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Cavitation erosion behavior of hydro turbine steels

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ABSTRACT

As cast 13/4 steel (CA6NM) finds wide application in hydroturbine underwater parts, which got eroded due to silt erosion and cavitation erosion. The cavitation erosion is highly depending on microstructure and mechanical properties. Nitrogen strengthened austenitic stainless steel (21-4-N steel) in as cast condition has been investigated as an alternative to 13/4 steel to overcome the problems of cavitation erosion. The results of vibration cavitation erosion tests show that 21-4-N steel is more cavitation erosion resistant than 13/4 steel.

KEYWORDS

Cavitation erosion;
Stainless steel;
Tension test;
Impact test.

INTRODCUTION

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 it was 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

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 40 mm × 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 microstructures of both the steel is given in figure 1.

TABLE 1 : Chemical composition of 13/4 and 21-4-N steel (wt %).

Steel	C	Si	Mn	Cr	Ni	N	S	Cu	Co	P	Mo	Fe
13/4	0.06	0.74	1.16	13.14	3.9	---	0.014	0.088	0.035	0.015	0.61	Bal.
21-4-N	0.56	0.25	9.90	23.42	4.28	0.38	0.001	0.16	0.06	0.041	---	Bal.

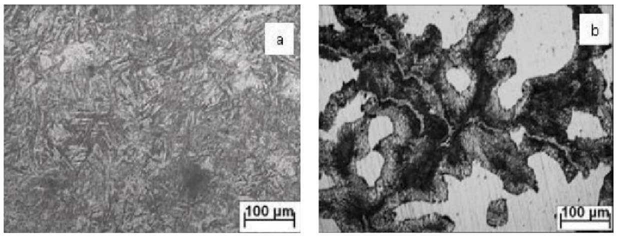

Figure 1 : Microstructures of (a) 13/4 martensitic stainless steel and (b) 21-4-N nitronic steel

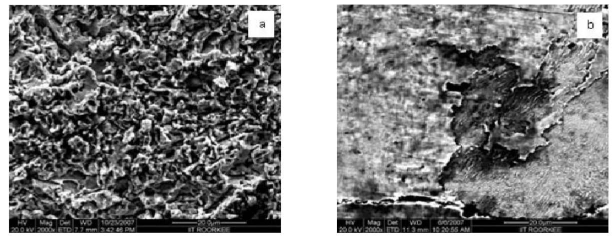

Figure 3 : Scanning electron micrographs of (a) 13/4 steel and (b) 21-4-N steel after 32 hrs of cavitation erosion test

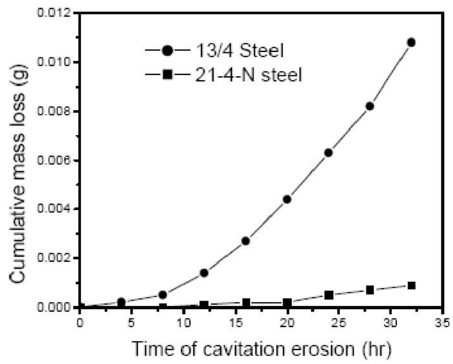

Figure 2 : Cumulative CE mass loss as a function of time for the steels in distilled water

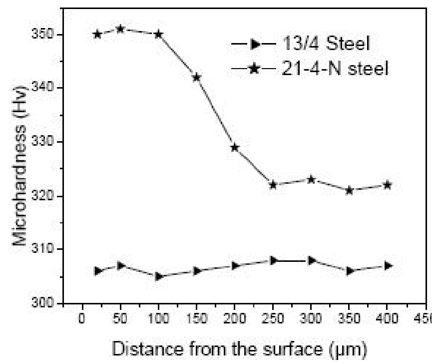

Figure 4 : Profile of microhardness vs. depth on a cross-section of the steels after cavitation erosion of 32 hrs

Figure 1 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. Apart 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 eutectic of austenite and carbide.

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 mechanical properties of 13/4 steel and 21-4-N steel are given in TABLE 2.

TABLE 2 : Mechanical properties of 13/4 and 21-4-N steel

Steel	Hardness (VHN)	Impact Energy (J)	YS (MPa)	UTS (MPa)	Ductility (% el)
13/4	305	64	899	930	14
21-4-N	320	9	466	676	17

The specimens for the cavitation tests were prepared using diamond cutter to a dimension of 10mm×10mm×3mm. The specimens were polished on belt, 1/0, 2/0, 3/0, 4/0 and finally on cloth wheel, and the carefully cleaned and weighed to an accuracy of 0.1mg before and after the tests. The hydrodynamic cavitation erosion behaviour of the studied alloys was investigated with an ultrasonic vibration test device in distilled water at room temperature. 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.

RESULTS AND DISCUSSION

During the cavitation erosion tests of 32 hrs, the specimens were examined at 4hrs intervals at which the weight loss was measured. Figure 2 shows the cumulative mass loss versus cavitation duration of the tested steels. The 21-4-N steel exhibits higher cavitation resistance as well as longer incubation period than the corresponding values of 13/4 steel.

Figure 3 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 3a is not so clear as that in figure 1a. The ferrite content of 13/4 steel eroded faster as comparison to martensite, the deeper dark portion in Figure 3a 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 3b). The figure 3b reveals that the slip lines appear in austenite grains.

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 process of material removal from eroded surface of 13/4 steel shown in figure 3a indicates that the plastic deformation of martensite lathings is restrained by their boundaries.

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 3b). 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.

The austenitic grades of steels usually owe their wear resistance to their work hardening characteristics[10]. 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[11], so martensitic transformation is restrained. Based on the microhardness change after 32 h of cavitation erosion (Figure 4). 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 21-4-N steel is more cavitation erosion resistant than that of 13/4 steel, due to austenitic structure, higher hardness and ductility, high work hardening ability and forming and transferring mode of high hardness layer. In this context, we can say that 21-4-N steel can be a good substitute for 13/4 steel for the fabrication of under water parts of hydraulic turbines.

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