Influence of swirling cryogenic jets on erosion of AISI 310 stainless steel

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The erosive effect of swirling jets on 310 austenitic stainless steel at low temperatures was analyzed. Four incidence angles and two swirl numbers were used under impact of Al_2O_3 particles with average size of 50 µm with a velocity of 20 m s^{-1}. The total exposure time for the tests was 480 s using a novel cryotribometer with an indirect heat exchanger filled with liquid nitrogen. SEM microscopy was used to evaluate the wear mechanisms. According to the erosion tests results the maximum erosion rate was observed at high angles of incidence, which showed a brittle tendency of the material.

Keywords: Cryogenic jets, austenitic stainless steel, sub-zero temperatures, swirl number

1. Introduction

Swirling flows have gained interest in many technical applications, for instance in cyclone separators, burners, propellers, dredgers, excavators and hydraulic turbines [1], and lately swirling flow has been found in cryogenic liquid turbine expanders [2]. Moreover, austenitic stainless steels are extensively used for service at sub-zero temperatures. This work was developed due to the limited information on swirling jet flows at cryogenic temperatures, in addition to gaining knowledge about the ductile-brittle behavior in solid particle erosion (SPE) tests on austenitic stainless steel samples at low temperatures.

2. Methods

In the present study, SPE tests were conducted on AISI 310 austenitic stainless steel using a cryotribometer designed to control nozzle rotation, flow velocity, air stream temperature, and orientation relative to impinging cryogenic stream. The tester produces cryogenic jets from -70 to -170 ºC by means of a heat exchanger and liquid nitrogen. The SPE tests were carried out at two regimes, non-swirling jets (S=0) and swirling jets at S=0.03. Abrasive Al_2O_3 particles were used as erodent. The incidence angles used were 30º, 45º, 60º and 90º in the near field (the standoff distance was equal to the diameter of the nozzle). The total exposure time for tests was 480 s. The hardness of the stainless steel was monitored after each test, to evaluate its behavior against changes in temperature.

Table 1: Test conditions of SPE tests.

Nozzle diameter (mm)	4.8
Sample surface temperature (ºC)	-170 ± 10
Swirl numbers	0 and 0.03
Particle velocity (m s^{-1})	20
Abrasive particles	Al_2O_3 with average size of 50 µm
Incidence angles (º)	30, 45, 60 and 90
Test duration (s)	120, 240 and 480

2.1 Swirl number equation [1].

$$S = \frac{\int_0^R U_{axial} U_{tangential} r^2 dr}{R \int_0^R U_{axial}^2 r dr} \quad (1)$$

2.2 Results

Optical and SEM images were obtained to characterize the wear mechanisms into the wear scar. The erosion tests results indicated that the maximum erosion rates were observed at high incidence angles. Profilometry traces were obtained to observe the distribution of erosion along the surface, as well as the mass loss and erosion rates at different swirl numbers and temperature were obtained to analyze the severity of swirling cryogenic jets against samples of austenitic stainless steel.

3. Discussion

It is well known that the hardness of stainless steel increases with the decrease in temperature, in this way it is to be expected that the erosion rates also undergo a change with respect to the decrease in temperature. Additionally, the swirling jet flows add an additional aspect which can modify the behavior of the impinged material. This is due to the fact that the behavior of SPE against the surface of a material can be classified as ductile or brittle depending on the angle where the maximum erosion occurs; that is, when the maximum occurs at low angles the material has a ductile behavior, if it occurs at angles close to the normal, the material has a brittle behavior.

4. References

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