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Surface characterization of polytetrafluoroethylene (PTFE) transfer films during rolling–sliding tribology tests using X-ray photoelectron spectroscopy

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Abstract

A disk-on-disk Amsler wear tester simulating the rolling–sliding motion and high pressure during wheel/rail contact, was used to study the wear performance of PTFE including its film transfer and material flow properties. The chemical composition of the transfer film formed on the wheel-disk surface at various test stages were analyzed by X-ray photoelectron spectroscopy (XPS). The friction curve of the PTFE films obtained on the Amsler can be divided into three regions, according to the friction level and disk surface morphology. Initially, there is a rapid increase of friction coefficient which is presumably accompanied by a fast material transfer from pre-coated rail-disk to the wheel-disk surfaces. In the second region, the friction remains stable throughout and the XPS results show the presence of PTFE on the wheel-disk surface which confirms a transfer of material between the two contact surfaces. In addition, the splitting of F 1s and C 1s photoelectron peaks of PTFE, as a result of a discrepancy in surface charging, suggests that the transfer film exists in two forms: thick patch and thin film. With an increase in rolling cycles, the thick patches become thinner, as well as its coverage reduces. By contrast, the thin film gains both in thickness and coverage. Using a simple model, the thin film is calculated to be only a few nanometers thick. At the beginning of the third region, only a thin film is left on the surface. Additional rolling leads to a rapid rise in friction and the transfer film thickness continues to decrease. The evidence supports the removal of PTFE out of the contact zone, and a high friction coefficient ($\mu = 0.6$) is reached at the end of the test indicating an un-lubricated metal–metal contact. No major tribochemical reaction of PTFE is observed during this study.

Keywords: Wheel/rail contact; Friction; Surface; X-ray photoelectron spectroscopy (XPS); Friction modifier; Third body; Polytetrafluoroethylene (PTFE)

1. Introduction

Friction conditions at the wheel/rail interface are a controlling factor in determining wear rates, noise levels and energy consumption in railway system [1,2]. Fundamental studies and field practices have already indicated that friction should be controlled not only at the wheel-flange/the rail-gauge interface, but also at the interface between the wheel-tread and the top-of-rail (TOR). TOR friction management is very different from conventional oil/grease lubrication currently used at the wheel-flange/rail-gauge interface. TOR friction control must maintain the railhead friction at an intermediate range (0.30–0.35), in order not to impair train handling, braking and traction [3]. This technology has attracted a lot of interest from railways because of its advantages in wear reduction, energy saving and environmental concern [4].

The main idea of TOR friction control is to apply a carefully engineered solid thin film at the wheel/rail interface. This film will mix with and modify the naturally occurring “third body” interfacial layer on top of the rail in regard to its composition, rheological properties and friction behavior [5–7]. Therefore, it is crucial to understand the surface and tribology properties of the combined “third body” materials under wheel/rail contact conditions, which typically involve both high contact pressures (>800 MPa) and a rolling–sliding motion. Previous work by Beagley et al. on TOR natural “third body” focused on its composition and its impacts on the interfacial friction [8]. Recently Berthier et al. investigated the particles of iron

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wear debris and iron oxides on the TOR surface and the material flow at the contact zone, as well as transfer between wheel and rail surfaces [9]. Their results show that this natural third body initially is made up of particles from wheel and rail, which then flows into the contact zone to accommodate the sliding between wheel and rail and combine more solid and fluid contaminants. In addition, Kelsan Technologies Corp. together with NRC-CSTT (Center of Surface Transportation Technology of National Research Council of Canada) have studied the rheological and frictional properties of solid powder and engineering composite films at the wheel/rail interface for many years [10]. It was found that the friction and wear performance of the third body films not only depend on their compositions and rheological properties, but also are strongly affected by railhead contamination.

The transfer and distribution of soft polymeric materials that may be present at the wheel/rail interface is of particular interest. In particular it is important to understand how these materials interact with the counter surface and form a ‘third body’ layer under a hybrid rolling. Information such as film thickness, composition and physical state could be very useful in understanding its interaction with the substrate which ultimately governs the tribological properties of the polymer. The polymer polytetrafluoroethylene (PTFE) has been used widely as a lubricating coating in engineering applications due to its chemical inertness, very low friction, and high thermal stability. Despite a large wear rate, PTFE forms a thin and highly oriented film at the counter surface during sliding contact against a hard surface, resulting in a very low friction coefficient (0.05–0.10). A good review of the friction and wear properties of PTFE can be found in reference [11]. For railway applications, PTFE has potential to be used as a solid lubricant and polymeric matrix for flange lubrication [7,12]. A number of tribological studies on PTFE have been published, however their focus was mainly on friction and wear performance under pure sliding conditions [11,13]. Due to an increased interest in space applications such as hybrid bearing, the transfer film lubrication of PTFE or its composite under a combination of rolling and sliding have been studied under extreme environment conditions (at cryogenic temperatures [14], or in vacuum [15]). Information is still limited regarding its tribological behavior at wheel/rail interface under hybrid rolling and high contact pressure.

In this study PTFE film transfer and material flow was investigated under simulated wheel/rail contact. The wear test was performed on a disk-on-disk Amsler and the change of film surface morphology as well as chemical composition was examined. X-ray photoelectron spectrometer (XPS) was employed to monitor the transfer and flow of PTFE film at the contact by following the photoelectron signals of C and F atoms which make up the polymer structure. These signals can provide information regarding potential tribochemical reactions and help understanding of the mechanism by which the soft polymeric material behaves at the wheel/rail contact zone. The methodology used is applicable only to PTFE due to its characteristic F 1s signals, with its C 1s peaks being easily distinguishable from that of air-borne carbon based contamination. Although other hydrocarbon polymers would be harder to analyze this way, the results of this study for PTFE should provide a starting model for describing more generally how polymeric materials behave under wheel/rail contact.

2. Experimental

2.1. Disk-on-disk Amsler wear test

The Amsler machine is a twin-disk tribometer that runs two cylindrical disks against each other with a fixed applied pressure and creepage which is defined as the relative velocity difference of the two disks [10c]. The upper and lower disks respectively simulated the rail and the wheel. The diameters and angular velocity for the rail-disk were 48.15 mm and 232 rpm, whereas for the wheel-disk, they were 45.00 mm and 256 rpm. It gave tangential velocities of 0.585 and 0.603 m/s, respectively, resulting in a creepage of 3.03%. A load of 984 N was applied between the two disks producing a Hertzian pressure of 860 MPa at the disk contact zone. Fig. 1 shows the disk assembly which was made up of a ring sandwiched between two metal pieces to prevent the ring from sliding during the rolling–sliding contact. The wheel- and rail-rings had widths of 9 and 3 mm, respectively. Both rings were made of 4340 HTSR steel with a HBN hardness of 350 and with a surface roughness of 2.3 ± 0.2 μm.

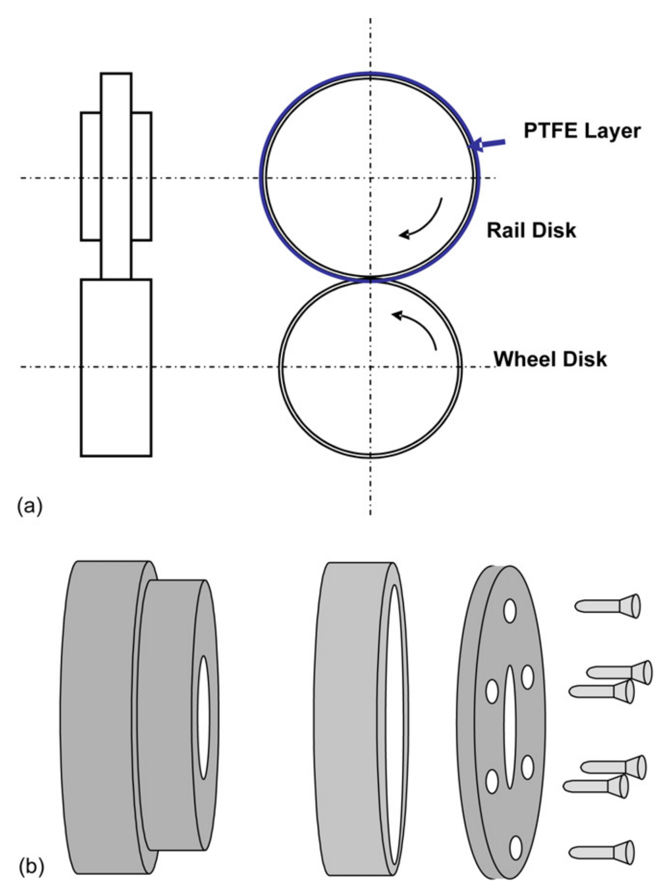

Fig. 1. (a) A disk-on-disk Amsler test machine with two cylindrical disk assemblies running against each other and (b) various parts making up the disk assembly.