seals [3,4]. Abrasive wear has been defined as wear by displacement of material from the surfaces in relative motion caused by the presence of hard protuberances or by the presence of hard abrasives either between the surfaces or embedded in one of them [5]. It may result from many causes including abrasives suspended in fluid, wear debris from tribo-parts, products of corrosion, airborne dust or a rough counterface finish [6,7]. Such abrasives may move freely to abrade both surfaces by a three-body abrasive wear mechanism. They may also become partially imbedded in one of the contact surfaces and act as a cutting tool resulting in two-body abrasion of the other mating surface [7,8]. Moreover, the metallic sealing counterface can also be worn and roughened by a corrosive wear mechanism and then wear of the sealing material occurred by a two-body abrasion wear mechanism. As a result, the abrasive wear is a main failure mechanism which is difficult to avoid in sealing system.

The abrasive wear has brought the widespread attention among researchers due to its destructive character and its high occurrence frequency. But the most commonly used test configuration for three-body abrasion according to ASTM standard, which is that of a test specimen loaded against a rotating rubber-wheel with abrasive particles (dry sand or wet sand) being entrained into the contact zone [9,10]. While there are few literatures focused on the abrasive wear characteristics of the rubber material. Up to now, most existing work on the friction and wear behaviors of polymers have been conducted against a relatively smooth and flat counter-pair, and the condition of the presence of abrasive particle has not been considered [11–15]. Dong et al. [16] had studied the wear behaviours of nitrile butadiene rubber (NBR) under sand water-lubricated conditions against a stainless steel counterface. They indicated that the mass concentration of sand, applied load and sliding velocity had significant effects on the tribological properties (e.g. wear volumes and surface roughness) of the rubbing pairs. Zhang [11,17] investigated the wet abrasion on several elastomeric materials, including nitrile rubber (NBR). The summary of these two different mechanisms for seal abrasive

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wear is that a local micro-tearing process and a general micro-layering process. Moreover, the 'Particle size effect' is a well-known phenomenon in two-body and three-body abrasion and also in abrasive erosion [18,19]. There remains considerable debate about the mechanisms responsible for the particle size effect. The only indisputable fact is that it arises as a result of several competing factors, such as material properties, third body behaviors, fracture of the abrasive, etc. Rubber is a viscoelasticity material, the friction force between rubber and a hard surface has two contributions commonly can be expressed in terms of the contribution of adhesion, deformation (hysteretic) components [11,20]. Hence, for rubber in two-body abrasion wear, the contribution of adhesion and hysteresis to tribological behaviors probably much more dependent on the topography of mating surface (e.g., abrasive size), yet there is still no consensus on rank and importance of the abrasive.

In this article, the friction and wear characteristics of nitrile butadiene rubber (NBR) in two-body abrasion wear with varied abrasive sizes are investigated to understand the abrasive wear failure at the sliding sealing interface between the rubber and degradative tribo-pairs. The effects of abrasive size on the friction coefficient, wear rate and damage mechanisms are discussed. This study aimed to provide a theoretical base to mitigate abrasive wear damage in rubber seal applications.

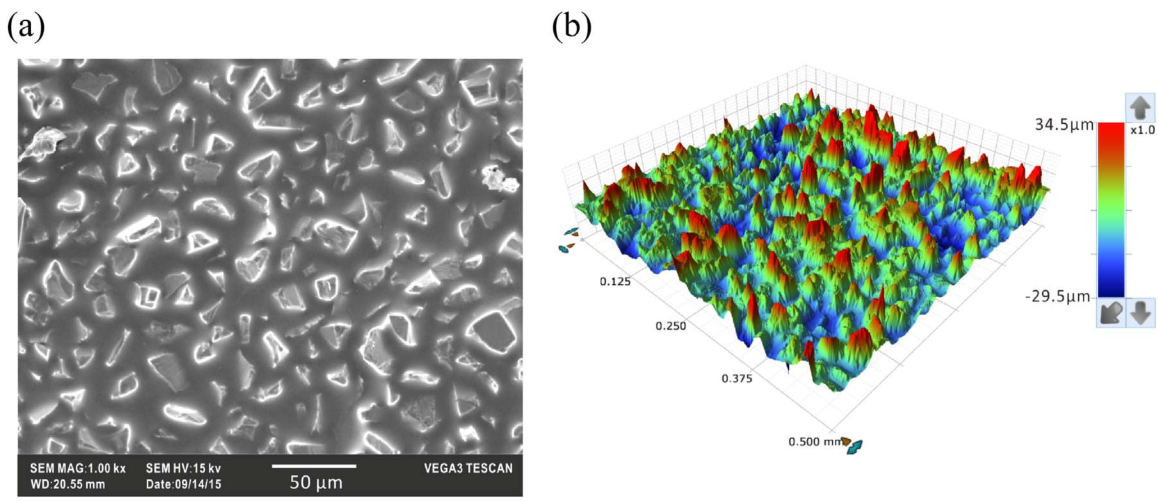

Fig. 1. SEM micrograph (a) and 3D surface profiles (b) of the P800 SiC sandpaper surface.

Table 1
Mechanical properties of NBR elastomer at room temperature.

Elongation at break (%)	Tensile strength at break (MPa)	Mass density ρ (g/cm^3)	Volume change rate	Shore hardness (A)	Poisson ratio	Young's modulus E (MPa)
398	≤ 30	1.36	< 5	70.2	0.49	7.86

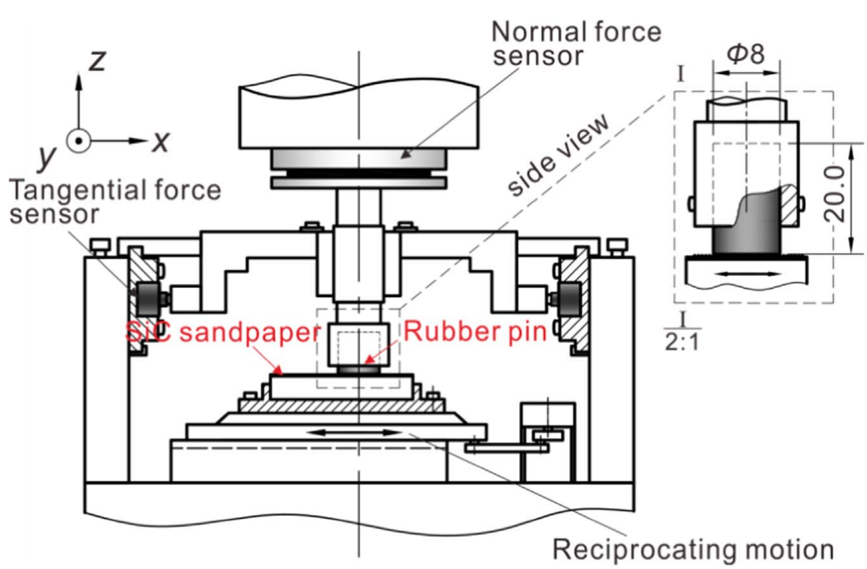

Fig. 2. Schematic diagram of the abrasive wear tester.