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Effect of carbon on the cavitation erosion resistance of Fe-Ni-C austenitic alloys

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Abstract. The effect of strain-induced martensitic transformation on the cavitation erosion resistance of Fe-20Ni-*x*C (*x*= 0.4 to 0.9-wt.%) carbide-free and fully austenitic alloys was investigated with respect to strain energy as an initiator for strain-induced martensitic transformation. The strain energy increased with increasing carbon concentration. The cavitation erosion behavior of High-C specimens is worse than that of low-C specimens. The cavitation erosion resistance decrease was thought to occur as a result of the higher incremental energy required to initiate martensitic transformation, which then made it difficult to transform austenite into martensite with respect to increasing carbon concentration. Therefore, in this study, the effect of carbon on strain-induced martensitic transformation was investigated by measuring the critical energy required to initiate strain-induced martensitic transformation (CESIMT). The relationship between the critical energy and the cavitation erosion resistance was also investigated with Fe-20Ni-*x*C (*x*=0.4 to 0.9-wt.%) alloys.

1. Introduction

Cavitation erosion is a common cause leading to damage of components in hydraulic machinery and liquid-handing systems [1]. In fact, propeller repair due to cavitation erosion is routine maintenance in dockyards. Cavitation, which is defined as the generation and collapse of bubbles in liquids [2], arises from local pressure fluctuations, within a liquid, due to flow or vibration. When bubbles collapse near a solid surface, intense stress pulses are exerted on the surface. A great deal of research has been conducted to correlate the cavitation erosion resistance of materials with mechanical properties and microstructures [1~6]. In spite of these efforts, there are unknown factors concerning the material parameters that characterize cavitation erosion resistance. Yet, the sole effect of the strain-induced martensitic transformation on the improvement of the cavitation erosion resistance has not been investigated in previous research. Therefore, in this study, the effect of carbon on strain-induced martensitic transformation was investigated by measuring the critical energy required to initiate the strain-induced martensitic transformation (CESIMT). The relationship between the critical energy and the cavitation erosion resistance was also investigated with Fe-20Ni-*x*C (*x*=0.4 to 0.9-wt.%) alloys.

2. Experimental procedure

Fe-20Ni-*x*C (*x*=0.4 to 0.9- wt.%) alloys were prepared by an induction melting furnace in an Argon atmosphere. At a fixed Ni concentration of 20-wt.%, carbon was introduced from 0.4 to 0.9-wt.% in order to make carbide-free and fully austenitic phases. The chemical compositions of the alloys were analyzed using an optical emission spectrometer, and the results are presented in Table 1. Schematic representation of the vibratory cavitation erosion test equipment and the dimensions of the tensile test specimens are presented in Fig. 1.

The tensile tests were performed at room temperature at a strain rate of 1.667×10-3s-1 by attaching a feritscope on the tensile specimen. The feritscope was used to detect the amount of martensite phase transformed during tensile tests. The energy needed to form 0.3-vol.% martensite was defined as the critical energy required to initiate strain-induced martensitic transformation (CESIMT). This is because martensite was not clearly observed under an optical microscope when its volume fraction was less then 0.3-vol.%. The CESIMTs were obtained from strain-stress curves. Cavitation erosion tests were performed using vibratory cavitation erosion testing equipment according to ASTM G32-03. During the cavitation erosion test, the cumulative weight losses of Fe-based alloys were measured every 2-hrs for a period of 15-hrs, and then every 5-hrs up to 50-hrs, and converted to weight loss per unit area (mg•cm-2). The specimen surfaces were examined using an optical microscope before the test and at regular intervals during the test. X-ray diffraction analysis was conducted before and after tests to identify the strain-induced martensitic transformation.

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3. Results and discussion

CESIMT as a function of carbon concentration is presented in Fig. 1 through strain-stress curves and strain-martensite volume fraction curves. The shaded areas show the strain energy needed to form 0.3-vol.% martensite. As shown in Fig. 1, the shaded area increased as carbon concentration increased. Also, it was found by strain-martensite volume fraction curves that the increasing rate of the martensite volume fraction decreased as carbon concentration increased.

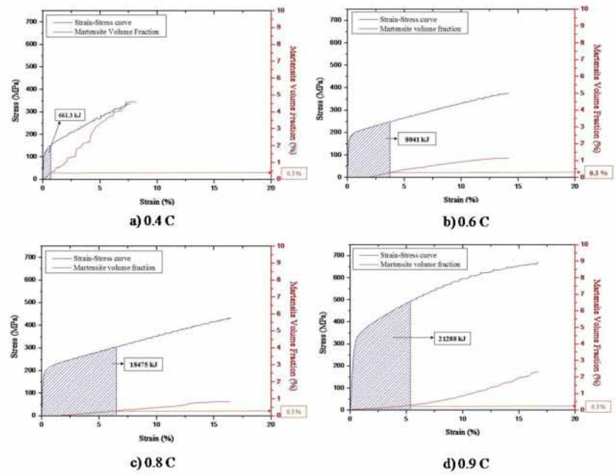


Fig. 1 Strain-stress and strain-martensite volume fraction curves with increasing carbon concentration.

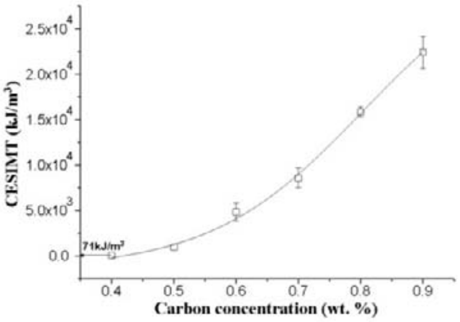


Fig. 2 CESIMT as a function of carbon concentration

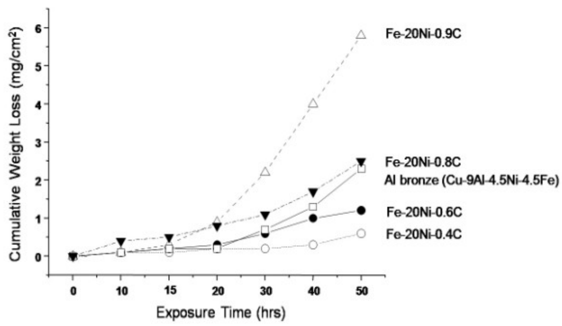
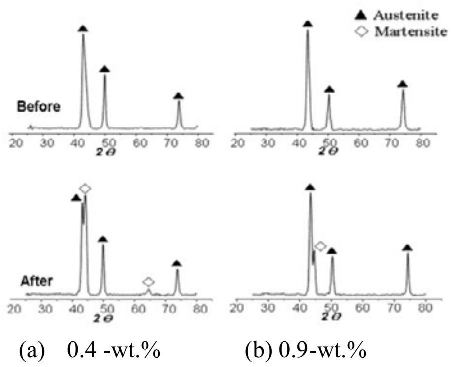


Fig. 3 Comparison of the cumulative weight losses of Fe-20Ni-*x*C (*x*=0.4 to 0.9-wt.%) alloys as a function of exposure time.

The CESIMT as a function of carbon concentration is presented in Fig. 2. As shown in Figure, CESIMT increased approximately from 70 to 22400 kJ/m^3 with carbon concentration increasing from 0.4 to 0.9-wt.%. Based on the results presented in Fig. 1 and Fig. 2, it is thought that it was more difficult to strain-induce martensitic transformation with an increasing carbon concentration. Fig. 3 shows the cavitation erosion behavior of the tested alloys expressed in weight loss as a function of exposure time. The incubation period is defined as the time in which the materials can withstand cavitation erosion without weight loss. The incubation times of the alloys 0.4, 0.6, 0.8 and 0.9C were 5, 7, 10, and 12-h, respectively. Hence, additions of Fe-20Ni-0.4 and 0.6-wt.% alloys showed improved cavitation erosion characteristics compared with that of Al bronze.



(a) 0.4 -wt.% (b) 0.9-wt.%

Fig. 4 XRD data of Fe-20Ni-*x*C (*x*=0.4 and 0.9-wt.%) (a) before the test and (b) after the test.

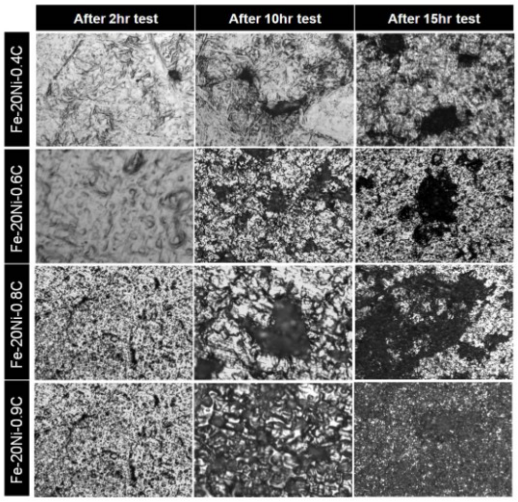


Fig. 5 Optical micrographs of damaged surfaces for Fe-20Ni-*x*C (*x*=0.4, 0.6 and 0.9-wt.%) before and after 10 and 20-hrs of cavitation erosion testing.

According to Wang's reports [7], energy absorption during strain-induced martensitic transformation was thought to be one of the factors that increase cavitation erosion resistance. This theory considers that a higher fraction of Fe-20Ni-0.4C alloy's austenite phases were transformed into martensite than the Fe-20Ni-0.9C alloy at the same number of test time as presented in Fig. 4. The surface morphology of all the tested alloys was observed using an optical microscope before and after the exposure to cavitation for 5, 10 and 20-hrs and is shown in Fig. 5. The eroded surface of specimens of the Fe-20Ni-*x*C (*x*=0.4 and 0.9-wt.%) alloys before and after testing. Deformation of the high-C alloys was more severe than that of the low-C alloys. It was considered that lower CESIMT alloys with a lower carbon concentration had improved cavitation erosion resistance than higher CESIMT alloys. In this respect, strain-induced martensite is thought to improve the cavitation erosion resistance.

4. Conclusions

This work set out to investigate the effect of strain-induced martensitic transformation on the cavitation erosion resistance for Fe-20Ni-*x*C (*x*=0.4 to 0.9-wt.%) carbide-free and fully austenitic alloys. As the carbon concentration increases, the energy required to initiate strain-induced martensitic transformation (CESIMT) increased. In the case of the lower carbon alloy, the incubation period was prolonged about 2 times longer than that of the higher carbon alloy. This difference is considered to be due to the enhancement of energy absorption by strain induced martensitic transformation. The cavitation erosion resistance was thought to have improved due to the applied external energy absorption during strain-induced martensitic transformation. Strain-induced martensite on worn surfaces was thought to be one of the controlling factors that improved the cavitation erosion resistance. Also, the weight loss after 50-hrs lessened. As a result, the cavitation erosion resistance of the austenitic Fe-based alloys can be obviously improved due to the energy absorption of phase transformation

References

[1] A. Karimi, J.L. Martin, International Metals Review, 31 (1986) 1
[2] T. Okada, Y. Iwai, S. Hattori, N. Tanimura, Wear, 184 (1995) 231
[3] W. Bedkowsi, G. Gaisiak, C. Lachowicz, A. Litchtarowicz, Wear, 230 (1999) 201
[4] R.H. Richman, A.S. Rao, D.E. Hodgson, Wear, 157 (1992) 401
[5] D.A. Woodford, Metallurgical Transactions, 3 (1972) 1137
[6] P.G. Clem, M. Rodriguez, J.A. Voigt and C.S. Ashley, U.S. Patent 6,231,666. (2001)
[7] Zaiyou Wang, Jinhua Zhu, Materials Science and Engineering A, 358 (2003) 273