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Investigation of erosion of stainless steel by two-phase jet impingement

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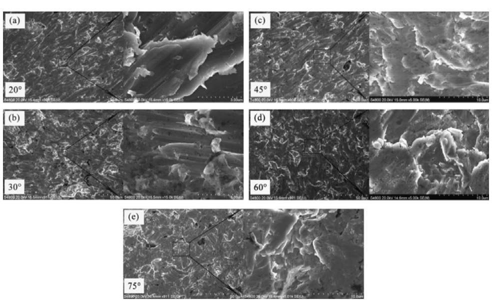
GRAPHICAL ABSTRACT

Surface analysis on 316 after 2 h exposure to jet impingement erosion (JIE) at different impact angles (a) 20° (b) 30° (c) 45° (d) 60° (e) 75°.



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ABSTRACT

The study has been conducted to assess the performance of 304, 316 and the effect of various working conditions under high velocity jet impingement in various types of media containing particles in normal water. Mass loss per unit area vs. exposure time is used to evaluate the erosion rate of the stainless steel. The surface morphologies before and after the erosion tests are observed by High-power optical microscope and scanning electron microscopy. The results show that particle concentration and particle size have significant effects on the mass loss of stainless steel. In addition, the type of particles and steels do effects on it. The maximum erosion rate is found to occur in the testing duration around 12–15 h and the erosion mechanism for different impact angle is obviously different. Using Finnie's cutting model, the calculation result agrees well with the experiment results and demonstrates that both target materials wear follow a linear relationship with the kinetic energy of impinging particles.

1. Introduction

Surface erosion of material by solid-particle impact is a problem in nature and many multiphase flow industrial devices [1]. Despite tremendous developments in the material improvements, jet impingement erosion (JIE) still remains an unsolved problem. Material removal in water jet impingement in various materials leads to the identification of four primary modes by which water drop impingement can produce damage in materials. These are, direct deformation, stress wave propagation, lateral outflow jetting and hydraulic penetration. The damage produced by one or more of these loading conditions on a material surface exposed to a single or multiple water drop impact is responsible for initiating damage and subsequent material removal [2–11]. The evaluation of damage

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produced in target materials due to single water drop loading cycle is a complex dynamic process, which involves a number of closely phased actions. Several important properties of materials, such as material being cast, forged, rolled, or various working conditions play an important role to effect impingement erosion [12–19].

JIE is an important problem found in thermal power engineering, for example, nuclear power engineering. Nuclear energy plays a significant role as clean energy in decreasing CO_2 emission in the world. High temperature, high pressure and high velocity fluid flows are three characteristics in the main pipe of nuclear plant. The safety of the main pipelines as the life pipe in the nuclear plant is extremely important. The fuel rods and reactor assembly expose to the corrosion–erosion and jet impingement erosion of high sub-cooled coolant jet impingement erosion, which generates many particles. The coolant following with particles flows into the main pipe, resulting in the physical wear, chemical corrosion, corrosion–erosion, flow accelerate corrosion and so on, which is responsible for the failure of the main pipe, shown in Fig. 1(a). The damage caused by jet impingement with particles is severe. During experimental process, the experiment apparatus was breakdown, shown in Fig. 1(b). Both austenitic stainless steel 304 and austenitic stainless steel 306 with superior corrosion resistance and high temperature endurance, which determines their widespread applications in aeronautical, aerospace, marine and nuclear industries. pipes of nuclear plant are mainly made of austenitic stainless steel 304 and austenitic stainless steel 306, especially the main pipelines and second pipelines. It is essential to know the mechanism of degradation of materials to combat jet impingement erosion.

Finnie developed the micro-cutting model. Mohammadi and Luo [20] studied the single particle impingement current transients for prediction of erosion-enhanced corrosion on 304 stainless steel. Hu et al. [21] compared the cavitation erosion and jet impingement erosion and he found that the hardness of samples play a positive role in low JIE rate at normal impact angle, which has little effect on the JIE resistance at the impacting angle of 30°. Hu and Neville [22] studied the electrochemical response of stainless steels in liquid–solid impingement and he developed a methodology to determine the critical level of parameters to identify the transition between different regimes in erosion–corrosion.

So far, the problem of material erosion caused by liquid–solid two-phase impinging jet has not been investigated enough. Particularly, the mechanism of erosion of the stainless steel with various particles at high speed of impinging jet has little been found. In the present study the mechanism of degradation of materials due to liquid jet impingement erosion has been discussed and compared. And the damage mechanism is explained through analysis of mass loss, microscope observation and SEM observation and used to evaluate the behaviours of the two materials in the JIE condition. As a result, better understanding of the erosion process is helpful for the development of the two materials for this type of application.

2. Experimental procedure

The JIE test was conducted using a jet apparatus for erosion shown in Fig. 2(a). A jet with high flow velocity of 20 m/s was ejected from a nozzle of 13 mm in diameter and impacted on the sample (diameter 1.5 mm, in the shape of circle, shown in Fig. 2(b)). The chemical composition of 304 & 316 stainless steel is listed in Table 1. The impacted angle varies from 20° to 75°. Tap water containing sand was used as the test medium to accelerate the tests.

Before weighing, at first the specimen was cleaned by ethanol in an ultrasonic cleaning bath for at least 5 min, and then dried by blowing air, finally weighted by precision balance with an accuracy of 0.1 mg. All the data of mass loss was the average results of at least three parallel specimens. Each specimen was taken from the test periodically. The morphologies of the specimen surfaces and cross-sections at different intervals were observed by optical microscope.

3. Results and discussion

3.1. Mass loss

Fig 3(a) presents the mass loss per unit area of the 304 and 316 stainless steel at impacting angle of 30° in tap water with 0.2wt.%

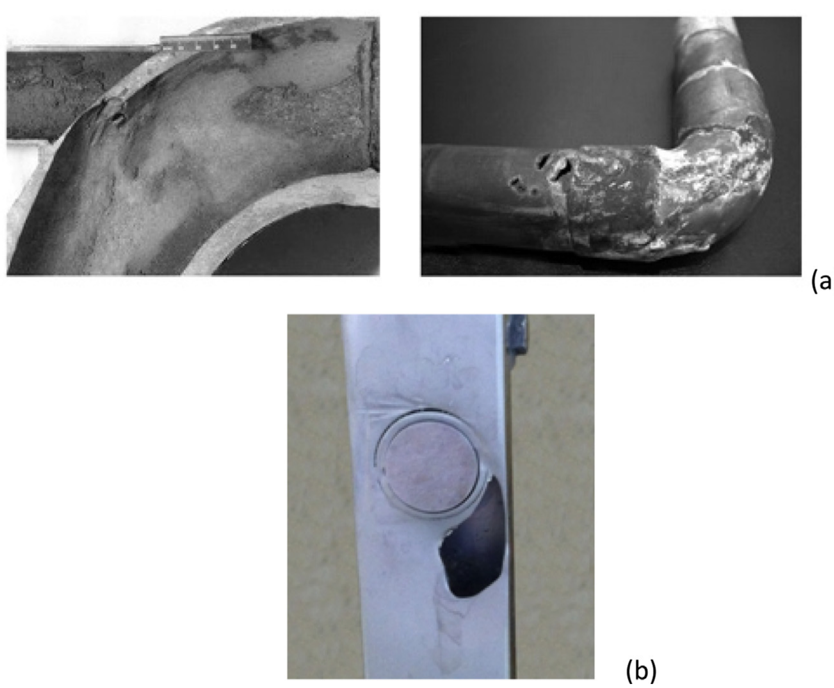

Fig. 1. (a) Degradation of industrial pipe; (b) experimental test part damage from JIE.