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Hydrogen effect on the cavitation erosion resistance of AISI 316L stainless steel laser surface-modified with NiTi

K.Y. Chiu [a], F.T. Cheng [a,*], H.C. Man [b]

[a] Department of Applied Physics, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong, China
[b] Department of Industrial and Systems Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong, China

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Abstract

AISI 316L stainless steel was laser surface-modified with NiTi for improving cavitation erosion resistance as reported in a previous study. The present study aimed at investigating the effect of hydrogen charging on the cavitation erosion resistance of the NiTi-modified layer, in comparison with 316L substrate and bulk NiTi plate. To compare the hydrogen effect, the three types of samples were subjected to the same electrolytic charging intensity. The change in surface morphology and in the phases present was studied by scanning-electron microscopy and X-ray diffractometry. The indentation properties were studied using Vickers microhardness test and nanoindentation test. Cavitation erosion test indicated that hydrogenation resulted in different degrees of decrease in erosion resistance in all the three types of samples, which could be attributed to different mechanisms. For 316L, the hydrogen effect was mild, congruent with the small change in indentation properties. For NiTi-modified 316L, the decrease in resistance was due to a drop in hardness and elasticity, while for bulk NiTi, the decrease was mainly attributable to the formation of hydrides leading to the presence of surface cracks.

Keywords: Laser processing; Stainless steel; NiTi; Cavitation erosion; Hardness; Elastic properties

1. Introduction

AISI 316L stainless steel is a widely used engineering material in liquid-handling systems and hydraulic machinery, mainly because of its good corrosion resistance and processibility, and also of its reasonable mechanical strength and cost. However, AISI 316L has a relatively low cavitation erosion resistance [1], which has limited its applications in severe cavitating environments.

Recently, the surface modification of AISI 316L using NiTi powder has been attempted by the present group of authors [2]. While improvement in cavitation erosion resistance and compatibility in corrosion behaviors have been verified [2,3], the effect of hydrogen ingress on the cavitation erosion behavior has not been studied. It has been reported that the ingress of hydrogen into NiTi would lead to degradation in mechanical properties [4–7] and cavitation erosion resistance [8]. The present study aimed at investigating the effect of hydrogen electrolytic pre-charging on the cavitation erosion resistance of NiTi-modified 316L. As-received 316L and bulk NiTi plates were also included for comparison since 316L was the substrate material while NiTi was the cladding material used in the laser surface modification.

2. Experimental details

AISI 316L stainless steel was laser surface-modified using preplaced NiTi powder as previously described [2], and the sample was designated as NiTi-modified 316L hereafter. The compositions of the as-received 316L, NiTi powder, and the top

Table 1
Composition in wt. % of various samples

	Fe	Cr	Ni	Mo	Mn	Ti
AISI 316L	66.5	17	12	2.5	2	–
NiTi plate	–	–	55	–	–	45
NiTi-modified 316L	45	12	25	–	–	18

Elements less than 2 wt. % were not included.

* Corresponding author. Tel.: +852 2766 5691; fax: +852 2333 7629.
E-mail address: apaftche@polyu.edu.hk (F.T. Cheng).

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layer (averaged over a depth of 0.2 mm) of NiTi-modified 316L were determined by EDS and shown in Table 1.

All the samples were spark cut to dimensions of 20×12 (surface)×2 mm (thickness). The samples were electrolytically charged with hydrogen at 23 °C in 0.25 M H_2SO_4 at a current density of 0.1 A/cm^2 for 4 h. For lower charging current densities or shorter charging times, most of the hydrogen would be present in the diffusible form [4] and not expected to affect the cavitation erosion resistance. The phases present before and after charging were studied by XRD. The surface morphology after hydrogenation was imaged by SEM. Vickers hardness was obtained at a load of 200 g. The nanoindentation curves were acquired at a maximum load of 200 mN. Cavitation erosion characteristics in deionized water at 23 °C were studied conforming to ASTM Standard G32–92 [9]. The peak-to-peak amplitude and the vibration frequency were 100 μm and 20 kHz, respectively, and the sample was placed at 0.5 mm below the horn tip. The sample was weighed at regular intervals and the weight was converted to a mean depth of erosion (MDE) [2].

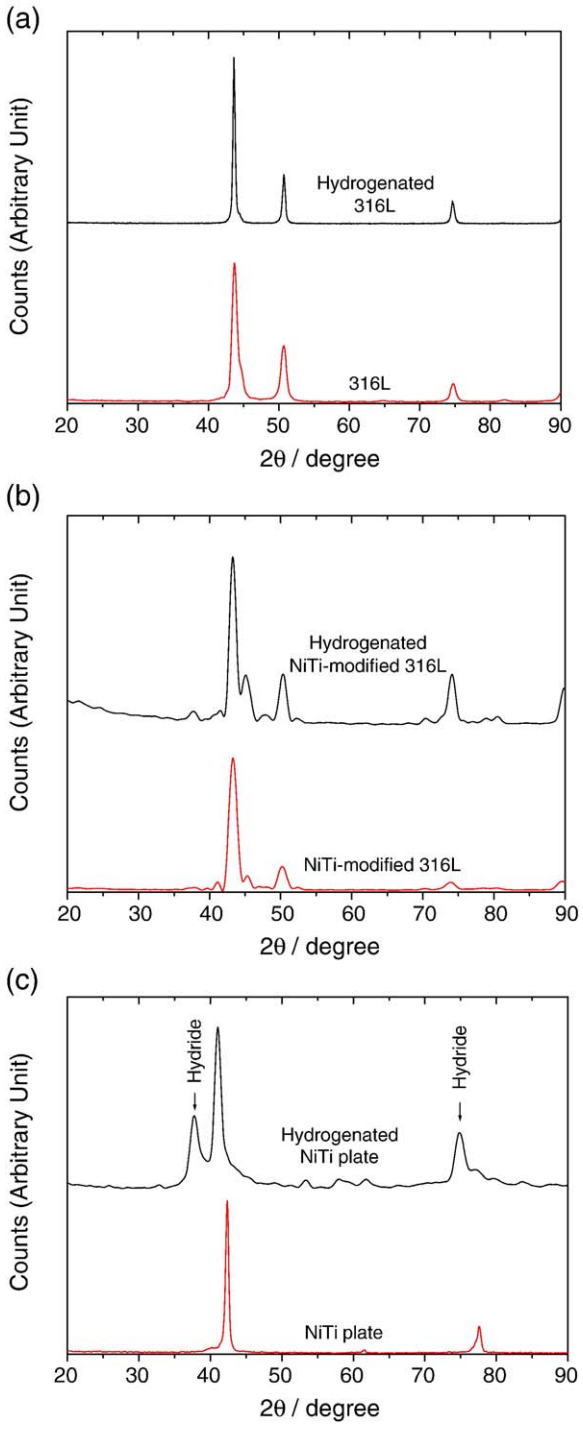

Fig. 1. XRD patterns of various samples before and after hydrogenation: (a) AISI 316L, (b) NiTi-modified 316L, and (c) NiTi plate.

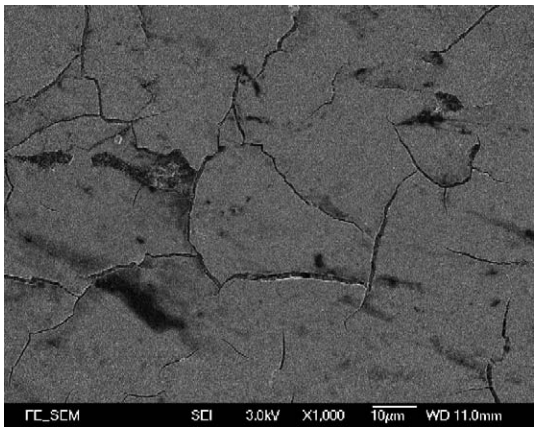

Fig. 2. SEM micrograph showing the presence of cracks on hydrogenated NiTi plate.

3. Results and discussion

The XRD patterns of various samples before and after hydrogen charging were shown in Fig. 1. For both AISI 316L and NiTi-modified 316L, hydrogenation at the intensity used in the present study did not lead to the formation of hydrides. For the NiTi plate, peaks corresponding to hydrides were present after hydrogenation (Fig. 1(c)) [4,10–12].

The presence of hydrides in the NiTi plate was consistent with the appearance of cracks on the sample surface shown in Fig. 2. The formation of surface cracks in NiTi after hydrogenation was also reported by other authors [11]. The cracks were formed due to the growth of hydrides, which have a higher specific volume than the matrix. On the other hand, the surface of samples AISI 316L and NiTi-modified 316L remained smooth and featureless, consistent with the conclusion that no hydrides were formed. It is known that Group IVa metals (such as Ti and Zr) and Group Va metals (such as V, Nb, and Ta) have much higher tendency to form hydrides than the ferrous alloys [13]. The composition in Table 1 clearly indicates that NiTi-modified 316L was Fe-based similar to AISI 316L, while NiTi contained a large amount of Ti. This compositional difference was responsible for the presence/absence of hydrides after charging.

The nanoindentation curves for various samples before and after hydrogen charging are shown in Fig. 3. The surface elastic behavior of the samples may be characterized by the depth recovery ratio η_h defined [14] as

$$\eta_h = \frac{h_{\max} - h_r}{h_{\max}} \quad (1)$$