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Slurry erosion characteristics and erosion mechanisms of stainless steel

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ABSTRACT

In the present study, slurry erosion experiments of stainless steel SUS-304 were carried out using new advanced erosion test rig, where the multiphase flows of alumina sand and water were utilized as the erodents. The results show that erosion rate was initially high and gradually reduced over the testing time. In addition, the erosion rate increased with an increase in impact velocity. The surface roughness increased with either increasing testing time or impact velocity. Further, the surface profiles of “W” shape were observed for all eroded samples. Microstructural characterization reveals two different erosion regimes: plastic deformation mechanism dominated at high impact angles, while plowing/cutting mechanism dominated at low impact angles. A correlation between the erosion rate, erosion profile and microstructure is also discussed.

1. Introduction

Slurry erosion study is vitally important in many engineering applications associated with the transportations of abrasive particles, particularly in oil and gas production systems, hydraulic machines, pumps, hydropower, mine industry, etc. [1–4]. Failures due to erosion can lead to detrimental economic consequences as well as safety concerns. The demand for longer service span, which eventually reduces the cost of maintenance, has motivated many research laboratories and companies to study slurry erosion for particular cases for specific applications [4–6]. Several standard laboratory tests, such as ASTM G65/75, pipe loop, jet impingement, toroid wheel, slurry pot or coriolis, have been built to understand the actual erosion situations of different materials under various environmental conditions [5,7–10]. Each test method has its own advantages and disadvantages. Some test rigs used centrifugal pumps, which are cost saving. However, the pump propellers are very prone to abrasive particles and damaged after a short time of use. This leads to a huge variation in flow velocity as well as the actual amount of slurry carried in a unit of time, and thus reduces the reliability of experimental results [5,11–14]. In this paper, we design a new slurry erosion test rig using a peristaltic pump, which eliminates the disadvantages of centrifugal pumps as abrasive particles transported through a rubber hose. The peristaltic pump gives accurate and consistent flow rates through a digital speed regulator, as well as an adjustable pressure of pulsation dampener.

Erosion of materials varies from material to material, testing conditions, types of abrasives and environmental conditions. The literature search shows that different types of materials, such as ductile and brittle metals, ceramic, polymer and composites, have been tested [15–22]. The reported results indicated different erosion characteristics such as U- and W-wear scars for brittle and ductile materials, respectively. Several types of abrasives have been used in erosion tests to simulate different situations occurred in our real life at certain places [3,4,23,24]. Particle size, shape, hardness and density as well as impact angles and impact velocity also play a crucial role in the erosion process [25]. Further, erosion becomes more serious when the testing environmental conditions become hostile and corrosive due to the synergic effect of erosion–corrosion [3,5,9,13].

However, the literature search also shows that a careful and detailed study on slurry erosion of stainless steel SUS304 using the peristaltic pump has not been published yet. Thus, this paper studies the erosion of stainless steel SUS304 at a representative impact angle of 90° with variations of testing time and impact velocity in the medium of angular alumina sand and tap water using the newly developed test apparatus equipped with peristaltic pump. The erosion characteristics and mechanisms are changed from location to location. Different characterization tools such as surface profilometer, scanning electron microscopy and atomic force microscopy were used to examine the nature of erosion, microstructure and its erosion mechanisms.

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2. Experimental procedure

2.1. Wet erosion test rig

The new advanced slurry erosion test rig using the peristaltic pump was developed according to ASTM-G73 as shown in Fig. 1 [20,23,24]. It is a closed, circulated and automated system. Sand particles and water are pre-mixed in the agitating tank using a frequency controllable motor. The tank bed and stirring blade were designed to incline 30° to the horizontal direction to achieve an auto-lift up mechanism so that sand particles are well mixed in the agitating tank at a low stirring speed. The medium of sand and water is then pumped to the pulsation dampener using a powerful and speed adjustable 40SPX Bredel peristaltic pump. The discharged flow is smoothened by regulating the pulsation dampener pressure before shooting to the sample through a 6.4 mm diameter stainless steel nozzle, and the discharged medium is then circulated to the agitating tank. The pulsation dampener pressure is set according to the discharged pressure at the nozzle for each flow velocity. The sample holder is designed to rotate from 0° to 90° and is adjustable in x and z directions. The distance from nozzle to the sample and the impact angle was pre-fixed at 12.7 mm and 90°, respectively. The mixing speed is optimized at 76 rpm. Flow velocity is adjustable using frequency through the digital indication knob on the controller.

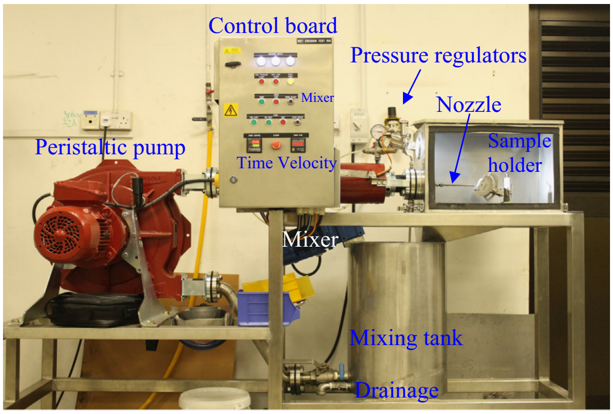

Fig. 1. Photograph of wet erosion test rig.

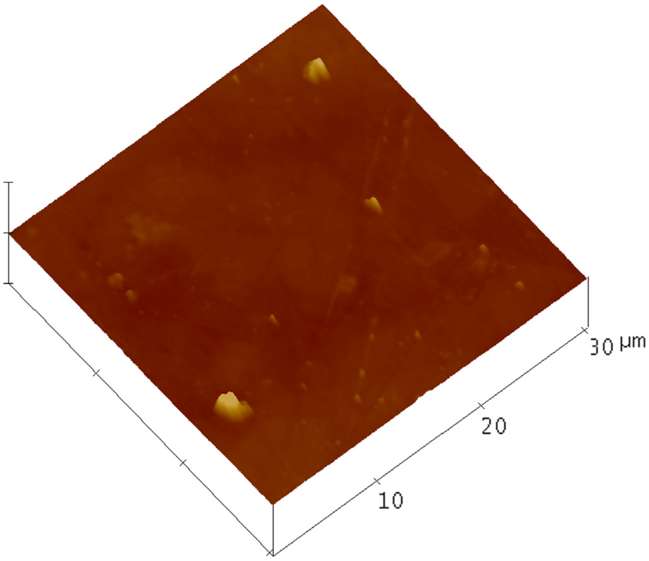

Fig. 2. AFM image showing a mirror sample surface condition prior to the test.

2.2. Sample preparation

The $25 \times 25 \times 5\ \text{mm}^3$ stainless steel SUS304 samples with an experimental density of $7929\ \text{kg/m}^3$ were cut from a $500 \times 500 \times 5\ \text{mm}^3$ sheet using a precision laser-cutting machine. Prior to laser cut, the stainless steel sheet was auto-polished to a mirror level with an average surface roughness of 25 nm (Fig. 2). All the furs at the sides of sample were removed and the samples were alcohol washed in an ultrasonic bath and then hot dried and kept inside the digital dry cabinet prior to the tests. The chemical composition of the stainless steel SUS-304 is C ~0.024%, Si ~0.55%, Mn ~1.8%, P ~0.03%, S < 0.001%, Cr ~18.2%, Ni ~8.2%, N ~0.049% and Fe balance. Its mechanical properties are as 0.2% proof strength ~296 MPa, 1% proof strength ~327 MPa, Tensile strength ~616 MPa, Elongation at 5 mm ~56%, elongation at 50 mm ~55% and Brinell hardness ~187.

2.3. Sand material

The sand material contains mainly aluminum oxide with an average size of 90 mesh with chemical composition of Al_2O_3 ~95%, TiO_2 ~3%, SiO_2 ~1.3%, F_2O_3 ~0.16%, and CaO ~0.5% (supplied by Pan-abrasive, Singapore). The sand has a density of $2400\ \text{kg/m}^3$ and a hardness of 9 (Moh). The microstructural morphology and size distribution of sand particle are shown in Fig. 3 with an average experimental angularity of 0.58. A constant 0.5 vol% of sand was used in this study.

2.4. Weight loss

Prior to the test, the samples were taken out from the dry cabinet and their weight was measured immediately to avoid the humidity effect, using a microelectronic balance with an accuracy of 0.00001 g. The samples after test were first water washed, air-blew and then alcohol washed in the ultrasonic bath, hot dried and kept inside the

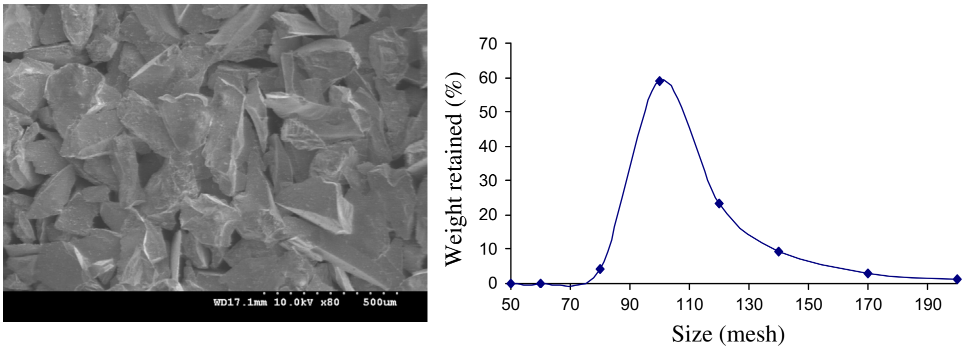

Fig. 3. Morphology and distribution of sand particles.