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Seal wear debris characterization for predictive maintenance

Surapol Raadnui

Department of Production Engineering, Faculty of Engineering, King Mongkut's University of Techology North Bangkok (KMUTNB), Pracharaj 1Road, Bang-Sue, Bangkok 10800, Thailand

A R T I C L E I N F O

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A B S T R A C T

It has been estimated that at least 30% of the maintenance expenditures of large refineries and chemical plants are spent on pump repairs. In turn, each dollar spent on pump repairs contains a 60 or 70 cents outlay for mechanical seals. Seal failure reduction is therefore a priority assignment for mechanical technical service personnel in the petrochemical industry. In general, careful examination is possible only if the entire failed seal is available. However, this specific circumstance is very rare. It was, therefore, in this particular research to propose a preliminary assessment through a systematic statistical design of experimental studies of the NBR rubber debris inspection for sliding wear: namely adhesion, abrasion, after acid attack and swelled NBR rubber specimens that point to further clues and lead to the root causes of most mechanical seal problems. A series of tests were conducted with NBR rubber specimens vs cast iron wheel. NBR rubber wear particles were systematically studied in a particular block-on-ring tribosystem to assess wear products both worn surfaces and wear debris morphology. Specifically, NBR wear debris morphology obtained through an optical microscope was used to classify NBR wear debris in conjunction with their generating wear modes/mechanisms. Implementation of such results from this particular work is a basic foundation in the study of the seal wear process and essential in the evaluation of the deterioration state of this specific tribosystem. Study of seal wear particles can then be applied for predictive maintenance.

1. Introduction

Wear particles represent crucial information in performing wear assessment. It has been found vitally important in monitoring the deterioration of critical components in industrial machinery. Characterization of wear particle morphology is crucial in the study of wear. Hence, study of wear particles can be applied in a predictive maintenance program of oil-lubricated industrial machinery [1–4]. Among wearing parts of critical machinery, wear of sealing material is an important factor that often shortens the machinery life. It may result from various causes including normal sliding wear, particulate suspended in lubricating medium, wear debris from contaminated lubricant, products of oxidized lubricant or a rough surface finish etc. Three main different seal wear mechanisms including adhesive wear, abrasive wear and fatigue wear can be identified when elastomer seal slides against a hard counter surface [5]. Abrasive wear occurs when an elastomer slides against a hard counterface with a shaft texture; abrasive wear takes place as a result of tearing of the sliding surface of the elastomer. Fatigue wear occurs on the surface of the elastomer when it slides against blunt projections on the hard counterface. When a highly elastic seal slides against a smooth surface, roll formation occurs [6]. Oil and heat resistance of elastomers have an important role in sealing application. When an elastomer and a base fluid, especially an incompatible fluid, are brought in contact with each other, the elastomer material may absorb (swelling) the base fluid or the base fluid may extract soluble constituents of the elastomer. The incompatible fluid may also react with the elastomeric seal materials and eventually leads to seal failure. A plethora of works have emphasized the study of worn seal surfaces, specifically in the corrective maintenance perspective, over the study of seal wear debris [7–11]. Both the above should be examined, but seal wear debris analysis, in conjunction with predictive maintenance and condition-based maintenance, seems a more profitable exercise where surface analysis requires stopping and possibly dismantling the machinery. In spite of the important role of wear in seal failure mechanisms, it has not been adequately studied referring to seal wear debris morphological analysis [12–14]. This study aims at systematically investigating the effect of wear factors on the wear products of sliding mechanisms and their contributions to overall wearing process of NBR elastomers, including sliding-adhesive, sliding-abrasive, after acid attack and swelled NBR specimens.

E-mail addresses: raadnui_s@yahoo.com, s_raadnui@yahoo.co.uk

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2. Experimental tools and techniques

A block-on-ring test configuration was chosen to simulate radial lip seal operating under unidirectional sliding conditions in all wear simulative tests. Typical seal wear tester, which is shown in Figs. 1–4, has been used to study seal wear of selected elastomer, the NBR seal (Nitrile Butadiene Rubber). The NBR used in this work has specific density of 1.30 g/cm^3, elongation at break of 450%, tensile strength of 25 MPa and hardness of 75 (shore A). This tester consists of a rotating shaft on which the seal sample is mounted. The shaft was rotated at 300 and 600 r/min, which in turn produced a sliding velocity of 2.1 m/s and 4.2 m/s. The series of tests were run for a period of 5, 10 and 15 min (total distance of 1.91 and 3.82 km). The test duration was limited up to 15 min due to high level of wear rate and severity specially for those from abrasive wear tests. In all wear tests, rubber specimens of 40 mm × 20 mm size and 6 mm thickness were used (except for abrasive wear tests where 40 mm × 20 mm size and 12 mm thickness were used due to high wear rate). A fixed applied load of 20 N was used throughout the wear tests by deadweight. The tests simulated the major seal failure modes, namely adhesion, abrasion, after acid attack and swelled NBR. The worn surfaces, in particular the collected seal worn particles, were examined by the optical microscope. The difference in the weight measured before and after the wear tests gives the weight loss. The wear factors are shown in Table 1.

Hence, from Table 1, design of experiments was selected to determine the pattern of observations to be made. More specifically, the use of full factorial experiment provides an efficient and effective method for determining the most significant wear factors and interactions in a given wear experimental design problem. It is a methodology based on statistics and other disclipines to gain an efficient and effective planning of wear experiments with a view to obtain valid conclusions from the analysis of wear experimental data. The wear test is carried out with fixed applied load of 20 N at all tests, variable wear mode, sliding speed and test duration. Twenty four experiments were conducted as “full factorial experiment”, so as to investigate which wear factor significantly affects the dry sliding seal wear for the selected combinations of wear mode/mechanism, sliding speed and test duration. As shown in Table 1, three level factorial designs are constructed assuming that it is of interest to estimate linear effects free and clear of two-factor interactions, and those three-factor interactions rarely exist in nature. Hence, little effort should be spent to estimate them, particularly at the beginning of an experimental program. Two-factor interactions, on the other hand, occur quite frequently and a good experimental design is the one that estimates them directly or separates them from the linear effects. As was pointed out earlier, three-factor interactions rarely take place. Therefore, in this study, only three main effects and three two-factor interaction effects were considered in the experimental design. All other effects were considered as trivial effects.

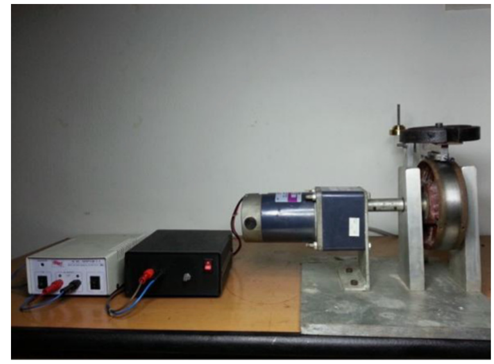

Fig. 3. Seal sliding adhesive wear tester.

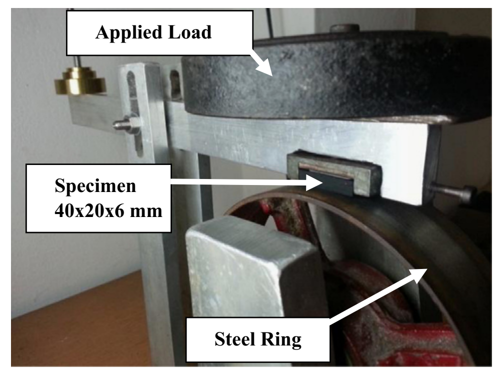

Fig. 4. Sliding adhesive seal contacting surface.

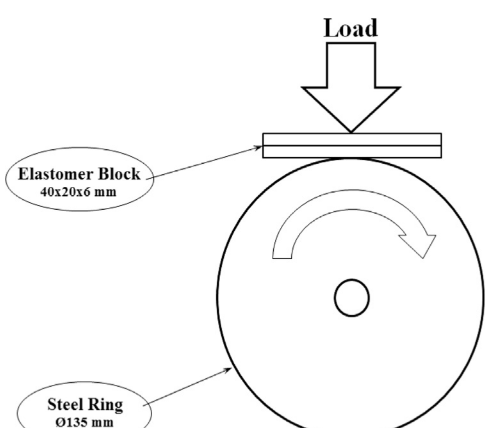

Fig. 1. Schematic diagram of contact interface between specimen and a steel ring.

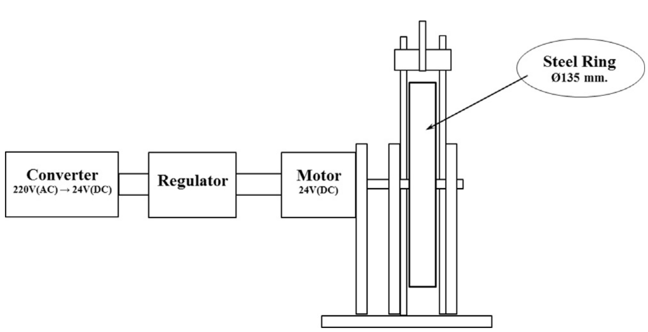

Fig. 2. Detailed schematic diagram of adhesive wear tester.

Table 1
Seal sliding wear test factors.

Level	Sliding Wear Mode (A)	Test Duration (minutes) (B)	Sliding Speed (m/s) (C)
1	Abrasion	5	2.1 (total sliding distance of 1.91 km)
2	After acid attack	10	4.2 (total sliding distance of 3.82 km)
3	Swelled NBR	15	–
4	Adhesion	–	–