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Cavitation erosion behavior of nitrogen strengthened austenitic stainless steel in comparison to martensitic stainless steel

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ABSTRACT

Nitrogen strengthened austenitic stainless steel (termed as 21-4-N steel) in as cast condition has been investigated as an alternative to 13/4 steel (termed as CA6NM) to overcome the problems of cavitation erosion in hydro turbine underwater parts. The cavitation erosion of 21-4-N and 13/4 steels was investigated by means of an ultrasonic vibration processor. As cast 13/4 steel finds wide application in hydroturbine underwater parts, this got eroded due to silt erosion and cavitation erosion. The cavitation erosion is highly depending on microstructure and mechanical properties. The results show that 21-4-N steel is more cavitation erosion resistant than the 13/4 steel. The eroded surfaces were analyzed through scanning electron microscopy and microhardness testing was also carried out at the cross section of the eroded surface for erosion mechanisms.

KEYWORDS

Microstructure;
Austenitic steel;
Cavitation erosion.

INTRODUCTION

Cavitation is a phenomenon of formation and collapse, within liquid, of cavities or bubbles that contain vapour or gas or both of them. The collapsing of the cavities on the material surface exerts high pressure, causing damage[1]. Cavitation erosion is a usual damage phenomenon in flow-handling parts of hydraulic turbines, and the service life and capability of such parts are reduced by the damage[2]. The cast martensitic chromium nickel stainless steel (13/4 martensitic stainless steel) has wide application areas in hydro turbines, pumps and compressors. This is because of its good mechanical properties and corrosion resistance. The current trend of using smaller and faster hydraulic machinery with high pressure head has lead to cavitation erosion damages[3]. The cavitation erosion resistance of an alloy depends on many material properties, especially those that promote the binding of the cavitation energy to the structure[4,5]. Most researchers have correlated the cavitation erosion resistance of materials with structure, hardness, work-hardening ability, superelasticity and superplasticity, or strain induced phase transformation, etc.[6-9].

In this investigation we decided to explore the cavitation erosion behaviour of a nitrogen strengthened austenitic stainless steel (21-4-N steel) in comparison to 13/4 steel, which is believed to have higher hardness, high work hardening ability and may find application in hydro turbine under water parts.

Experimental procedures

Cast 13/4 steel and 21-4-N steel were used in this investigation. The chemical composition (wt %) of the above alloys are given in TABLE 1. Long bars of 40mm×40 mm cross section were received from M/S Star Wire (India) Ltd. Ballabhgarh (Haryana). Specimens for metallographic examination, tensile tests, impact tests, hardness test and cavitation erosion tests were machined from these bars.

The Vickers hardness numbers (VHN) was determined using Vickers hardness tester at 30Kg load. The tensile tests were performed on cylindrical specimens at room temperature by using a computer controlled HT Hounsfield machine as per ASTM standard (ASTM: E 8M-03). Impact tests were carried out on standard Charpy V-notch bars at room temperature in accordance with the ASTM standard (ASTM : E 23-96).

The specimens for the cavitation tests were prepared using diamond cutter to a dimension of 10mm×10mm×3 mm. The specimens were polished on belt, 1/0, 2/0, 3/0, 4/0 and finally on cloth wheel. The samples were cleaned in acetone, dried, weighed to an accuracy of 1×10^{-4}g using an electronic balance, eroded in the ultrasonic vibratory test device in distilled water at room temperature for 4 hr and then weighed again to determine mass loss. The schematic diagram of ultrasonic vibratory testing processor is given in figure 1[10]. The equipment consists of Zirconate titanate transducer element that produces axial oscillations at the tip of an attached horn velocity transformer. The sample holder was placed coaxially with a small gap of 0.5mm, and the width of the gap was determined by referring to the related standard[1]. In the test, vapour filled bubbles are created in the gap during the upward motion of the tip, forming a cavitation zone. This zone collapses during the subsequent downward motion of the tip, causing cavitation erosion at the specimen surface. The ultrasonic vibration test device had a frequency output of 20KHz and a power output of 250W. The

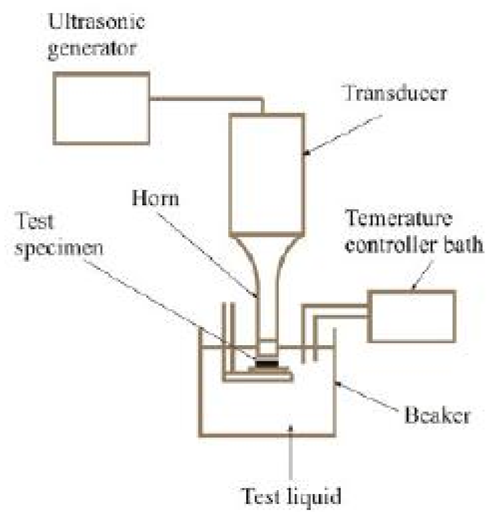

Figure 1: Schematic of the ultrasonic vibratory test device

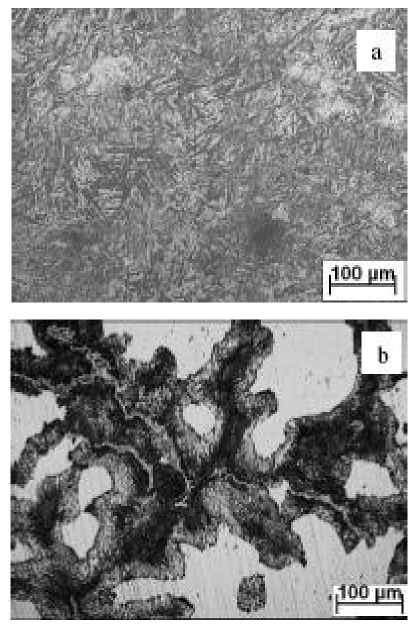

Figure 2: Microstructures of (a) 13/4 steel (b) 21-4-N steels

eroded surfaces were studied on SEM to identify the mechanism of erosion.

RESULTS AND DISCUSSION

Microstructure and mechanical properties

Figure 2 shows the microstructures of 13/4 steel and 21-4-N steel in as cast condition. The microstructure of 13/4 steel consists of packets of very fine, untempered lath/martensitic needles (Figure 2a). Apart

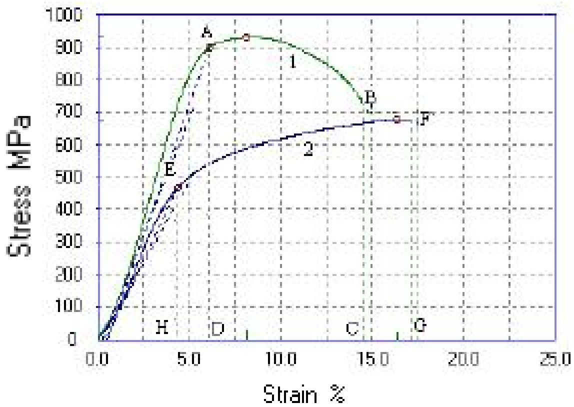

Figure 3: Engineering stress strain diagram of (1) 13/4 and (2) 21-4-N steels

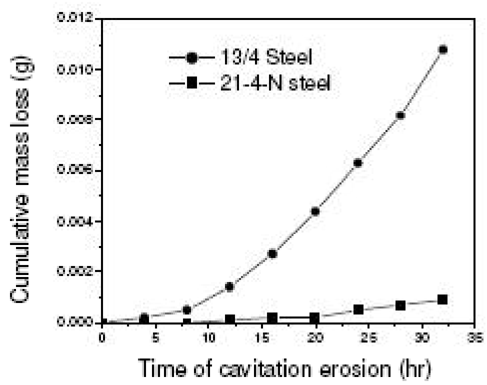

Figure 4: Cumulative CE mass loss as a function of time for the steels in distilled water

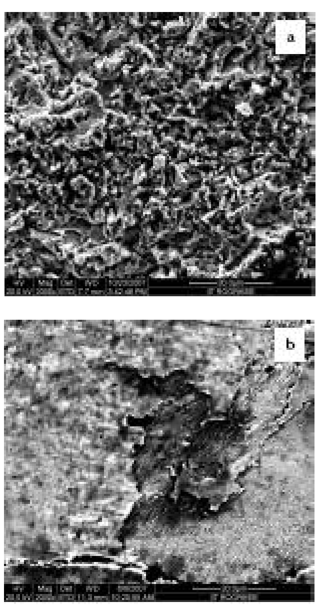

Figure 5: Scanning electron microscopy of (a) 13/4 and (b) 21-4-N steels after 32 hrs of cavitation erosion test

from these packets, the structure exhibits a second phase, which is δ-ferrite. The as cast 21-4-N steel, which is a nitrogen strengthened austenitic stainless steel having low Ni and higher concentration of C possesses predominantly austenitic phase along with the precipitates of carbides. Due to higher concentration of N and possesses high C:Cr ratio the carbide precipitated in 21-4-N steel has may be M_7C_3 carbides. In the microstructural examination of this steel, the massive core of carbides (dark portion) is surrounded by a eutectic (Figure 2b), which according to Padilha et al.[11] consists of austenite and carbides.

The mechanical properties of 13/4 steel and 21-4-N steel are given in TABLE 2 and the engineering stress-strain diagram of 13/4 and 21-4-N steels is given in figure 3. The 13/4 martensitic stainless steel possesses significantly higher values of impact energy, YS and UTS than the corresponding values in the 21-4-N steel. The hardness and ductility (% elongation) in martensitic stainless steel are marginally lower in comparison to 21-4-N steel.

Cavitation erosion test

During the cavitation erosion tests of 32 hrs, the specimens were examined at 4hrs intervals at which the mass loss was measured. Figure 4 shows the cumulative mass loss versus cavitation duration of the cavitation erosion test. The 21-4-N steel exhibits higher cavitation resistance as well as longer incubation period than the corresponding values of 13/4 steel.

Figure 5 shows scanning electron micrographs of eroded surfaces of the tested steels, after 32 hrs of vibration cavitation erosion testing. Because the microstructure of 13/4 steel is martensitic lathes, the deformation is restrained in martensite lathings after cavitation erosion. Since the material is removed from the surface of 13/4 steel as cavitation erosion damage goes on, the shape of martensite lathings in figure 5a is not so clear as that in figure 2a. The ferrite content of 13/4 steel eroded faster as comparison to martensite, the deeper dark portion in Figure 5a indicates the removal of ferrite. In contrary to 13/4 steel, the cavitation erosion damage morphology of nitrogen strengthened austenitic stainless steels (21-4-N steel) is different due to its austenite structure. The damage develops mainly at the austenite carbide grain boundaries (Figure 5b). The Figure 5b reveals that the slip lines appear in austenite

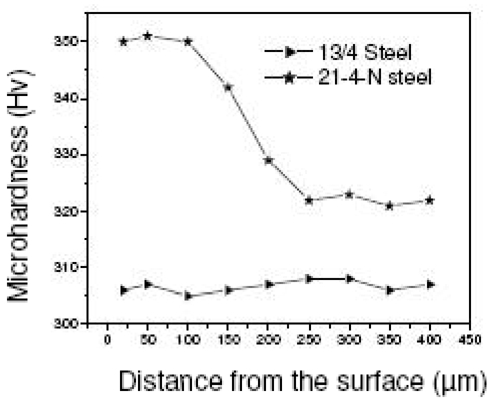

Figure 6: Profile of microhardness vs. depth on a cross-section of the steels after cavitation erosion of 32hrs

grains.

Effect of microstructure on the cavitation erosion

The cavitation erosion resistance of 21-4-N steel is the highest in spite of its lowest impact energy than that of 13/4 steel; however, it has higher hardness and ductility. The cavitation erosion resistance of materials is usually closely connected with their microstructure[2]. The ferrite content in 13/4 steel eroded faster during cavitation erosion and consequently deep cavities are formed as shown in the SEM of eroded 13/4 steel (Figure 5a). The Cavitation erosion performance of 21-4-N steel is different from that of 13/4 steel due to its austenite microstructure. During cavitation erosion process the material removal took place in two ways. First the material is removed from the austenite and carbide grain boundaries, and second, slip lines appear in the austenite grains, and material is removed from slip lines in austenite grains by ductile fracture mode (Figure 5b). No martensitic transformation occurs in 21-4-N steel under heavy impact of microjets, because the higher concentration of N (0.38%) significantly enhanced the austenitic stability.

Effect of tensile toughness on the cavitation erosion

It is observed that higher cavitation erosion resistance of 21-4-N steel is also linked to its tensile toughness, which is higher than that of 13/4 steel. The tensile toughness of the 13/4 steel, as calculated from ABCD in the plastic range the area below the engineering stress strain curve between the YS and fracture stress, is 68 MJm^{-3}, whereas for 21-4-N steel, as calculated from the area EFGH, it is 73MJm^{-3} (Figure 3). Levin et al.[12] have reported that the tensile toughness of a material is its ability to absorb energy in the plastic range. This goes to show that during cavitation attack the tensile stresses developed contribute significantly towards the mechanism of erosion.

Effect of strain hardening on the cavitation erosion

The austenitic grades of steels usually owe their wear resistance to their work hardening characteristics[13]. Development of wear resistant Hadfield steel, for example, is primarily based on its self work hardening characteristics. In this context the mechanism of high cavitation erosion resistance of the 21-4-N steel can be explained by its work-hardening. It is generally known that phase transformation during cavitation erosion process such as strain-induced martensitic transformation can absorb cavitation microjet impact energy[7,9]. As a result, it can improve cavitation erosion resistance of materials. N and Mn elements can stabilize austenite and improve the deformation strengthening ability of the steels[14], so martensitic transformation is restrained. Based on the microhardness change after 32 h of cavitation erosion (Figure 6). It is assumed that the surface microhardness increases because of work-hardening when the surface is impinged by microjets. In the course of cavitation erosion process, the microhardness of eroded surface reaches a maximum and decreases as cavitation erosion is continued. W. Liu et al.[6] have explained the change in microhardness as forming and transferring mode of high hardness layer in a stable austenite of Cr-Mn-N steels. The microstructure of 21-4-N steel is austenitic, and after cavitation erosion, its microhardness increases due to austenite work-hardening, then decreases in result of crack initiation and propagation. Thus the higher cavitation erosion resistance of 21-4-N steel should be attributed to its, high hardness coupled with ductility, high work hardening ability and forming and transferring mode of high hardness layer.

CONCLUSIONS

In view of the results obtained so far, the as cast 21-4-N steel is more cavitation erosion resistant than that of 13/4 steel, due to austenitic structure, higher hardness and ductility, high tensile toughness, high work hardening ability and forming and transferring mode of high hardness layer. In this context, the 21-4-N steel can be a good substitute for 13/4 steel for the fabrication of under water parts of hydraulic turbines.

ACKNOWLEDGMENT

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