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Study on the cavitation erosion behavior of Fe-based hardfacing alloys containing Mn, Ti and V for replacing Co-based Stellite 6

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Abstract

Stellite 6 has been used as hardfacing material of valve components in nuclear power plant industry and other applications. Stellite 6 contains more than 60 wt. % Co and it was recognized that Stellite 6 used in valve hardfacing is one of the main sources of Co, which is the major contributor to build up the radiation field in nuclear power plants. Thus it is largely responsible for the occupational radiation exposure of plant maintenance personnel. Also the price of Co is expensive and highly varying. Therefore, there have been many efforts to develop Co-free hardfacing alloy. We have also developed Fe-based new alloy, of which sliding wear and cavitation erosion resistance were almost equivalent to those of Stellite 6. In the present study, the effects of Mn, Ti and V on the cavitation erosion behavior of the alloy were investigated. The Fe-based new alloy containing V had similar cavitation erosion resistance to Stellite 6 but the others containing Mn and Ti were inferior to Stellite 6.

KEYWORDS

Hardfacing alloy, Cavitation erosion, Stress-induced phase transformation

I. Introduction

Co-based Stellite 6 has been traditionally used as the hardfacing material for nuclear power plant valves due to their superior wear resistance and the inherent high corrosion resistance, strength and ability to retain hardness at elevated temperatures. However, the wear and corrosion products of Co-containing alloys are released into the primary cooling water and transported to the reactor core where a high radioactivity of ^{60}Co is produced by neutron capture reaction of ^{59}Co. The radioisotope, ^{60}Co, with its penetrating gamma rays and long 5.3-yr half-life, is the primary offender to build up the radiation field. So Stellite 6 which contains more than 60 wt. % ^{59}Co is the major contributor to occupational radiation exposure to plant maintenance personnel [1, 2]. Furthermore, Co is a costly commodity as well as its price fluctuates significantly. Accordingly, to diminish the amount of the released Co is a very important problem that should be solved sooner or later. To reduce contamination of Co is directly connected to minimize occupational radiation exposure to plant maintenance personnel, to cut operating costs, and to conform to the as-low-as-resonably-achivable principle advocated by the International Commision on Radiation Protection[1]. Various methods for reducing radiation field in nuclear power plants have been developed. One of the most effective methods to reduce Co contamination is substituting Co-based Stellite 6 for Co-free hardfacing alloys such as Fe-based and Ni-based alloys [3-5].

Cavitation erosion is the major cause of damage to flow-control valves such as the globe and the swing check valves which experience sudden changes in water pressure. It is caused by the formation and sudden collapses of vapor bubbles in the liquid near the metal surface. Repeated collapses of these cavities can result in the severe mechanical shock and wear to metal surfaces [1, 2]. Recently, the Fe-based new alloy (Fe-20Cr-1.7C-1Si wt.%) which possibly replaces the Co-based Stellite 6 has been developed. Previous investigations have shown that the Fe-based new alloy had excellent resistance to sliding wear and cavitation erosion [6,7]. In the present study, the effects of Mn, Ti and V addition on the cavitation erosion behavior of the Fe-based new alloy were investigated.

II. Experimental Procedure

1. Specimens

Specimens to check the effect of concentration of each metal, Fe-based alloys containing 2 and 5 wt.% Mn, 1 and 2 wt.% Ti and V were prepared by ingot casting, respectively. In order to compare to their cavitation erosion characteristics, NOREM 02 and Stellite 6 which were deposited on 12-mm thick SUS 304 plate by GTAW (Gas Tungsten Arc

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Welding) were also prepared.

2. Cavitation erosion test

Cavitation erosion tests were performed with a vibratory cavitation erosion testing equipment according to ASTM-G32 [8]. The schematic diagram of the apparatus is shown in Fig. 1.

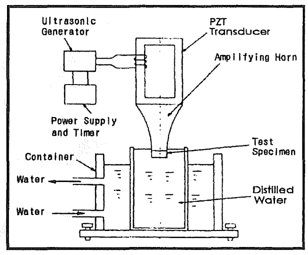


Fig. 1 Schematic representation for vibratory cavitation erosion test equipment.

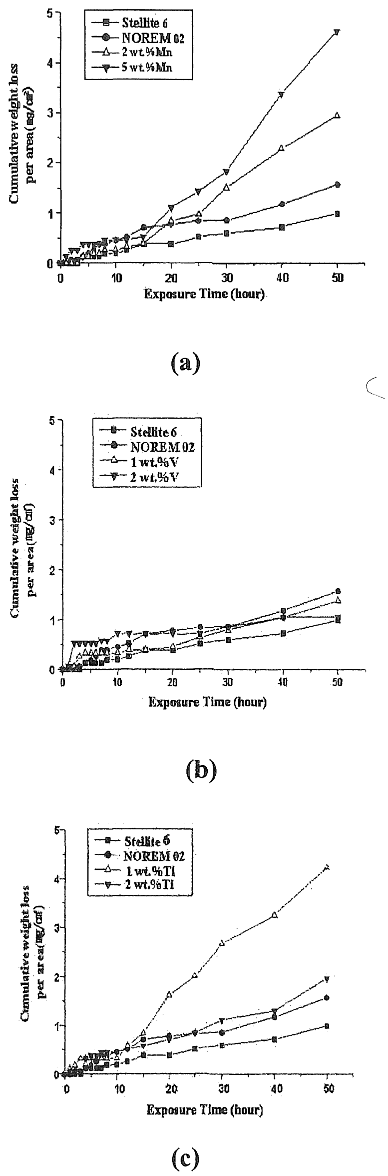


Fig 2. Compare the cumulative weight losses of Stellite 6, NOREM 02, and (a) Mn, (b) V, (c) Ti added Fe-based new alloy as a function of exposure time.

III. Results and discussion

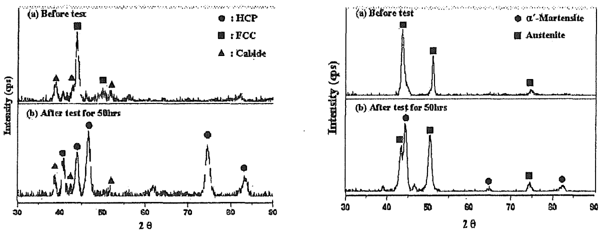
Fig. 2 shows the cumulative weight losses of the Fe-based alloys containing Mn, V and Ti, Stellite 6 and NOREM 02. The weight loss of these alloys was plotted as a function of exposure time. The incubation period is defined as the time at which the erosion rate deviates from the initial low erosion rate during the cavitation erosion test. The steady state erosion rate is defined as the erosion rate after the incubation period [8]. It is found from Fig. 2 that Stellite 6 has the longest incubation time (3 hours) among all specimens but NOREM 02 is the shortest, approximately 1 hour. The cumulative weight losses for Stellite 6, the alloys containing 1 and 2 wt.% V after the cavitation exposure of 50 hours are 0.97 mg/cm^2, 1.36 mg/cm^2 and 1.04 mg/cm^2, respectively. These values are smaller than those of the alloys containing Mn and Ti and NOREM 02 which deals with Stellite 6 replacing material. The cavitation erosion resistances of the alloys containing 1 and 2 wt.% V are similar to Stellite 6. The alloy containing 2 wt.% Ti has the weight loss of 0.32 mg/cm^2 at 4hours, 1.95 mg/cm^2 at 50hours. The alloy containing 1 wt.% V is 0.32 mg/cm^2 at 4hours, 1.36 mg/cm^2 at 50hours and in the case of the alloy containing 2 wt.% V is 0.52 mg/cm^2 at 2hours, 1.04 mg/cm^2 at 50hours as shown in Fig. 2.

According to Heathcock et al.[9], austenite steels have high resistances to the erosion. The high erosion resistance of these steel results from low stacking fault energy(SFE), the $\gamma \rightarrow \alpha'$ phase transformation and effects the hardening of matrix.

In the case of the Fe-based new alloy with an austenitic structure, the cavitation erosion resistance is also considered to be dependent on the degree of SFE and the $\gamma \rightarrow \alpha'$ phase transformation. It is also known that the cavitation erosion resistance of fcc Stellite 6 is dependent on the $\gamma \rightarrow \varepsilon$ phase transformation in the matrix.

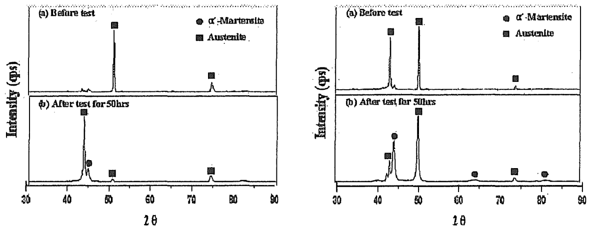
As well as, according to K. C. Antony, it has been known that the cavitation erosion resistance can be improved by suppressing the initiation and propagation of cracks in alloys with the low SFE because the stress-induced phase transformation and/or formation of twin can absorb the local stresses resulting from bubble collapse[10].

X-ray diffraction analysis was conducted to make an investigation whether or not these phase transformations which is able to improve the cavitation erosion resistance occurred. X-ray diffraction patterns of Stellite 6, NOREM 02, and the alloys containing Mn, V and Ti before and after the cavitation erosion test are shown in Fig. 3. through 6.



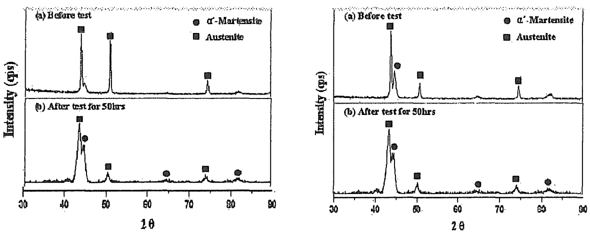
(a) (b)

Fig. 3. X-ray diffraction pattern of (a) Stellite 6, (b) NOREM 02.



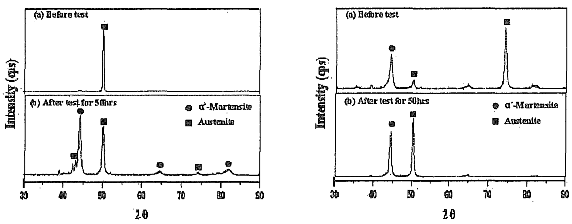
(a) (b)

Fig. 4. X-ray diffraction patterns of (a) 2 wt.% Mn, (b) 5 wt.% Mn.



(a) (b)

Fig. 5. X-ray diffraction patterns of (a) 1wt.% V, (b) 2 wt.% V.



(a) (b)

Fig. 6. X-ray diffraction patterns of (a) 1 wt.% Ti, (b) 2 wt.% Ti.

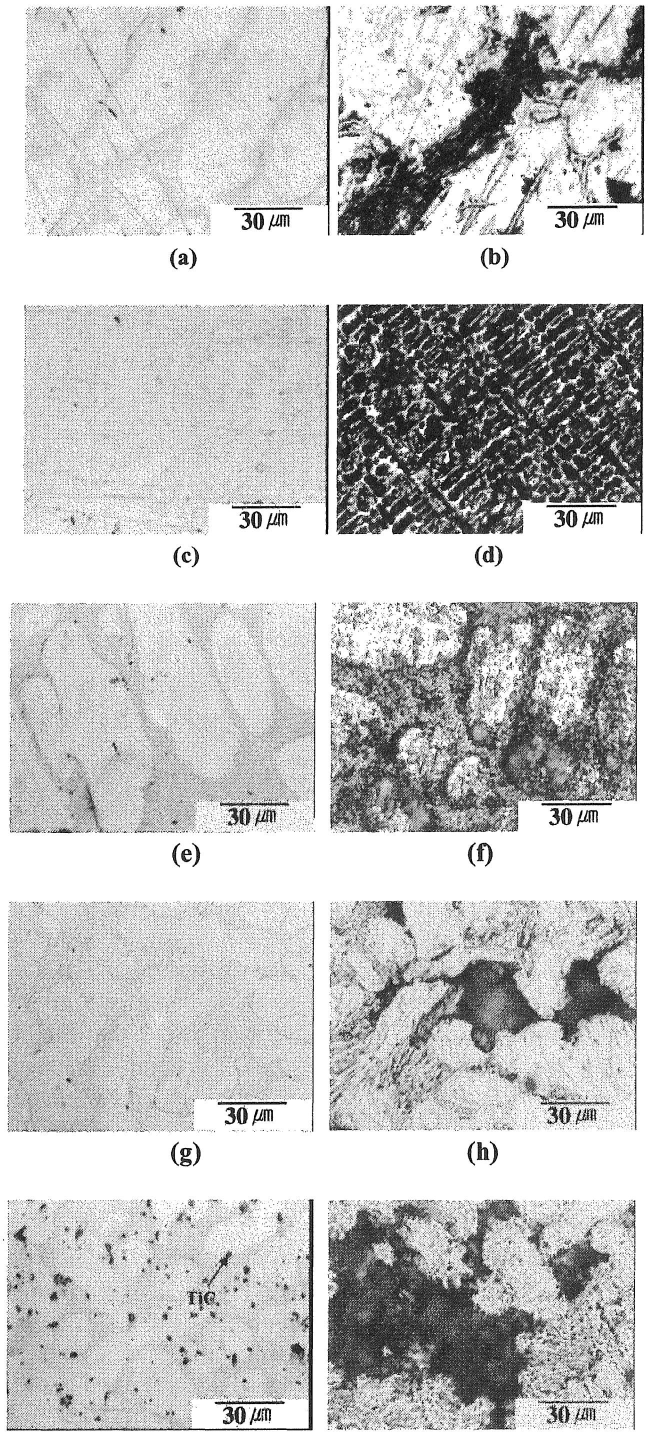


Fig. 7. Optical micrographs showing cavitation erosion surfaces of (a) Stellite 6 1h, (b) Stellite 6 20h, (c) NOREM 02 1h, (d) NOREM 02 20h, (e) 2 wt.% Mn 1h, (f) 2 wt.% Mn 20h, (g) 2 wt.% V 1h, (h) 2 wt.% V 20h, (i) 2 wt.% Ti 1h, (j) 2 wt.% Ti 20h

Mn was added to improve the cavitation erosion resistance by occurring the $\gamma \rightarrow \varepsilon$ phase transformation. But The addition of 2 and 5 wt.% Mn was not appeared the $\gamma \rightarrow \varepsilon$ phase transformation but only the $\gamma \rightarrow \alpha'$ phase transformation is found as shown in Fig. 4. Namely, the effect of Mn addition on the cavitation erosion resistance is very little and 2 and 5 wt.% Mn addition is not enough to be improved the cavitation erosion resistance by the $\gamma \rightarrow \varepsilon$ phase transformation. In the case of V and Ti, the $\gamma \rightarrow \alpha'$ phase transformation were increased after the exposure test. In spite of the low SFE, the cavitation erosion resistances of the Fe-based alloys containing V and Ti alloys are not improved than that of the Fe-based new alloy which was similar to Stellite 6.

Fig. 7. shows that the surface morphologies of Stellite 6, NOREM 02, and the alloys containing 2 wt.% Mn, 2 wt.% Ti and 2 wt.% V which material losses were comparatively less than those of 5 wt.% Mn, 1 wt.% V and 1 wt.% Ti as shown in Fig. 2., observed by an optical microscope. When materials were exposed to erosion, a crack can be initiated at the interfaces between the hard carbide and the soft matrix. The crack spreads to long distances and finally creates macroscopic pits at the carbide region.[11]. The dark area is the material loss part by the cavitation erosion and the bright area is not. The black spots in this figure indicate carbide formations and the white area is the matrix. In the case of all the alloys containing Mn, Ti and V, material loss is also initiated at the matrix-carbide interfaces and gradually propagates into the matrix. As shown in Fig. 7, it can be confirmed with the naked eye that the material losses of the alloys containing 2 wt.% Ti and 2wt.% V are less than those of 2 wt.% Mn addition alloy. That is, the cavitation erosion resistance of the Fe-based alloys containing 2 wt.% V is better than that of the Fe-based alloys containing Mn and Ti.

IV. Conclusions

From the cavitation erosion tests of the Fe-based alloys containing Mn, Ti and V for 50 hours at room temperature, the following conclusions could be achieved.

1. The cavitation erosion resistance of the Fe-based alloys containing 2 wt.% V was similar to that of Stellite 6. But the Fe-based alloys containing Mn and Ti were not better than the Fe-based new alloy which was similar to Stellite 6.

2. The cavitation erosion resistances of the Fe-based alloy containing V were improved due to the absorption the incident cavitation energy by stress-induced phase transformation and the hardened matrix which could effectively suppress the crack propagation initiated at carbide-matrix interfaces.

3. The 2 and 5 wt.% Mn addition was not enough to improve the cavitation erosion resistance. The expected ε-martensite phase transformation did not occur but the α′-martensite phase transformation occurred in these conditions.

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