Effect of Impact Angle on the Erosion–Corrosion Behavior of AISI 420 Stainless Steel in 3.5 wt.% NaCl Solution

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Erosion, erosion–corrosion, and synergistic behaviors of AISI 420 stainless steel were studied in 3.5 wt.% NaCl solution containing silica sand with the size of 250–500 μm as erodent particle. The erosion and erosion–corrosion tests were carried out according to ASTM G11909 standard and the synergism was calculated. The tests were performed using a slurry jet apparatus at a jet velocity of 6.5 m/s, sand concentration of 90 g/l, and various impinging angles of 20 deg–90 deg. Scanning electron microscope (SEM) was used to study the eroded surfaces and erosion mechanisms. The SEM images showed that under low impacting angles, cutting deformation was the main erosion mechanism while impact and work hardening could be responsible for material removal at high impacting angles. The results showed that the maximum erosion–corrosion and synergism rates occurred at an impingement angle of about 50 deg while the maximum pure erosion rate was obtained at impingement angle of about 35 deg. Energy dispersive spectrometry (EDS) analysis showed that an oxide layer was formed on the surfaces of the samples during erosion–corrosion tests. This oxide layer could make the surface more brittle and could lead to an increment of about 15 deg in the angle of the maximum removal rate. The formation and the subsequent removal of the nonprotective oxide layer as well as possible initiation and propagation of pits during erosion–corrosion tests could lead to higher erosion–corrosion rate compared to pure erosion resulting in a positive synergism under the conditions tested. [DOI: 10.1115/1.4029939]

Keywords: erosion–corrosion, pure erosion, synergism, impingement angle, oxide layer

Introduction

Erosion–corrosion is one of considerable technical importance in several types of applications, including coal gasification or liquefaction, steam turbines, jet turbines, in the in-bed evaporator tubes, water walls, and convention pass surfaces of fluidized bed combustion systems [1]. Erosion is a mechanical wear process, while corrosion is a material degradation process which occurs due to chemical or electrochemical action [2]. When these two processes act together the conjoint action of erosion and corrosion in aqueous environments is known as erosion–corrosion. The combined effects of erosion and corrosion can be significantly higher or less than the sum of the effects of the processes acting separately. This net effect is called synergism [2–5]. Synergism could be expressed through the following equation:

$$ S = T - (W_0 + C_0) \quad (1) $$

where $T$ is the total wear-rate due to erosion–corrosion, $W_0$ is the wear-rate due to pure erosion, $C_0$ is the wear-rate due to pure corrosion, and $S$ is the wear-rate due to synergistic effects [6–8].

Variables affecting erosion–corrosion can be broadly separated into three types: impingement variables (slurry composition, flow velocity, temperature, particle concentration, and angle of incidence), particle variables (particle shape, size, hardness, and friability (ease of fracture)), and material variables (all the material properties such as hardness, work hardening behavior, and microstructure) [1].

Impingement angle has a decisive role in erosion–corrosion studies. Materials are broadly classified as ductile or brittle, based on the dependence of their erosion rate on impingement angle [1]. Ductile materials such as pure metals have a maximum erosion rate ($W_0$) at low angles of incidence (typically 15 deg to 30 deg), while for brittle materials such as ceramics, the maximum is at or near 90 deg [1].

Lopez [9] studied the effect of two impingement angles of 30 deg and 90 deg on erosion–corrosion behavior of AISI 420 stainless steel in the slurry composed of 70 wt.% $H_2SO_4 + 3.5\%$ NaCl solution and 30 wt.% of $SiO_2$ particles with mean diameter of 210–300 μm. He found that under impact velocities of 4.5, 6.9, and 8.5 m/s, the erosion–corrosion rate at impingement angle of 90 deg was higher than 30 deg.

Burstein and Sasaki [4] studied the effect of the impact angle on the erosion–corrosion behavior of AISI 304L stainless steel and found that the maximum values of both erosion and erosion–corrosion rates in chloride solution occurred at oblique angles between 40 deg and 50 deg, and the synergism was positive in all conditions and greater for lower angles.

Other authors have also reported positive erosion–corrosion synergism in slurry wear tests of stainless steels [4,10,11]. Positive synergism means that erosion can increase corrosion tendency and corrosion can enhance erosion in different ways. For example, in the erosion–corrosion of passivating materials such as AISI 316 stainless steel, the corrosion rate can be increased with removal of passive layer by erodent particles and corrosion may promote erosion by dissolving the work-hardened layer on the sample surface [12].
AISI 420 stainless steel in 3.5 wt.% NaCl solution had the following results:

1. At impingement angles of 30 deg and 50 deg, plastic deformation resulted in wear grooves in the direction of impact and tonguelike cutting edges. At normal impact of particles, plastic deformation and craters were induced at the sites of the impacts.

2. Maximum pure erosion and erosion–corrosion rates were obtained at impingement angles of about 35 deg and 50 deg, respectively. This 15 deg shift in the impingement angle of maximum removal rate could be due to the formation of the brittle oxide layer on the surface of erosion–corrosion sample.

3. The synergism rates were positive at all impingement angles. The maximum synergism rate was also obtained at an impingement angle of 50 deg.

4. The maximum number of pits was obtained on the erosion–corrosion surfaces at impingement angle of 50 deg. The pits were not observed on the erosion–corrosion surface at an impingement angle of 90 deg. The pits were not also observed on the surfaces of pure erosion samples at various impingement angles.

5. The percent synergism which was the ratio of synergism rate to total erosion–corrosion rate, increased as impingement angle increased and became stable beyond impingement angle of 50 deg.

References