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Research on cavitation erosion and wear resistance performance of coatings

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ABSTRACT

Depending on the nature of the working medium and working conditions, corrosive and cavitation damage shall arise to pump's components. In industrial applications the corrosion-reducing coatings are sprayed on hydraulic components. But it is questionable whether such products actually do help under wear or cavitation loads or not. Abrasive jet wear tests were carried out to determine the wear resistance of coating materials: polymers and ceramics, cast iron, and steel of various types. The samples were loaded for five hours, and finally the wear depth was measured as a determining indicator of the sample's wear resistance. Results of investigation on anti-erosion performance of epoxy resin, ceramic and Polyurethane (PU) coatings brushed on alloy steel surface were also presented. Cavitation erosion tests were performed on the ultrasonic rig. The mass loss and surface morphology of the specimens were examined by balance analysis and 3-D laser microscopy, respectively. The investigations showed excellent wear-resisting performance of ceramic coatings, which is better than wear-resistance of stainless steel, cast iron and high chrome alloy steel. But the excellent wear-resisting performance could not guarantee a good erosion-resisting performance. The ceramic coatings' anti-erosion performances were inferior to that of gray cast iron, and hardly comparable to those of stainless steels. The basic factors that influenced coating's cavitation erosion endurance were adhesion and thickness of coatings. Analysis of coating's degradation mechanism showed that PU coatings could withstand longer incubation period thus enhancing the materials' cavitation erosion resistance. Several practical cases were analyzed, showing some guidance for coatings' application.

1. Introduction

Pressure decrease in fast flowing liquid is the main reason for cavitation phenomenon. The dissolved gas is the source of cavitation nuclei [1]. The dynamic load at the moment when cavitation bubble collapses lasts for a few microseconds or nanoseconds [2].

Alloys are usually used in process equipment and hydraulic machinery. Poor cavitation erosion resistance of impellers' material poses a serious obstacle for its application in hydraulic machinery [3]. High wear applications cannot be avoided, when hydraulic machinery has to be subjected to heavy static or dynamic impact loads. Materials' response to static

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conditions is different from response to dynamic conditions. Under dynamic impact loads, as during cavitation, materials' resistance to deformation is lower [4].

Over the last few decades, considerable efforts have been devoted to enhance the erosion resistance of steel by depositing protective coatings on its surface [5–7]. The coatings can be easily formed on the surface of steel, which can exhibit smooth surface and good mechanical properties, such as high hardness, high elastic modulus or high oxidation resistance [8]. Many fluid machinery components are supplied with coatings to prolong their lifespan and to improve their work efficiency.

However, when bubble collapses on the coating's surface, a high temperature may be achieved, which could influence the coatings' properties, for example makes coatings more ductile [9]. Thousands of pressure pulses act on the surface when bubbles collapse. The coating may undergo local thermal softening, which has an essential influence on the coatings' deformation. The thermal mismatch between the coating and substrate may also result in adhesion failure [10]. Coatings with weak adhesion could soon be peeled off. If the coatings can avoid adhesive fracture, they protect the substrate from corrosive fluid.

Adhesion plays an important role in the incubation period and ensures the protection of the substrate material against mass loss. The outstanding results observed in any given coating can be attributed to the strong adhesive connection. When a coating is very ductile, it is easy to cause the dislocation movement and peeling off of the coating [11].

In addition, cavitation erosion investigations proved that the cavitation erosion resistance of conventional materials (stainless steel, etc.) depends on their mechanical parameters (hardness, Young's modulus, tensile strength, and fatigue strength) [12–15]. More energy is needed to be absorbed before fracture, if the hardness and Young modulus are high. Delamination may also happen due to the large difference in hardness and Young's modulus between the substrate and coating.

Taking the above statements into consideration, the main aim of this work was to reveal the factors which were responsible for the resistance of coatings. These factors were combination of the properties that were essential in conditions of dynamic impact. And the secondary aim was to find coatings with higher wear-resistance and higher erosion-resistance.

2. Experiment on wear resistance

2.1. Experimental method and materials

In order to simulate the wear of FGD (flue gas desulfurization) slurry pump, abrasive jet wear tests were carried out to determine the wear resistance to solid particle attack of several coating materials, cast iron, and other steels. With a view to comparing the materials' resistance, blast wear experiments were performed under the same impact intensity. And wear problem of most slurry pump increases significantly when the linear velocity is greater than 15 m/s. (Wear is serious for a general slurry pump: the rotating speed is 750 r/min, the impeller diameter is 400 mm, and the linear velocity is $3.14 \times 0.4 \times 750/60 = 15.7$ m/s). Solid particles in pumped FGD slurry are often 100–200 grade mesh. Because the large particles are filtered or precipitated in the pre-treatment process. The upper limit of particle concentration of FGD slurry pump is 60%. So the test conditions are as follows:

The samples were buffeted by slurry jet of high concentration (60%, 1.3 kg/l) and high speed. The slurry was a mixture of high hardness quartz sand (particle size: 100–200 grade mesh, 0.7–1.5 mm grain's size) and water, which was sprayed onto the specimens at a velocity up to 18 m/s and an impinging angle of 90°, as shown in Fig. 1. The samples were 3 mm thick. The impact lasted for 5 h, and finally the wear depth was measured as an indicator to determine the sample's wear resistance. The samples' materials are shown in Table 1.

2.2. Experimental results

After the samples were buffeted by slurry for 5 h, the sample surfaces were worn as shown in Fig. 2. The stainless steel sample (304) was penetrated after 2 h. The wear depth is shown in Fig. 3.

As shown in the test results above, the wear resistance of Resto SiC Fine Bead, which is a kind of ceramic coating, is the best and even better than wear-resistant steel Cr30A. Stainless steel 304 is the worst because of its low hardness. The wear resistance of PU coating is comparable to those wear-resistant steels.

3. Cases of wear-resistant coatings' practical application

3.1. Ceramic coatings

Circulating pump transporting flue gas desulfurization (FGD) slurry in a power plant in Shanghai, is one of the main equipment in FGD section. It is responsible for transporting the lime slurry into the absorption tower spraying acidic gas such as SO_2 (sulfur dioxide). The transported medium is the lime slurry, which contains solid particles with a concentration of 15–20%. The main ingredients are $CaSO_4$, $CaCO_3$ and a small amount of high hardness particles, such as SiO_2 and Al_2O_3. Particle size of solid powder is around 300 grade mesh. The liquid is acidic, and pH ranges from 4 to 6, and the temperature ranges from 45 to 60 °C. Concentration of chloride ions (Cl^-) is below 20,000 ppm. Particles such as SiO_2 and Al_2O_3 are the ballast