Fretting corrosion behavior of Zn-Al-Mg-RE coating under dry friction and NaCl solution

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Abstract: The fretting behavior of Zn-Al-Mg-RE coating prepared by high velocity arc spraying was studied for the first time in this paper. All specimens were fretted in air and 3.5% NaCl solution independently. The worn surfaces of the coating were investigated by scanning electron microscopy and X-ray energy dispersive spectroscopy. Fretting tests have shown that friction coefficient in 3.5% NaCl solution was similar compared to that measured under dry condition for Zn-Al-Mg-RE coating. Study of worn surfaces revealed the main mechanism in dry friction was the oxidative wear; while in 3.5% NaCl solution, the main mechanisms were delamination process and abrasive wear.

Key words: high velocity arc spray; microstructure; fretting

Fretting is a small amplitude oscillatory movement which occurs between contacting surfaces [1]. Accurate prediction of the fretting damage of mechanical components, e.g., wire cable of off shore oil platforms and ship is extremely critical for safe, reliable, and economical operation [2]. Fretting includes fretting wear, fretting fatigue and fretting corrosion. Fretting corrosion is the deterioration of a material that occurs at the interface between two contacting surfaces due to a small oscillatory movement between them and the corrosive of the medium [3]. Fretting corrosion often occurs in particular environment such as marine. Alternative load which resulted in fretting derived from ship wobbling and spray in splash zone. Steel structure used in marine environment not only corroded severely but also subjected to fretting damage. The fretting process is quite complex due to a number of factors; the competition between the wear and corrosion processes, the presence of sliding and impact motions, and the friction- induced thermo-mechanical effects resulting from the thermal constriction phenomenon introduced by the micro- and macro-contact configuration at the contact interface [4].

The surface of marine steel structure often covered corrosion resistance coatings. However, the study of fretting corrosion behavior of coatings is limited and much effort is still needed to explore the fretting corrosion mechanism. As a surface modification technology, Electric arc spraying is known to be one of the economical thermal spraying processes with an ability to produce dense coatings and has gained great success in the protection of metal parts [5]. Arc spraying has been used widely to coat engineering structures to protect them against corrosion and wear [6]. This paper chose an arc spraying Zn-Al-Mg-RE coating which was used in severe corrosive environment [7]. The fretting and fretting corrosion behavior of arc spraying Zn-Al-Mg-RE coating were investigated in this paper.

1 Experiment

1.1 Materials and coating preparation
Mild steel substrate with a dimension of 25mm×20mm×3mm was used in this study. Before spraying, steel substrates were treated by grit blasting, acetone degreasing and ultrasonic cleaning. The coatings were prepared by an arc spraying system developed by National Key Laboratory for Remanufacturing, which included a power supply, a wire feeder, a control unit and a high velocity arc spraying gun. A Zn-Al-Mg-RE cored wire with 2mm diameter was used as the spraying material. Two consumable wires were fed automatically to meet at a point in an atomizing gas stream. The process parameters were optimized as follows: An electrical potential 36V, with a current intensity 120A was applied across the wire electrodes. The spraying distance was 200mm and the compressed air pressure was 0.7 MPa.

1.2 Tribological tests
Tribology tests for Zn-Al-Mg-RE coating were performed on the CETR UMT-2 micro-tribometer in ambient atmospheric condition. GCr15 ball with diameter of 4mm was chosen as the counterpart. A normal load of 5N, testing time of 30 min...
and linear displacement amplitude of 100µm were used as the fretting test parameters. All the fretting tests were conducted at room temperature. The tests were performed in two conditions: dry condition (air) and 3.5% NaCl solution. For fretting test in 3.5% NaCl solution, GCr15 ball/sample flat contact was totally immersed in the solution. The variation of friction coefficient was recorded using a data acquisition system and a computer. After the wear tests, the morphologies of each wear scar were observed by scanning electron microscope (SEM, Quanta200) coupled with an energy dispersive spectroscopy (EDS).

2 Results and Discussion

2.1 Friction Coefficients

Friction coefficients of Zn-Al-Mg-RE coating in different conditions were showed in Fig. 1. The friction coefficient of sample wear in dry condition had two steady stages. At the first stage, the friction coefficient was about 0.15. Sliding about 300s, the value of friction coefficient suddenly raised to 0.56 and then attained a steady value.

The steady-state friction coefficient value of Zn-Al-Mg-RE coating in 3.5% NaCl solution was similar to that in dry condition. This result was different from some research reports. M.R. Bateni observed that carbon steel samples and stainless steel samples were showed a lower friction coefficient in 3.5% NaCl than in dry friction. He contributed the reduction of friction coefficient between the substrate and the counter-face to the corrosion solution [8]. B. Panda investigated fretting behavior of rail steels and found the wear damage in 3.5% NaCl was lower than that in dry friction due to lubricating effect of the solution and the near neutral PH [9]. In this paper friction coefficient was similar in two conditions probably because the debris was insoluble in 3.5% NaCl. Debris can not be taken away immediately from wear surface by solution, which formed a rough surface. This effect offset the lubrication provided by solution.

Fig. 1 Friction coefficients of Zn-Al-Mg-RE coating in different conditions

2.2 Damage analysis

The wear surface morphology of Zn-Al-Mg-RE coating in dry friction was showed in Fig. 2. It can be seen that the wear of Zn-Al-Mg-RE coating presented in a mild way with little grinding crack on the wear track. A mild worn surface was formed, on which there was just some debris produced during sliding. X-ray dispersion analysis of the friction surface showed strong Zn, Al and O peak heights, as shown in Fig. 2. Oxygen content in abrading section such as A point was much more than that in non-abrading area (B point), which indicated oxide-wear on the coating surface. Frictional heating is only generated over the real contact area.

Fig. 2 SEM imagine of wear surface of Zn-Al-Mg-RE coating in dry friction

A typical SEM micrograph of the fretting wear scar of Zn-Al-Mg-RE coating obtained after fretting in 3.5% NaCl solution was shown in Fig. 3. X-ray dispersion analysis of the fretting region was also shown in Fig. 3 respectively. Compared to Fig. 2 it could be found that the coating damage in 3.5% NaCl was much severe than that in dry condition. Plough friction and plastic flow was occurred on the friction surface of Zn-Al-Mg-RE coating during it fretting in 3.5% NaCl solution. Microscopic observation showed that predominant fretting wear mechanism of the coating in 3.5% NaCl solution were delamination and combination with griding abrasion.

Fig. 3 SEM imagine of wear surface of Zn-Al-Mg-RE coating in 3.5% NaCl

On the contrary, a comparison of the oxygen content of the central region in the fretted zone (A) and the non abrading section at the edges (B) revealed that the wear surface was lack of oxygen, which indicated the fretting zone was lack of oxide. It was probably because metallic debris reacted with oxygen dissolved in solution in the mechano-chemical reac-
tion. A magnified image of the central region of fretted zone in 3.5% NaCl was showed in Fig. 4.

Fig. 4 Magnified image of the central region of wear track

The fretted zone experienced a severe damage due to the extensive shear deformation and the ploughing action of the GCr15 ball. Fatigue crack (marked by arrows) was also found in Fig. 4. Crack was prone to initiation on the subsurface of the coating in corrosive medium and propagated under friction force and alternative shearing stress, which accelerated the damage rate or velocity of the coating. The oscillatory micro-movements at the contact surface induced fretting wear, fretting corrosion and sometimes, fatigue cracks. The formation of cracks at the edges of the fretted zone confirms such an occurrence. In case of fretting corrosion, an additional electrochemical corrosion component also becomes a part of the fretting process. Because solution was actually agitated as a result of the sliding movement; oxygen diffusion was accelerated in solution and the oxygen concentration polarization corrosion was promoted. The corrosion products were not dissolved and can not be taken away from the fretting zone immediately, so debris generated during fretting accumulated quickly and limited only to a very smaller area due to fretting movement, which formed griding abrasion. Although the sample was rinsed by deionized water, some debris was still seen in Fig. 4.

It was comprehensive function of wear and corrosion that resulted severe damage of Zn-Al-Mg-RE coating in 3.5% NaCl solution. Fretting involved damage due to mechanical interaction and oxidation process. Moreover, the continuous removal of corrosion products from the coating surface at the contact zone generally accelerates the crevice corrosion process in the exposed area. The coating surface without corrosion products oxidized once more when exposed to corrosion medium. This process circulated continually, so the delamination was formed.

3 Conclusions

1) The period of transitional stage of Zn-Al-Mg-RE coating was shorter in dry condition than that in 3.5% NaCl solution.

2) Oxidation process was the main mechanism in dry condition, while in 3.5% NaCl solution fretting scars of Zn-Al-Mg-RE coating was severe. Plough friction and delamination were the predominant wear mechanism. During fretting corrosion crack was prone to initiation.

3) Oxygen diffusion was promoted because sliding motion actually agitated the solution. Electrochemical corrosion became a part of fretting process and accelerated fretting corrosion, which resulted severe damage for Zn-Al-Mg-RE coating in 3.5% NaCl solution.

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