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Wear and damage transitions of wheel and rail materials under various contact conditions

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ABSTRACT

This study discusses a $T\gamma/A$ method of plotting wear data from a twin-disc machine for identifying the wear and damage transitions of wheel and rail materials. As found in previous work, three wear regimes (mild wear, severe wear and catastrophic wear) of U71Mn rail material were identified in dry rolling–sliding contact tests. It was determined that the damage mechanism transforms in the different wear regimes. Here earlier studies were extended to establish wear behavior for the presence of a number of third body materials (oil, water, friction enhancers) and a rail cladding process designed to make wheels and rails more durable. This has provided much needed data for Multi-Body Dynamics (MBD) simulations, and will allow better predictions of profile evolution of wheel and rail over a wider range of conditions.

1. Introduction

The wear at the wheel/rail interface plays a vital role in determining the reliability of railway transportation. With an increase in speed and axle loads, the wear of wheel and rail materials is becoming more and more severe, which results in a significant decrease of wheel/rail system service life. Therefore, many researchers all over the world have explored and discussed the wear mechanisms of the wheel/rail system and the methods of alleviating the wear of wheel and rail materials [1–4].

It is well known that both rolling and sliding occur in the wheel/rail interface. When the wheel rolls on the straight track, the wheel tread is in contact with the rail head. In curves, the contact between the wheel flange and rail gauge appears, which results in greater sliding wear. Wear regimes and transitions have been identified using mapping methods and are defined in terms of slip and contact pressure and $T\gamma$ (tractive force $\times$ slip in the contact) [5–7]. Furthermore, the wear regimes are related to expected wheel/rail contact conditions and contact points. On the other hand, an Archard's sliding wear model, in which the wear is proportional to (sliding distance $\times$ load)/hardness, is often used to simulate the wear prediction of wheel and rail [7,8]. The comparison of results obtained with $T\gamma$ and Archard's law reveals a very good agreement in wear prediction [8].

Different products, such as lubricants, friction modifiers and traction enhancers can be added to the wheel/rail interface to help control friction and reduce damage. As the system is open, substances related to environmental conditions or that are just there accidentally can also be present (e.g. water, oil and leaves). While wear performance in dry conditions is well characterized, there is not enough data in the literature for the effects on wear across a wide range of conditions for the presence of third body materials. This information is very important to help improve wear prediction tools such as those integrated with Multi-Body Dynamics simulations.

As is known, friction plays a vital role in wheel and rail wear [2,3,9,10] and investigations and applications have indicated that lubrication of the wheel/rail contact is an effective method for reducing the wear of wheel and rail materials. Some investigations have been carried out on wear effects of greases used in curves for lubrication [6,11–15]. Using a lubricant significantly changes the wear rate of wheel/rail materials and the contact conditions for wear transitions [6]. Lewis et al. carried out some tests to assess the performance of ten different grease types used as curve lubricants [11]. It was found that there is an inverse relationship between retentivity (how long a fixed amount of grease provides lubrication) and wear rate. Grease retentivity is also greater with lower roughness and with more grease applied. Various lubricants may help reduce noise from the wheel/rail system [12]. It has also been proved that less wear and deformation is found under the water condition compared to dry or other grease conditions [13]. Furthermore, wheel/rail friction management has a strong influence on the power consumption in the wheel/rail contact [14].

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Friction modifiers can control the wheel/rail friction coefficient and the level of friction is significantly dependent on the amount applied top-of-rail (ToR) friction modifier [16].

The third body materials present in the wheel/rail interface by accident or due to environmental conditions, such as water, oil, leaf, iron oxides, etc. strongly influence the adhesion of wheel/rail and cause low adhesion phenomena [17–19]. When the adhesion in the wheel/rail interface is poor, traction enhancers (sand, alumina, etc) are often sprayed into the wheel/rail interface for improving the adhesion coefficient. However, various traction enhancers can increase wear rate of wheel and rail materials and aggravate surface damage correspondingly. Studies have investigated the influence of sanding particle size, feed rate, and wheel slip on improving adhesion and wear in the wheel-rail contact [17,18,20,21]. Furthermore, low adhesion is unlikely to occur while thick oxides with a rough surface give an extremely high adhesion and wear [19]. While these previous studies on causes of wear and wear prevention have been wide ranging, very specific contact conditions of wheel/rail are always adopted and there is not a wide range of wheel/rail contact information which is what is really needed for improving the wear prediction.

It is clear that the hardness significantly affects the wear and damage of wheel and rail materials. The high strength, fine lamellar pearlitic structure in rail steels is one of the most important factors for improving the wear resistance of material [22]. In addition, some researchers have explored the influence of laser surface treatment on the wear resistance of wheel and rail materials [23–25]. The results indicated that the laser treatment including laser dispersed quenching and laser cladding can significantly increase the hardness and wear resistance of wheel or rail material.

2. Aims and objectives of the investigation

The aim of this study was to develop wear information, via investigations from a twin-disc machine, to identify the wear regimes and damage transitions for wheel and rail materials with third body materials present in the wheel-rail contact. In order to present the wear data in a way that would allow a direct comparison with previous investigations, the approach of plotting wear rate in mass loss (μg), rolled (m) and contact area (mm^2) versus $T\gamma/A$ was used. This was used initially by Bolton and Clayton [26] and then in a number of subsequent studies [5,7,13,27–30].

In this study, a large amount of data relating to the wear of wheel and rail materials has been generated from a twin-disc machine under various contact conditions, which is composed of two rollers served as a wheel roller and a rail roller. Third body materials including water, oil, friction enhancers (sand, alumina particles and abrasive block) were used in the wheel/rail interface. Water is continuously added to the wheel/rail surfaces using a channel and oil (a typical lubricating oil used in the wheel-rail contact in China) is regularly brushed on the wheel/rail interface. The sand or alumina particles are continuously added to the wheel/rail interface through a pipe by means of gravity. The abrasive block is fixed on the wheel roller using a dead weight, which simulates the full scale contact condition in the field. Main composition of the sands is quartz and its hardness is about 1170 HV [31]. The diameter of sand is about 125 μm (Fig. 1a). The diameter of the alumina particles with about 2000 HV hardness is about 150 μm (Fig. 1b). The abrasive block with a hardness of about 275 HV is a synthetic resin material with four element composite structure and it is made of binder, friction particles, friction modifier and packing material [31]. It is found in Fig. 1c that the surface of abrasive block distributes with metal fiber and metallic particles. Its compressive strength is about 90 MPa and compression modulus is less than 9 GPa.

The wheel and rail rollers were clad with different alloy powders using a multimode cross flow CO_2 laser (TR-3000). Two kinds of laser clad layers (Co-based and Fe-based alloy layers) were used to explore the wear and damage characteristics of wheel and rail materials. They have uniform and compact microstructure and there are no visible crack and blow hole. Co-based alloy layer consists of dendrite and eutectic and the surface hardness is about 440 $HV_{0.5}$ [32]. Fe-based alloy layer is composed of F (Fe, Ni) solid solution and Cr_7C_3 carbide and the surface hardness is about 670 $HV_{0.5}$ [33]. Detailed information on the twin-disc machine and experimental approaches including the contact conditions (contact pressure, sliding speed, slip ratio, test duration, etc) can be found in previous publications [25,30–38]. The wear rate and $T\gamma/A$ value are calculated by means of the wear loss (measurement accuracy: 0.001 g) of wheel or rail rollers and contact conditions from previous publications.

3. Wear and damage transitions under various contact conditions

3.1. Dry wear

It is clear in Fig. 2 that the wear rate of U71Mn rail material has a distinct change with an increase in $T\gamma/A$ value. There are three wear regimes (mild wear, severe wear and catastrophic wear) in rolling–sliding wear tests. The transition of rail material wear results from different contact conditions. In the contact between the wheel tread and rail head, mild and severe wear are likely to occur. When the wheel flange and rail gauge corner contacts, large or full slip may be present, which causes severe to catastrophic wear. Furthermore, high temperature of wheel/rail contact resulting from the slip would cause thermal softening of material and it lead to catastrophic wear. It is clear in Fig. 3 that the damage characteristic of the rail material is closely related to the wear regimes. When mild wear occurs, the surface damage is slight and the oxidation wear is dominating [7,26]. There is no obvious subsurface damage (Fig. 3a). When the wear is in the catastrophic stage, serious spalling damage appears and there is visible fatigue

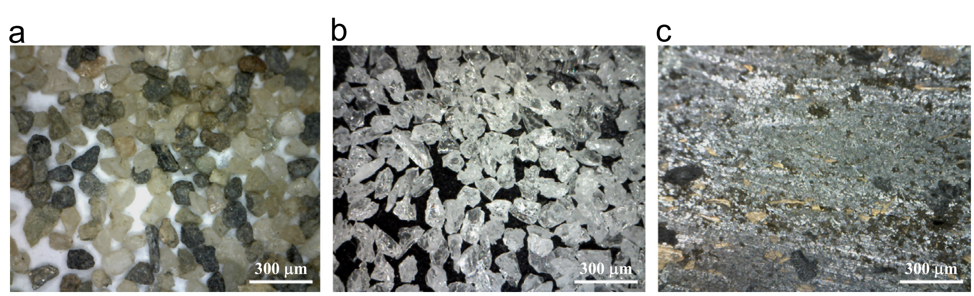

Fig. 1. Photographs of abrasive materials, (a) sand; (b) alumina particles; (c) abrasive block.