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The difference between synergistic erosion–corrosion and corrosion of mild steel in SiC suspension

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Abstract

The synergistic erosion–corrosion and corrosion characteristics of mild steel were studied by using rotating disk apparatus and immersing in 0.05 wt.% SiC suspension, respectively. The difference between cavitation erosion and corrosion was determined by scanning electron microscope (SEM), positron annihilation lifetime spectra (PALS) and X-ray photoelectron spectroscopy (XPS). It was found that the propagation of cracks in pit area induced by cavitation erosion did not appear in the course of corrosion. The PALS results showed that the size and number of vacancy cluster induced by cavitation erosion was much larger than that induced by corrosion damage. The results of core level band spectra indicated that there were chemical shifts in the case of cavitation erosion and no chemical shifts except 40 min corrosion in immersion process. The results of valence band spectra implied that the oxidation of mild steel induced by cavitation erosion was more than that induced by corrosion damage.
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1. Introduction

Cavitation erosion is a common mode of damage in engineering components in contact with fast-flowing or vibrating liquid, such as in ship propellers, hydroturbines and hydraulic systems [1–3]. Corrosion is a material degradation process which occurs due to chemical or electrochemical action. As for liquid containing microparticles, it is accepted that impinging microparticles remove the protective layer on the metal surface resulting in continuous exposure of fresh metal surface to the aqueous environment, which can accelerate the corrosion of metal. When these two processes act together, the conjoint action of erosion and corrosion in aqueous environments is known as erosion–corrosion.

Over the past several decades, there were a number of studies reports on synergistic effect of cavitation erosion and corrosion [4–6]. Many of these papers generally focus on the electrochemical behaviors such as electrode potential, corrosion current, and electrochemical corrosion rate [7–10]. Besides, there has been extensive work done in understanding the pure corrosion and pure erosion mechanisms [11,12]. However, only a little work was done about the difference between synergistic erosion–corrosion and pure corrosion damage, especially properties of oxidation and microdefects such as vacancies which is known to be the crucial factors to control the mechanical properties of alloy [13].

In this paper, the synergistic erosion–corrosion and pure corrosion of mild steel in 0.05 wt.% SiC (500 nm) was studied. The synergistic erosion–corrosion under flow field condition was studied by means of rotating disk apparatus. The pure corrosion damage was analyzed by immersing in SiC suspension with pH 7 at ambient temperature. After different experimental time, the samples were analyzed by using scanning electron microscope (SEM), positron annihilation lifetime spectra (PALS) and X-ray photoelectron spectroscopy (XPS). Those results have provided useful information on difference between synergistic erosion–corrosion and pure corrosion.

2. Experimental procedure

2.1. Materials and medium

The material used in the present study is a 0.15 mass% C mild steel with a small amount of Mn(0.4%), Si(0.05%), S(0.05%) and P(0.045%). The size

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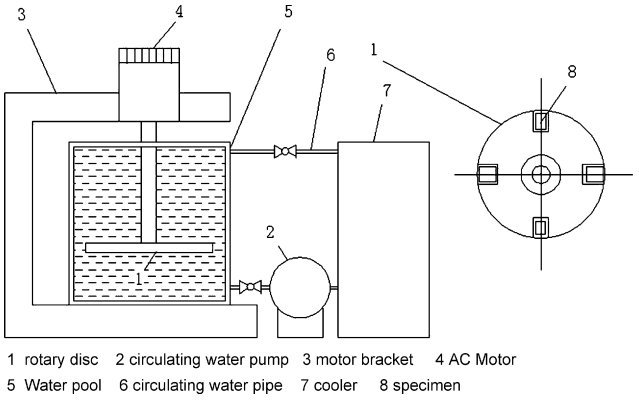

Fig. 1. Schematic diagram of cavitation erosion test apparatus.

of the sample was 40 mm × 30 mm × 6 mm. All the samples were ground with SiC paper up to 1200 grit so as to obtain uniform surface. The samples were degreased in acetone medium and dried before they were treated.

Our previous work has revealed that addition of particles with an average diameter of 500 nm to water produces cavitation damage that far exceeded that expected by the summation of the cavitation and particulate effects acting independently [14], which is similar to the results of Soh and Willis [15]. Therefore, the medium used in the experiment was 0.05 wt.% SiC suspension, which was produced by incorporating SiC particle with 500 nm in diameter into deionized water, and the temperature of the suspension in the experiment was kept at room temperature. Experiments were conducted after the mild steels were subjected to cavitation and corrosion for 10, 20, 30 and 40 min.

2.2. Test apparatus

The respective cavitation erosion was examined using a rotating disk apparatus as shown Fig. 1, which generates vortex and cloud cavitation and engenders damage in the case of actual hydraulic machinery. The apparatus consists of a stainless steel container, rotating disk, recycle pump and cooling apparatus. Four equispaced samples were installed on the rotating disk. In order to induce the cavitation, an orifice hole was made on the rotating-disk in front of each sample. The rotating speed of the rotating disk was 2400 round/min. As the sample installation site was 5 mm deep, the upper surface of the sample was 1 mm higher than the rotating disk surface. The fluid used in the experiment was 0.05 wt.% SiC suspension and the temperature of the suspension in the experiment was kept at room temperature by a water cooling apparatus.

2.3. Morphology observation

In order to analyze the effect of cavitation erosion and corrosion, scanning electron microscopy (SEM; model Quanta 200F system) was used to observe the surface morphology of mild steel cavitation erosion and corrosion after different time.

2.4. Microdefect analysis

PALS experiments were used to study the state of vacancies, which were carried out with a fast-slow coincidence ORTEC system with a time resolution of 190 ps (full width at half maximum). A 5×10^5 Bq source of ^{22}Na was sandwiched between two plates of mild steel. The measurements of the positron annihilation were performed at room temperature and the results were analyzed with POSITRONFIT-88 program in which variances of fit (o) between 1.105 and 1.101 were obtained. Three lifetime components (τ_1, τ_2, τ_3) and corresponding intensity (I_1', I_2', I_3') are obtained by subtracting source composition and background. τ_3 ($\approx$1 200) in each spectrum with an extremely small intensity I_3' (<1%) is considered as the results of positron annihilation on the surface of samples and source. This was disregarded in our discussion. Renormalizing I_1', I_2' and marking them as I_1, I_2, it is found that the shorter the positron lifetime (τ), the bigger the positron annihilation rate (λ) and $\lambda = \tau^{-1}$. Correspondingly, $\lambda_1 = \tau_1^{-1}$, $\lambda_2 = \tau_2^{-1}$ and the mean positron annihilation rate $\lambda_m = I_1\lambda_1 + I_2\lambda_2 = I_1\tau_1^{-1} + I_2\tau_2^{-1}$. Suppose that positron exist in two states: free or trapped by defects then according to two state trapped models [16], its annihilation rate (λ_b) in the bulk of alloy equals its mean value (λ_m), i.e. $\lambda_b = \lambda_m$. In order to identify the size of the vacancy clusters (V_n, where n is the number of vacancies), the experiments results were compared with the calculated positron lifetimes in the vacancy clusters by using a simple superimposed atom method [17].

2.5. X-ray photoemission spectroscopy measurement

To investigate the oxidation of cavitation erosion and corrosion, XPS experiments were taken using a PHI 5300 ESCA system. During XPS analysis, the base pressure in the instrument chamber was in the range of 10^{-8} to 10^{-9} Torr. The samples were cleaned by sputtering with Ar ions to remove surface contamination. The spectra were collected using Al Kα radiation and the overall energy resolution was about 0.8 eV.

3. Experimental results

3.1. Morphology

In order to study the development of the cavitation pits, the mild steel sample surface was observed after 10, 20, 30 and 40 min, respectively. The pictures of the damaged surface are shown in Fig. 2. In Fig. 2a, some pits appear on the surface after 10 min cavitation experiment and they disperse on the surface randomly. As shown in Fig. 2b, these pits with a dimension of 4 μm long and 2 μm wide have irregular shapes. Moreover, mild steel surface is little coarse owing to cavitation damage. The surface of mild steel after 20 min cavitation was shown in Fig. 2c, which clearly indicates more pits than that after 10 min cavitation experiment. The processes of crack linkage near existed pit are clearly illustrated in Fig. 2d. The tortuous nature of the crack path can be seen, together with the complex crack tip interactions and growth behavior at coalescence. After 30 min, the size of pit increases obviously as shown in Fig. 2e. Surface area which was surrounded by crack might fall out. Subsequently, pit become large and is extend outward as illustrated in Fig. 2f. After 40 min, it is obvious that the larger pits distribute randomly over the surface of mild steel. In this case, the growing process of cracks distributed not only in pit but also over the surface of mild steel, which was seen in Fig. 2g and h.

The surface morphology of specimens immersed in 0.05 wt.% SiC suspension for a period of 10, 20, 30 and 40 min is displayed in Fig. 3. In Fig. 3a, some circular pits appear on the surface after the 10 min immersion. The surface of pits is coarse and ramous as shown in Fig. 3b. After 20 min immersion, the size and dimension of pits increase obviously. In this case, the crack width increases within the pit area. The crack propagation and extension accelerate as shown in Fig. 3c and d. After 30 min immersion, the density of pit over mild steel surface increase owe to the formation of new pit. Surface within many of pits area might fall out partly as can be seen in Fig. 3e and f. In Fig. 3g and h, when mild steel have been immersed for 40 min, the size of some pit increase significantly, which presents irregu-

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