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EFFECTS OF NOBLE GAS ENVIRONMENTS ON FATIGUE CRACK GROWTH IN TITANIUM ALLOYS

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ABSTRACT

The effects of gaseous environments on fatigue crack growth behaviour of metals have been studied by many researchers. However, most of them are limited to the effects of hydrogen and oxygen. It is generally understood that the effects of noble gases such as xenon are negligible as compared to vacuum environments in most metals such as steels. In our previous research we have found that noble gases including helium, argon and xenon do affect the fatigue crack growth behaviour of pure titanium. The noble gases increase the fatigue crack growth rate and change the fracture surface appearance as compared to those tested in vacuum. This peculiar behaviour may be due to the active nature or the hexagonal structure of titanium. In this study, fatigue crack growth tests were carried out on a β-titanium alloy, which has a bcc structure, in noble gas environments. It was found that argon and xenon increased the fatigue crack growth rate of the β-titanium in the Paris regime and changed the fracture surface appearance as compared to those tested in vacuum, however, helium did not. Striations were clearly observed on fracture surfaces of specimens tested in argon and in xenon, while no obvious striations were found on those tested in vacuum and in helium. This may indicate that the observed effects of noble gases are related to both the active nature of titanium and crystal structures.

KEYWORDS

gaseous environment, noble gas, titanium alloys, fatigue crack growth, fractography

INTRODUCTION

Gaseous environments generally affect fatigue crack growth behaviour of ductile metals and alloys. It is well recognised that fatigue crack growth rate in air and in oxygen is faster than in vacuum in most metals and alloys [1]. This phenomenon is explained by the adsorption of oxygen on exposed slip steps which are produced upon loading, and this leads to the reduction of reversible slip on unloading [1]. However, the effects of gaseous environments other than oxygen and hydrogen have not been studied extensively.

Shimojo et al. [2] reported that fatigue crack growth rates of titanium increased in a pure nitrogen environment as compared to that in vacuum. Nitrogen is considered to be less aggressive than oxygen, but it can still react with titanium and, thus, could inhibit reverse slip. Though it is generally considered that noble gases do not affect fatigue crack growth, it is also shown that even noble gas environments can affect fatigue crack growth rate of pure titanium. Shimojo et al. [3, 4] showed that noble gas such as pure helium, argon and xenon increased fatigue crack growth rate as compared to that in vacuum. Fatigue crack growth rates in helium, argon and xenon were approximately twice that in vacuum and were almost the same as that in air. Additional findings showed that striations were clearly observed on fracture surfaces of specimens tested in helium and xenon, while less obvious striations were observed on those in vacuum and argon. These interesting results indicate that even noble gases may adsorb strongly on exposed slip steps and affect fatigue behaviour of titanium. However, most fatigue data obtained in noble gases, to date, are treated as reference data for more aggressive environments. Very little research has been carried out on the effects of noble gases themselves on fatigue behaviour of metals. Thus, the mechanism causing these effects of noble gases is still uncertain.

Noble gas atoms are less likely to form a strong bond with metals. But, on the other hand, titanium is a reactive metal, which means that titanium atoms form a bond easily with other atoms. The above-mentioned effects of noble gases on fatigue crack growth may result from the active nature of titanium and may appear on other titanium alloys, not limited to pure titanium (α-titanium, hcp structure).

In this research, fatigue crack growth tests are carried out on a β-titanium alloy, which has a bcc structure, in noble gases and the effects of noble gas environments on fatigue crack growth behaviour are discussed.

EXPERIMENTAL PROCEDURE

The material used was a hot-rolled and annealed β-titanium (Ti-15V-3Al-3Cr-3Sn) polycrystalline plate. This material has a microstructure that consists of equiaxial grains, the diameter of which was approximately 150 μm. Compact tension specimens of 50 mm width and 12.5 mm thickness were prepared from the material with an L-T orientation (the macroscopic crack plane is perpendicular to the loading direction, and the crack growth direction parallels to the transverse direction of the plate.)

Fatigue crack growth tests were performed under a sinusoidal loading control at a frequency of 10 Hz and a stress ratio of 0.1 using a servohydraulic fatigue machine with an environmental chamber made of stainless steel. The block diagram of the measurement system is shown in Fig.1. Crack length was monitored using a direct current potential drop technique. Some tests were carried out under constant load amplitude conditions and others were under constant stress intensity factor range (ΔK) conditions by feeding back the crack length measured. All tests were carried out at room temperature (approximately 24^{o}C) in an environment either vacuum or high purity noble gas of 1×10^{5} Pa. Attention was paid especially to the purity of the gases and the contamination that might have occurred during the introduction of the gases to the chamber. (The effects of air contamination on fatigue crack growth rate and on fracture surface appearance of α-titanium is discussed elsewhere [4].) The purities of the gases used are shown in Table 1. The chamber had been evacuated to vacuum (5×10^{-5} Pa) using a turbomolecular vacuum pump, before noble gas was introduced.

TABLE 1
PURITY OF NOBLE GASES USED

Gas	Purity (%)	Oxygen (ppm)	Nitrogen (ppm)
He	> 99.99999	< 0.05	< 0.05
Ar	> 99.9999	< 0.1	< 0.3
Xe	> 99.995	not detected	not detected

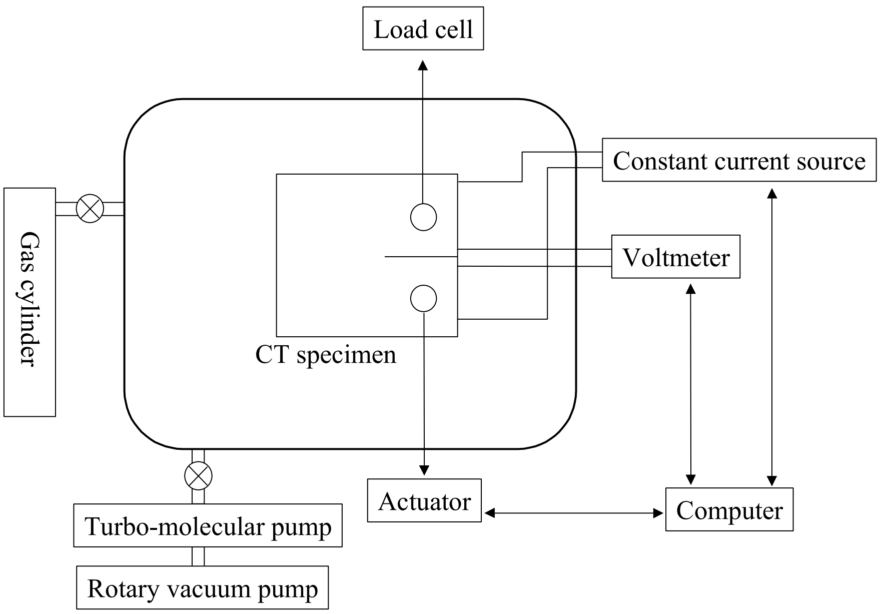

Figure 1: Block diagram of the measurement system

After the fatigue crack growth tests, fracture surface observations were carried out using a field emission gun scanning electron microscope.

RESULTS AND DISCUSSION

Figure 2 shows fatigue crack growth rate of β-titanium as a function of ΔK in vacuum and noble gases under both constant load amplitude and constant ΔK conditions. Fatigue crack growth rate measured in air is also included. Fatigue crack growth rates in air, argon and probably xenon are higher than those in vacuum. Fatigue crack growth rate of α-titanium in noble gases are approximately twice that in vacuum in the Paris regime [3, 4]. Irving and Beevers [5] showed that the fatigue crack growth rate of a titanium alloy in vacuum is slower than that in air by a factor of 2 to 3 in the Paris regime. These results agree with those shown herein. However, fatigue crack growth rate of β-titanium in helium showed different behaviour from that of α-titanium. Fatigue crack growth rate of β-titanium in helium was almost the same as that in vacuum, while that of α-titanium in helium was approximately twice that in vacuum at a given ΔK.

Fractorgraphs of β-titanium specimens tested in vacuum, helium, argon and xenon at ΔK of 13 MPa $m^{1/2}$ are shown in Fig. 3. Striations are clearly observed on fracture surfaces of specimens tested in argon and xenon, while less obvious striations are found on those tested in vacuum and helium.

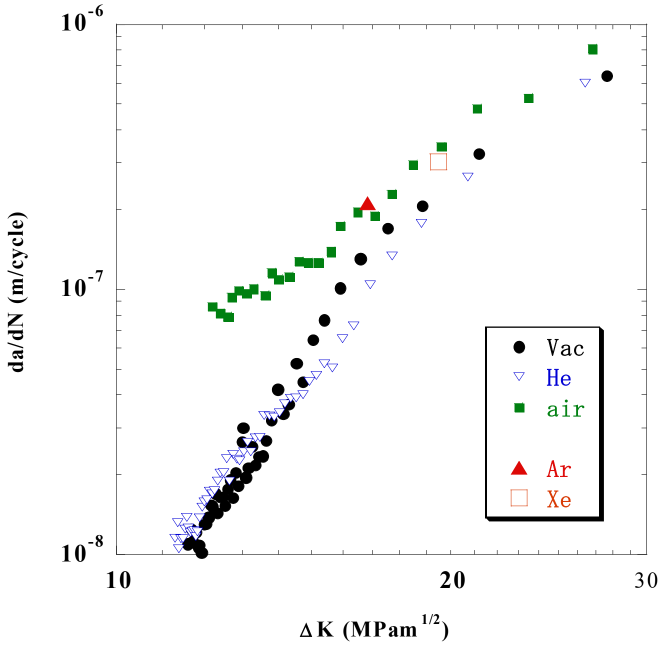

Figure 2: Fatigue crack growth rate of β-titanium in gaseous environments

Both an increase in crack growth rate and a change in fracture surface appearance indicate that even noble gases have interactions with a metal during plastic deformation. The difference in fracture surface appearance may be caused by the noble gas atoms entered the metal, not by simple adsorption on the surfaces. (Please note that the entrance of noble gas atoms has been confirmed on α-titanium [4].) The appearance of clear striations accompanies with an increase in crack growth rate. This may indicate that the entrance of noble gas atoms into the titanium matrix causes embrittlement and thus results in a change in deformation behaviour.

Fatigue crack growth rate of α-titanium increased in a helium environment as compared to that in vacuum, while that of β-titanium alloy did not. Fracture surface appearance of α-titanium tested in the helium environment was similar to that in the other noble gas environments, while that of the β-titanium alloy was similar to that in vacuum. These differences may be caused by the difference in crystal structure. The interaction between titanium matrix and entered noble gas atoms may be affected by the difference in crystal structure, that is the size of spaces among the titanium atoms. However, further studies are necessary to understand the details.

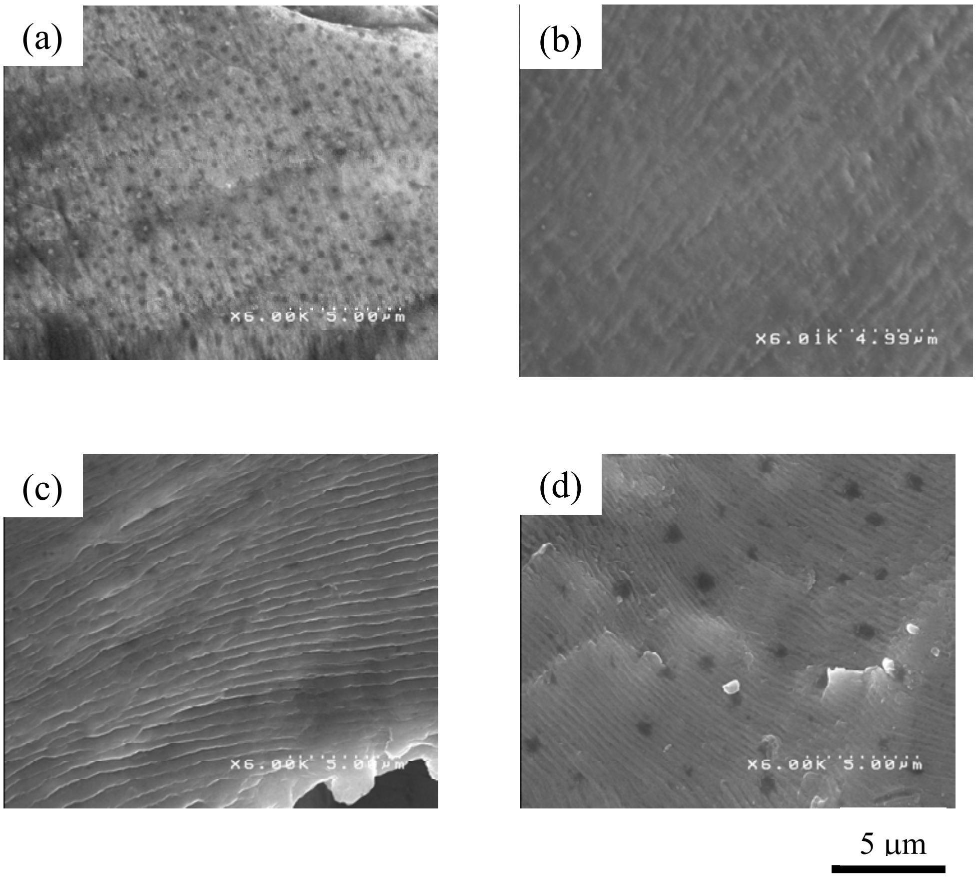

Figure 3: Fractgraphs of specimens tested in (a) vacuum,
(b) helium, (c) argon and (d) xenon

CONCLUSIONS

It was found that argon and xenon increased the fatigue crack growth rate of the β-titanium in the Paris regime and changed the fracture surface appearance as compared to those tested in vacuum, however, helium did not. Striations were clearly observed on fracture surfaces of specimens tested in argon and in xenon, while no obvious striations were found on those tested in vacuum and in helium. This may indicate that even noble gases have interactions with a metal during plastic deformation. These interactions are slightly different from those in α-titanium. Therefore, the interaction between titanium matrix and entered noble gas atoms may be affected by the difference in crystal structure, that is the size of spaces among the titanium atoms

Refereces

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