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Erosion Characteristics of Ti-Ni Base Alloys

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The erosion resistance was investigated in Ti-Ni base alloys, which have the superior thermomechanical properties and the high corrosion resistance. The erosion tests were conducted by the method, which collides the compressed water of the high temperature and high pressure with the specimen. The erosion, which is caused by a combination of the cavitation and the shear stress due to the high-speed hot water flow, can be estimated by this method. Specimens were Ti-50at%Ni and Ti-45at%Ni-5at%X (X: Ag, B, Fe, Nb, Pb), and Co-based alloy (Stellite 6) was used as a reference material. Influences of additional elements and hardness on the erosion resistance will be discussed by observations of damaged surface and evaluating the maximum damaged depth and the damaged cross-sectional area.
Key words : erosion, Ti-Ni base alloy, shape memory alloy, hot water jet, Co-based alloy

1. INTRODUCTION

Shape memory alloys, particularly Ti-Ni alloys, have superior mechanical properties and unique functions such as superelasticity and shape memory effect. Therefore, they are used as functional materials in the field of energy and medical industries and so on[1-4].

Some components in power plants are exposed to the pressurized high-temperature fluid flow conditions. Especially, the drain and control valves are subjected to the erosion-corrosion damage due to the high speed hot water. Therefore, the parts such as valve sheets and the overlay on steam turbine blades in power plants are made of high erosion resistant Co-based alloys [5]. However, the usage of these alloys is severely restricted in nuclear power plants, because the Co dissolved into the high temperature water is radio-activated in reactor core and thereafter it is deposited on the surfaces of cooling system pipes and components. Thus the materials of valve sheet are required for the erosion-corrosion and wear resistances.

The authors have reported that the damage of Stellite (Co-based alloy) under hot water jet is caused by cavitation and shearing stress [6]. Furtheremore, Ti-Ni alloys have high erosion and corrosion resistances [7-9].

The purpose of this study is to investigate the Ti-Ni base alloys with high erosion and wear resistances. In this present paper, the effect of the addition of a third element to Ti-Ni alloy on the erosion characteristics under hot water jet is investigated experimentally, comparing with the erosion resistance of Co-based alloy (Stellite 6).

2. EXPERIMENT

2.1 Specimen

Ti-Ni base alloy ingots were made by an arc melting method. The compositions of the alloys were Ti-50at%Ni and Ti-45at%Ni-5at%X (X: Ag, B, Fe, Nb, Pb), respectively. The solution treatment of ingots were performed at 1223 K for 3.6 ks. After this treatment, the disk specimens (ϕ16x3) were made. The surface of specimens was mirror finished. Furthermore, the specimens were annealed at 773 K for 3.6 ks. The transformation temperature and Vickers hardness is listed in Table I.

Ti-Ni base alloys with same copositions as alloys made by arc melting method were also fabricated by a spark-plasma sintering method. The sintering was performed in a vacuum below 13.3 Pa at 1123 K for 1.8 ks under loading of 20 kN.

Co-based alloy (Stellite 6) was used as the reference material and the value of Vickers hardness was 388.

Figure 1 shows the typical surfaces of the Ti-Ni base

Table I Transfomation temperature and Vickers hardness of Ti-Ni base alloys made by arc melting method.

Specimen (at%)	Transformation temperature (K) M_f	M_s	A_s	A_f	Vickers hardness
TN : Ti-50Ni	268.1	311.2	313.2	338.0	179
TNA : Ti-45Ni-5Ag	315.3	342.1	347.7	375.0	234
TNB : Ti-45Ni-5B	320.1	345.5	351.8	379.4	223
TNF : Ti-45Ni-5Fe	147.3	252.2	207.0	251.2	249
TNN : Ti-45Ni-5Nb	296.1	317.4	328.6	349.8	213
TNP : Ti-45Ni-5Pb	327.2	345.7	358.8	378.5	227

alloys before erosion tests, observed by Scanning Electron Microscope (SEM). It is found that the net-shaped parts exist in the all specimens. From results of EDX, the composition of point (1) is about Ti-60at%, Ni-30at%, and point (2) contains Ti-30at%, B-70at% or so. Therefore, it is found that point (1) is Ni poor, and point (2) is B rich. Moreover, the Ni poor parts like (1) exist in other Ti-Ni base alloys. Especially, the quantity of net-shaped parts is much in TNA, TNN and TNP, and less in TN.

2.2. Experimental procedure

Erosion tests were conducted by the method shown in Fig. 2. A specimen with 16mm in diameter and 3mm in thickness was exposed to the compressed hot water jet. Here the temperature T_{in} and pressure P_{in} of the compressed water were 473 K and 14.7 MPa, respectively. The water jet flow rate was 6-8 x10^{-6} m^3/s. The compressed water was gushing from the nozzle with a diameter of 0.3mm to atmosphere. Then, the high-speed water jet impacted on the specimen located at a distance of 10mm from the nozzle. This erosion test can estimate the damages caused by the cavitation and the shear stress due to the high speed water flow [10].

After erosion tests, the erosion damages were measured quantitatively with a surface roughness device. Figure 3 illustrates the determination of the damaged cross-sectional area and the maximum damaged depth of the erosion tested specimen.

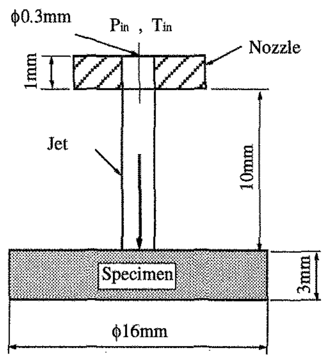


Fig.2 Schematic flow diagram.

3. RESULTS AND DISCUSSION

3. 1 Erosion characteristics

Figure 4 shows the damaged cross-sectional area per unit jet flow rate as a function of exposure time for Ti-Ni base alloys and the reference material. The erosion damaged area increases with increasing the exposure time for all materials. The values of damaged area of Ti-Ni base alloys are smaller than that of Stellite 6. Especially, its value of Ti-Ni alloy is the smallest in all materials. Furthermore, in Ti-Ni-X alloys, the values of Ti-Ni-Fe and Ti-Ni-Pb are small. The increase of damaged area is considered to be caused mainly by the shear stress due to the high speed water flow. Thus the Ti-Ni base alloys show the high erosion resistance to the high speed shear flow.

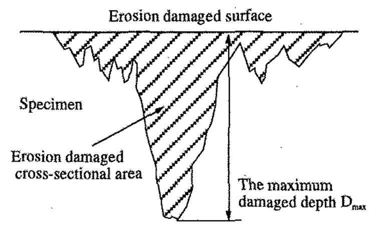
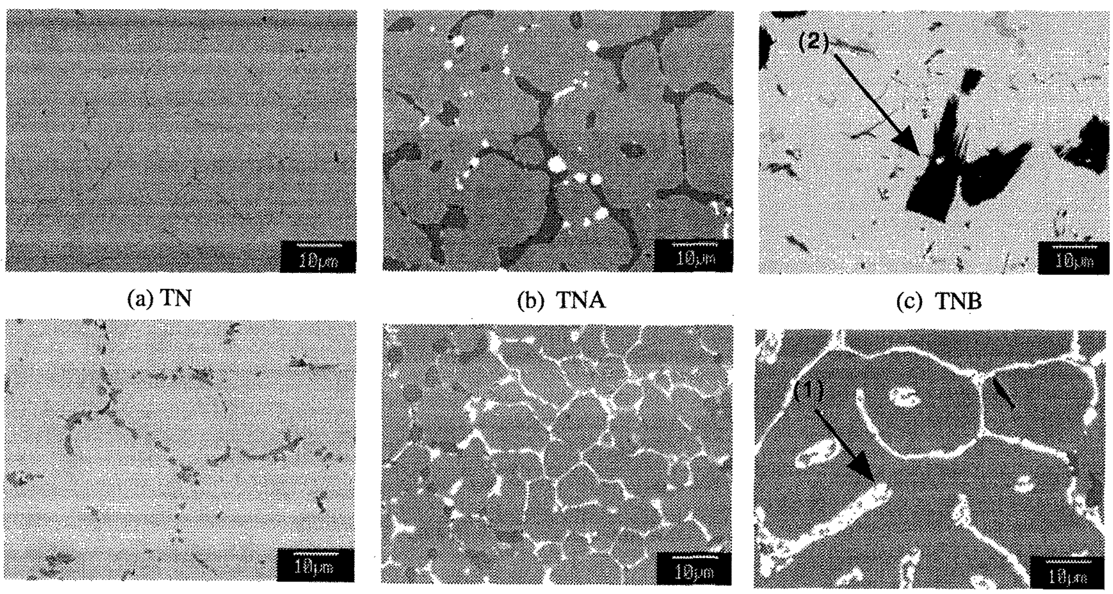


Fig.3 Determination of the damaged cross-sectional area and the maximum damaged depth.



(a) TN (b) TNA (c) TNB

(d) TNF (e) TNN (f) TNP

Fig.1 Microstructures of specimens before test.

On the other hand, the damaged depth is considered to be caused mainly by the cavitation. Figure 5 shows the maximum damaged depth per unit jet flow rate as a function of the exposure time. The maximum damaged depth increases linearly with increasing the exposure time. The values of damaged depth in Ti-Ni-Ag and Ti-Ni-Nb are larger than that of Co-based alloy. However, those of Ti-Ni, Ti-Ni-Fe and Ti-Ni-Pb are smaller than that of Co-based alloy.

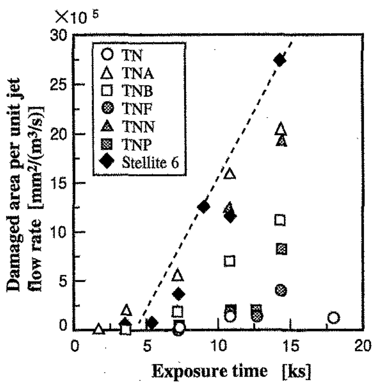


Fig.4 Damaged area per unit jet flow rate in Ti-Ni base alloys and Co-based alloy.

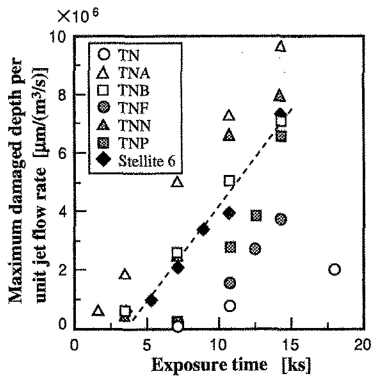
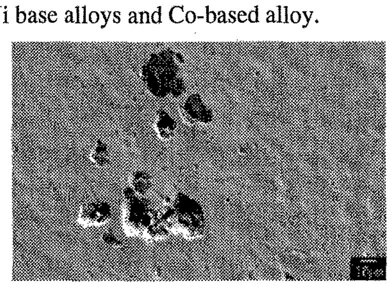
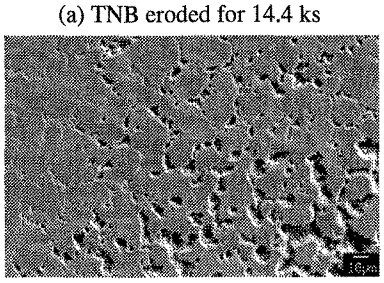


Fig.5 Maximum damaged depth per unit jet flow rate in Ti-Ni base alloys and Co-based alloy.



(a) TNB eroded for 14.4 ks



(b) TNN eroded for 7.2 ks

Fig.6 Appearance of damaged surface (alloys: made by arc melting method).

From these results, Ti-Ni alloy shows a high erosion resistance to the high speed shear flow and cavitation. Figure 6 shows the appearance of damaged surface exposed to hot water jet. The net-shaped parts are damaged selectively. These parts are B or Nb rich and Ni poor as seen in Fig.1. These parts do not show the shape memory effect and superelasticity. However, these parts does not exist in a Ti-Ni alloy. The shape memory effect and superelasticity improves the erosion resistance [11]. Therefore, Ti-Ni alloy is considered to show a high erosion resistance in Ti-Ni base alloys.

3.2 Comparing with spark-plasma sintering

Figure 7 shows the comparison of maximum damaged depth of Ti-Ni-Ag and Ti-Ni-Fe made by arc melting with those of spark-plasma sintering. In the figure, STNA and STNF denote the specimens fabricated by the spark-plasma sintering. The maximum damaged depth of specimens

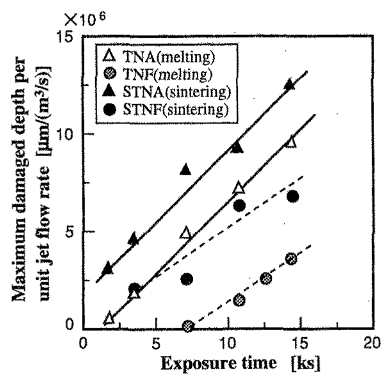
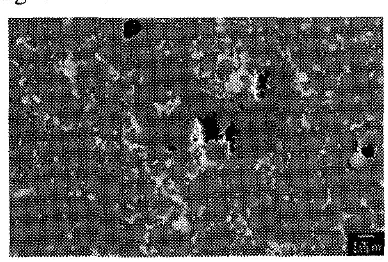
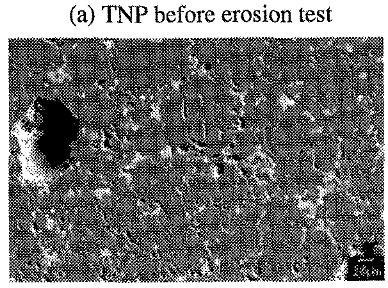


Fig.7 Comparison of melting method with sintering method.



(a) TNP before erosion test



(b) TNP eroded for 10.8 ks

Fig.8 Appearance of damaged surface (alloys: fabricated by spark-plasma sintering method).

fabricatited by sintering is larger than those of melting. However, the variations of damaged depth with exposure time are almost same in both melting and sintering specimens. The difference in damaged depth between melting specimen and sintering specimen appears significantly in an early exposure time. The density of specimen fabricated by sintering is about 97% [12]. Therefore, the surface of specimen exists pores as seen in Fig.8(a). These pores promote the erosion damage as seen in Fig.8(b), and the damage increases abruptly in an early exposure time.

3.3 Discussion

The difference in the morphology of the erosion due to the hot water jet impact becomes clear from Fig. 9. Here, the ratio of the damaged area to the damaged depth of all Ti-Ni base alloys is smaller than that of Co-based alloy, and there are no remarkable differences between all Ti-Ni base alloys. Therefore, it is found that the Ti-Ni base alloys have high erosion resistance to high speed shear flow.

Figure 10 shows the relationship between the damage rate in depth and hardness. The damage rate of Ti-Ni-X alloys decreases with increasing hardness. This behavior shows the very good correspondence with the results obtained by cavitation tests [11]. However, the damage rate of Co-based alloy with high hardness is large. The temperature of Ti-Ni base alloys is higher than that of water jet and will be 40-170 K higher than A_f point. Thus Ti-Ni base alloys are parent phase, and damage of alloys in the parent phase is smaller than that of martensitic phase [11]. Therefore, it is thought that Ti-Ni base alloys with low hardness comparing with Co-based alloy show the high erosion resitance.

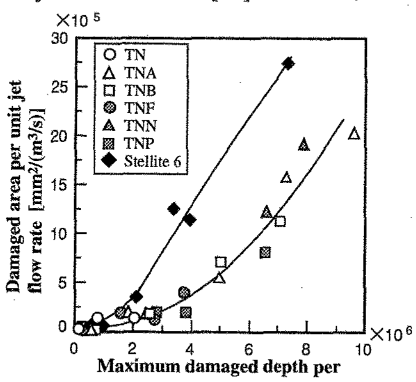


Fig.9 Relationship between damaged area and the maximum damaged depth.

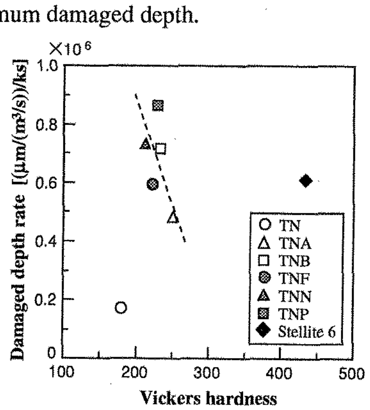


Fig.10 Relationship between damaged area and the maximum damaged depth.

4. CONCLUSIONS

The effect of the addition of a third element to Ti-Ni alloy on the erosion characteristics under hot water jet is investigated experimentally, and a Co-based alloy is used as a reference material. The results obtained are summarized as follows:

(1) Ti-Ni base alloys have higher erosion resistance than Co-based alloy and especially, show a high erosion resistance to the high speed shear flow.

(2) In Ti-Ni-X alloys, the addition of Fe and Pb is effective for the high speed shear flow and cavitation erosion.

(3) The morphology of erosion in Ti-Ni base alloys does not depend on the additional elements.

(4) It can be suggested that Ti-Ni base alloys will be one of the promising alternative materials for Co-based alloys.

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