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The role of lanthanum oxide on wear and contact fatigue damage resistance of laser cladding Fe-based alloy coating under oil lubrication condition

W.J. Wang, Z.K. Fu, X. Cao, J. Guo, Q.Y. Liu *, M.H. Zhu

Tribology Research Institute, State Key Laboratory of Traction Power, Southwest Jiaotong University, Chengdu 610031, China

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ABSTRACT

This study explores the role of lanthanum oxide on the wear and contact fatigue damage resistance of laser cladding Fe-based alloy coating on the wheel and rail materials under oil lubrication condition using a rolling–sliding wear machine. The laser cladding Fe-based alloy coating on the wheel/rail materials significantly improves the wear and rolling contact fatigue damage resistance of rollers. La as a surface active element is easy to distribute mostly over the grain boundary and then the use of lanthanum oxide is beneficial for refining the grain and microstructure of cladding coating. An optimum amount of 1.2% La_2O_3 content is given for achieving outstanding wear and contact fatigue damage resistance of laser cladding Fe-based alloy coating.

1. Introduction

The wear and rolling contact fatigue of wheel and rail materials have a vital important role on the operating safety of the wheel/rail system. Therefore, the control of wear and fatigue related defects are an ongoing concern for both safety and cost of railway transportation [1–3]. Many preventative measures for the wear and damage of the wheel/rail system have been explored and applied [4–7]. Lewis et al. [4] found that the friction coefficient of wheel/rail of grease lubricated is less than 0.1 and there is a distinct inverse relationship between surface roughness and grease retentivity (how long a fixed amount of grease provided lubrication). Descartes et al. [5] proposed an approach to evaluate new lubricants (oil or grease) suitable for the wheel flange/rail gauge corner contact. The lubricant oil has a significant effect on reduction of both the lateral force which is a factor causing the wear of wheel flange and rail gauge corner [6]. Wang et al. [7] developed a new asymmetrical rail grinding method for preventing the oblique crack damage of curve track. It is noted that the wear resistance of material is closely related to the hardness and microstructure. Therefore, increasing hardness of materials has an obvious reduction of wear rate of the wheel/rail system [8]. On the other hand, this may result in other related rolling contact fatigue damage due to the loss of toughness of material. The rail materials with bainitic structure are developed and used for improving the wear and rolling contact fatigue resistance. Compared with the pearlitic rail, the rail steel with bainitic structure exhibits better wear and fatigue resistance [9–10].

The laser cladding is a method using which metals with better mechanical and tribological performances can be welded on top of the original substrate material [11–13]. This method can not only produce a cladding coating with better wear and damage resistance, but also repair the worn wheel or rail surface. Lewis et al. [14] investigated the fatigue characteristics of different laser cladding materials which are used to repair damaged rail. Guo et al. [15] explored the microstructure and wear characteristic of laser cladding Co-based alloy coating on single wheel or rail material and the wear rate of the wheel/rail system was reduced by the deposition of the laser cladding layer on either the rail or the wheel. How to obtain better wear and fatigue damage resistance of the laser cladding coating is becoming an important studying issue.

In this study, the laser cladding Fe-based alloy coating is obtained on the wheel and rail materials and the wear resistance and contact fatigue damage of the coating was investigated under oil lubrication condition using a rolling–sliding wear machine. Particularly, the role of lanthanum oxide on contact fatigue behaviors of the laser cladding Fe-based alloy coating was assessed.

* Corresponding author. Tel.: +86 28 87603724.
E-mail address: liuqy@swjtu.cn (Q.Y. Liu).

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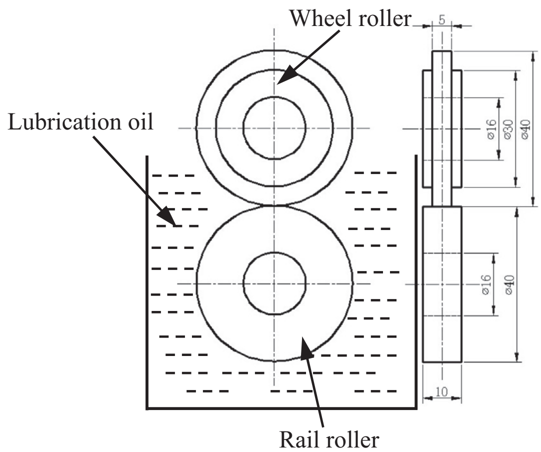

Fig. 1. Scheme size of wheel and rail specimens.

2. Experimental methods

2.1 Testing equipment

It notes that the contact fatigue damage performance of material is easy to be explored under the oil lubrication condition. So, the wear and contact fatigue testing was carried out using a rolling–sliding wear machine under the oil lubrication condition (MMS-2A) [16]. The tester is composed of two rollers with a diameter 40 mm served as a wheel specimen (upper roller) and a rail specimen (lower roller). The scheme size of wheel and rail specimens is shown in Fig. 1. Two rollers are powered and controlled by a DC motor and different slip ratios of wheel/rail rollers are obtained by changing the gear-pair. The contact width of wheel and rail specimens is 5 mm. The upper specimen was mounted in a swinging bracket to which a normal force (from 0 to 2000 N) is applied by a compressed spring. The normal and tangential forces of the wheel/rail interface are measured and recorded using load sensors (measurement error: $\pm 5\%$).

2.2 Experimental materials and parameters

The wheel and rail rollers are cut from the wheel tread (China grades: CL60) and rail head (China grades: U71Mn), respectively and their chemical compositions in weight percentage are given in Table 1. The wheel and rail rollers were cladded with Fe-based alloy powder (chemical compositions shown in Table 2) using a multimode cross flow CO_2 laser (TR-3000). The powder is added using a powder feeder, shown in Fig. 2. Before the laser cladding, the lanthanum oxide (La_2O_3, purity: 99.99%) is added to Fe-based alloy powder by means of mechanical mixing and its content with different mass fractions are 0%, 0.4%, 1.2% and 2.0%. The size of laser beam (Fig. 2) is about 1×7 mm^2 and the power is 1.9 kW. The scanning speed is 200 mm/min and the flow rate of alloy powder is about 15 g/min. The thickness of cladding coating is about 1 mm. All wheel and rail rollers after laser cladding are polished and the surface roughness (R_a) is about 0.6 μm.

In this study, the normal force of 1003 N is used to simulation the maximum Hertzian contact stress of about 850 MPa by means of the Hertzian rule [16]. The slippage ratio is 3.83% and the rotational speed of rail roller is 400 r/min (0.837 m/s). The number of cycles of rail roller is 8.64×10^5. The interface of wheel/rail contact was lubricated using T300 anti-wear lubrication oil (viscosity: 12.5–16.3 mm^2/s at 100 °C) during the rolling wear process (Fig. 1).

All experiments were carried out in the ambient condition (temperature: 18–23 °C, humidity: 50–70%). The wheel and rail rollers were cleaned in acetone and weighted using an electronic balance (JA4103, measurement accuracy: 0.001 g) before and after testing. The wear rate of wheel/rail rollers was determined by mass loss. The surface hardness of wheel and rail rollers was measured using a Vickers hardness instrument (MVK-H21, Japan). The microstructure, the wear damage of wheel and rail rollers with and without laser cladding coating were analyzed by examining the wear scars and sections cutting in directions longitudinal to the rolling direction using optical microscopy (OLYMPUS BX60M, Japan) and scanning electronic microscopy (SEM) (SM-6490LV, Japan).

Table 1
Chemical compositions of wheel and rail rollers (wt%).

Roller	C	Mn	Si	S	P
Wheel	0.55–0.65	0.50–0.80	0.17–0.37	≤ 0.040	≤ 0.035
Rail	0.65–0.76	1.10–1.40	0.15–0.35	≤ 0.030	≤ 0.030

Table 2
Chemical compositions of the powder (wt%).

Element	C	Si	B	Cr	Ni	Fe
Content	0.8–1.2	1.0–2.0	3.8–4.2	16–18	9.0–12	Vol.

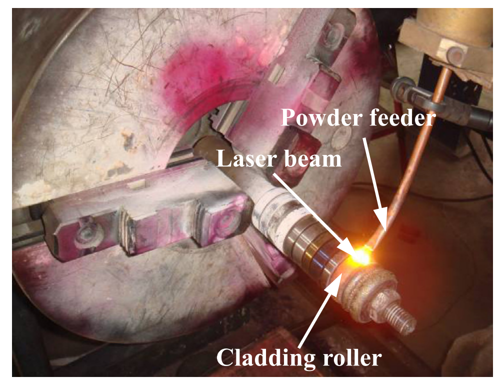

Fig. 2. Photograph of laser cladding.

3. Results

3.1 Microstructure and hardness

It is clear in Fig. 3 that a uniform and compact laser cladding coating is obtained and there are no any cracks or stomata. The heat-affected region exists between the cladding region and substrate material. The laser cladding coating consists of dendrites and eutectic, shown in Fig. 3b. According to the XRD analysis [17], (Fe, Ni) solid solution and Cr_7C_3 carbide are main compositions in the cladding Fe-based alloy coating. The formation of carbide is beneficial to enhancing the hardness of laser coating. So, it illuminates from Fig. 4 that there is an obvious increase in the surface hardness (average value of ten times) of the laser coating compared with the wheel or rail material. Furthermore, the use of different contents lanthanum oxide results in a little increase on the surface hardness of the cladding coating due to the same microstructure.

3.2 Wear resistance

The friction coefficient of wheel/rail specimens without cladding coating in Fig. 5 shows that the friction coefficient is very low