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Investigation on microstructure and wear characteristic of laser cladding Fe-based alloy on wheel/rail materials

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ABSTRACT

The aim of this study is to investigate the influence of laser cladding Fe-based alloy on microstructure and wear characteristic of wheel/rail materials using a rolling–sliding wear testing apparatus. Especially, the effect of lanthanum oxide on the properties of laser cladding coating was explored in detail. The results show that the laser cladding Fe-based alloy coating consists of dendrites and eutectic and is composed of (Fe, Ni) solid solution and Cr_7C_3 carbide. The hardness and wear-resistance of wheel/rail materials are enhanced using laser cladding. The wear and surface damage of wheel/rail rollers dramatically alleviate owing to the refinement of the microstructure when adding lanthanum oxide into laser cladding coating. The wear mechanism of wheel/rail rollers turns from severe spalling and delamination wear (untreated specimens) to slight peeling (with 1.2% La_2O_3). Furthermore, the plastic deformation of wheel/rail rollers undergoing laser cladding is significantly thinner than that of untreated rollers. In summary, laser cladding Fe-based alloy coating can be used to prolong the wear life of wheel and rail materials.

1. Introduction

Because of the friction of wheel/rail interface, the wear damage has become increasingly severe [1,2]. The increase of axle load leads to excessive wear of wheel/rail materials and remarkably decreases the service life of wheel/rail system. A variety of damages appear on wheel and rail surface such as the side wear of rail, rail corrugation, fatigue cracks, and so on [3–5]. Therefore, lots of researchers have reported some results for improving the wear resistance of materials and declining the damage of wheel/rail system by means of new wheel/rail materials and lubrication [6–8]. In addition, the rail grinding technology has been applied widely to deal with rolling contact fatigue problems around the world [9].

At present, laser surface treatment has been used widely to protect the contact surface from wear and fatigue damage [10–12], such as laser quenching, laser melting, laser cladding, and so on. Especially, laser cladding can be used to repair the damaged surface of materials due to wear and improve wear-resistance of materials [12]. Zhang studied the microstructure and properties of Fe-based composite coating and the results showed that the cladding layer with a hardness of 1030 $HV_{0.2}$ possessed good wear and corrosion resistance [13]. Lewis investigated the fatigue characteristics of different laser cladding materials to be used to repair damaged rail [14]. In addition, it should be noted that the lanthanum oxide has a significant influence on the microstructure and abrasive wear of surface coating [15].

In this study, the microstructure of laser cladding Fe-based alloy coating on wheel/rail materials was investigated. Furthermore, the wear and surface damage behaviors of wheel/rail materials without or undergoing laser cladding were explored using a rolling–sliding wear testing apparatus by means of various examinations.

2. Experimental details

The wear experiments were carried out using a rolling–sliding wear testing apparatus. There are two rollers with a diameter of 40 mm serving as a rail roller (lower specimen) and a wheel roller (upper specimen). The rollers are powered and controlled by a DC motor. The line contact width of wheel/rail rollers is 5 mm. The size of specimens is shown in Fig. 1. The normal force of 438 N is adopted to simulate the maximum contact stress of about 526 MPa between the wheel and rail rollers. The rotating speed of lower roller (rail specimen) is 200 r/min. The slippage ratio between the wheel and rail rollers is 3.83%. The number of cycles of rail roller is 2.88×10^5.

The real wheel/rail materials from the field are used to manufacture wheel/rail rollers. The chemical compositions of wheel and rail materials are shown in Table 1. In this study, the contact surfaces of

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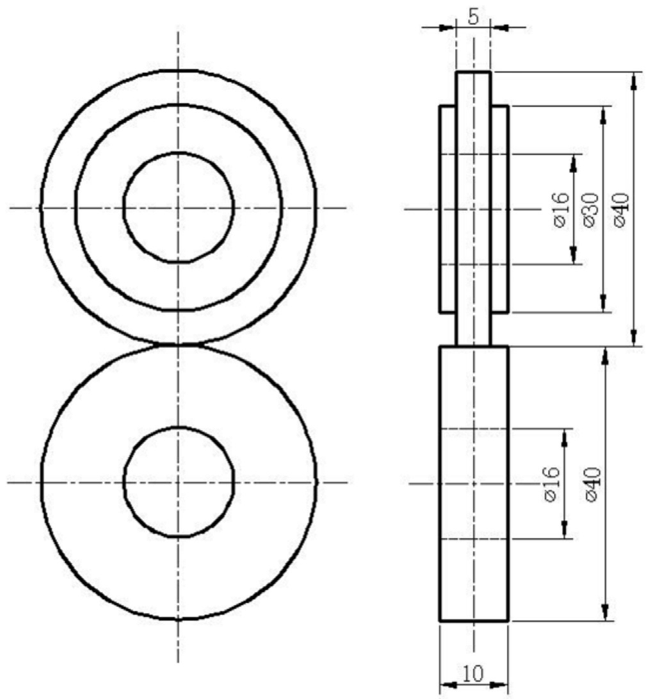

Fig. 1. Scheme size of specimens.

Table 1
Chemical compositions of wheel/rail materials (%wt).

Materials	C	Si	Mn	P	S	V
Wheel	0.62	0.82	0.79	0.013	0.012	0.010
Rail	0.65 ~ 0.76	0.10 ~ 0.50	0.80 ~ 1.30	$\leq$ 0.025	$\leq$ 0.025	0.030

Table 2
Chemical compositions of Fe-base alloy powder (%wt).

Powder	C	Si	B	Cr	Ni	Fe
Fe-based alloy	0.8 ~ 1.2	1.0 ~ 2.0	3.8 ~ 4.2	16 ~ 18	9 ~ 12	Vol.

wheel/rail specimens are cladded using a multimode cross flow CO_2 laser (TR-3000). During the laser cladding process, the rectangular spot size of laser beam is 1 × 7 mm and the power is 2 kW. The scanning speed is 200 mm/min and the flow rate of powder is 15 g/min. Before laser cladding, each wheel/rail roller with a diameter of 38 mm is manufactured. The thickness of once laser cladding is 1 mm in this experiment. So, the diameter of wheel/rail rollers achieves 40 mm by means of once laser cladding. All wheel and rail specimens (untreated and treated) are polished before experiments and their surface roughness (R_a, measured length: 4 mm) is about 0.32 ± 0.018 μm.

Fe-based alloy powder with the form of spherical and rod-like particles is used to clad on the wheel/rail materials and the chemical compositions are given in Table 2. The alloy powder has properties of de-oxygenation and slagging owing to the existence of B and Si element. B_2O_2 and SiO_2 are formed during the laser cladding process and thin film is produced on the surface of cladding coating. The film can prevent the Fe element in the alloy powder from being oxidized. The size of particles is about 200 mesh. The results indicate that the lanthanum oxide (La_2O_3) has important effect on decreasing the defects of cladding coating, e.g., pore and impurity [15]. Therefore, the lanthanum oxide is used to add to Fe-based alloy powder by means of mechanical mixing in this study. SEM micrographs of Fe-based alloy powder with different contents of lanthanum oxide (0, 0.4% and 1.2%) are shown in Fig. 2. It is found that the powder of lanthanum oxide evenly adheres to the surface of Fe-based alloy particles.

All tests are performed under the ambient condition (temperature: 18 ~ 23 °C and relative humidity: 20% ~ 50%). The wheel/rail specimens are cleaned in alcohol and weighed using an electronic balance (JA4103, measurement accuracy: 0.001 g) before and after testing. The wear rate is defined as the ratio of wear mass loss (g) to rolling distance of rail roller (m). The microstructure and wear damage behaviors of wheel/rail rollers with laser cladding coating are examined by means of Vickers hardness instrument (MVK-H21, Japan), optical microscopy (OLYMPUS BX60M, Japan), X-ray diffraction (XRD) (Bruker D8 Discover, Germany) and scanning electronic microscopy (SEM) (JSM-6490LV, Japan).

3. Results

3.1. Microstructure of laser cladding coating

It is found from SEM micrographs in Fig. 3 that the microstructure of cladding coating is uniform and compact and there is no crack and stomata. The coating is divided into cladding region, combining region and heat-affected region. It is visible that the coating consists of dendrites and eutectic. During the cladding process, when the laser beam leaves from the laser bath, the substrate and Fe-based alloy powder solidify rapidly, which leads to the occurrence of dendrites [16]. The un-solidified liquid metal fills the intervals among solidified dendrite and then nucleates and re-solidifies. As a result, the eutectic is formed. It is well known that the microstructure mainly depends on the temperature gradient (G) and solidification rate (R) during the laser cladding process [17]. According to solidification theory, the G/R value has a significant effect on the microstructure morphology of cladding coating [18,19]. At the early stage of laser cladding, the columnar crystal is easy to appear owing to large G/R value. With laser cladding continuing, the dendrite crystal is dominant due to the decline of G/R value [18]. With the content of lanthanum oxide increasing, the eutectic crystal and dendrite crystal of cladding coating are refined markedly (Fig. 3).

According to X-ray diffraction spectrum (Fig. 4), Fe and Ni elements form (Fe, Ni) solid solution and Cr element easily forms Cr_7C_3 carbide. Furthermore, the use of lanthanum oxide does not produce new phase in the X-ray diffraction spectrum. It is clear from EDX analysis in Table 3 that the content of Fe element in dendrite microstructure is higher than that of in eutectic microstructure. On the contrary, the content of Cr element in dendrite microstructure is lower than that in eutectic microstructure.

3.2. Hardness and wear rate

It is found in Fig. 5 that the surface hardness of wheel/rail specimens undergoing laser cladding Fe-based alloy increases significantly. The increasing ratio of hardness of wheel and rail rollers with laser cladding coating is about 114% and 159% compared with the wheel/rail materials. Furthermore, it is observed that the use of lanthanum oxide has no obvious influence on the surface hardness of wheel/rail rollers with laser cladding coating. It can be seen in Fig. 5(b) that the hardness of rail roller remains stable and then decreases markedly to the hardness of substrate with an increase of depth. It is concluded that the thickness of cladding coating is about 1 mm. Meanwhile, there is no obvious difference of the change of hardness under different content of lanthanum oxide conditions.