# Tensile and high cycle fatigue properties of Zirconium alloy at elevated temperature

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## 1. Introduction

Zirconium (Zr) alloys have been extensively used as cladding materials for fuel elements in nuclear reactor systems due to their low thermal neutron absorption cross-section, excellent corrosion resistance and good mechanical properties at high temperatures. Zirconium alloy containing 1.0 wt% Sn and small amounts of Fe and Cr is widely used as a spacer grid.[2] In the present study, tensile tests were carried out for Zirconium alloy sheet-type specimens with different orientation and temperature conditions. In addition tention-tention fatigue test (stress ratio R=0.1) was studied at room temperature. The specimen surface was observed through scanning electron microscopy (SEM), and fracture mechanisms of the specimens were evaluated.

## 2. Experimental procedures

### *2.1 Material and specimen*

Material used in this study is zirconium alloy for spacer grid. Tensile and high cycle fatigue specimens with having width of 12.5 mm and thickness of 0.46 mm were cut from the thin plate such that was in the longitudinal and transverse directions as shown in Fig. 1. The chemical compositions of zirconium alloy are summarized in Table. 1

### *2.2 Testing method*

Tensile and high cycle fatigue tests were conducted on a MTS 810 servo-hydraulic test machine, according to ASTM standard E8, E21. And strength was observed both in longitudinal and transverse directions of the sheet-type specimen.

Tensile tests were conducted in displacement control mode at a constant of 2mm/min. An extensometer with a total gauge length of 25 mm was used. Test temperatures are chosen at R.T., 300℃, 350℃, and 400 ℃.

Fatigue testing was conducted at a cyclic frequency of 10Hz by using a sinusoidal waveform. Stress ratios, R (= $K_{min}$/ $K_{max}$), of 0.1 were applied and held constant for each individual test on separate specimens. Before fatigue testing, the specimens were mechanically polished with emery paper. After experiment, fracture surface were analyzed in detail using a scanning electron microscope(SEM).

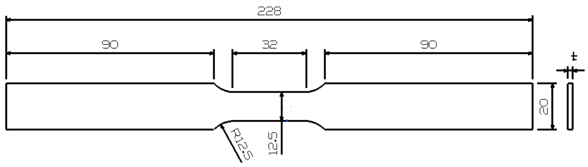


Fig. 1. Configuration and dimensions of specimen for tensile and fatigue tests

Table1: Chemical compositions of Zirconium alloy

| Chemical compositions (wt%) | | | | | | |
|---|---|---|---|---|---|---|
| Nb | Sn | Fe | Cr | T.E. | O | Zr |
| 1.0 | 1.0 | 0.11 | - | - | - | Bal. |

## Results

### *3.1 Tensile properties*

Tensile tests were performed at the temperatures of R.T., 300℃, 350℃, 400℃ in order to evaluate tensile strength. Fig. 2 and Fig. 3 indicate the dependence of on temperature and specimen's direction. As can be seen in the figure, the ultimate strength of L and T specimens at 350℃ showed about 50% and 55% lower than those at room temperature, respectively. While the Yield strength of L and R specimens at 350℃ showed about 59% and 65% lower than those at room temperature, respectively. Thus, yield strength and ultimate strength significantly decreased with increasing temperature. Also depending on the direction of specimen showed a different behavior. For the ultimate strength, L specimen showed higher strength than that T specimen. In the contrast, For the yield strength, L specimen showed lower strength than that of T specimen. According to the publication, depending on the temperature and stress conditions, including Zr and Zircaloy-4 alloy change Slip and twin systems. The prismatic slip of $(10\bar{1}0)$, $\langle 11\bar{2}0\rangle$ occurs at room temperature. (0002) poles of L and T specimen are concentrated around vertical direction for specimen's loading direction. Therefore, when specimen transformed, prismatic slip easily happen rather than twin. If the Prismatic slip serve as the main deformation mechanism. In case of L direction specimen, most concentrated direction and degree of loading direction and (0002) pole is 90$^o$ and In case of T direction specimen, most concentrated direction and degree of loading direction and (0002) pole is 70~80$^o$

Thus, Because L specimen has a higher Schumid factor than T specimen, yield strength of the T specimen shows lower than that of T specimen.

### *3.2 High cycle fatigue behavior*

High cycle fatigue lifetimes of Zirconium alloy, as a function of the cyclic stress ranges, are depicted in Fig. 4. The fatigue life time decreases as the cyclic stress range increases. The difference of fatigue lifetime between two specimens is minor.

The fatigue strengths of L and T specimens at room temperature are 325MPa and 310MPa, respectively. In the short life region (<$10^5$), it was nearly the same for L and T specimens. While in the long life region (≥$10^5$), fatigue strength of L specimen showed higher than that of T specimen.

### *3.3 Microscopic observation*

Fracture mechanism was examined in detail through microscopic observation. Fig. 5(a) Zirconium alloy tensile tested at R.T., 350 °C. It is evident from this figure that the failure occurred by dimple fracture and the fracture mode is ductile. In the tested at R.T and 350, Dimple size of 350℃ has grown larger than at room temperature. Therefore, the reason of decreasing Yield strength and Ultimate strength depend on the size of dimple. Fig.5(b) Clearly shows that the preferential plastic deformation leads to high stress concentrations at grain boundary and to developed slip bands.

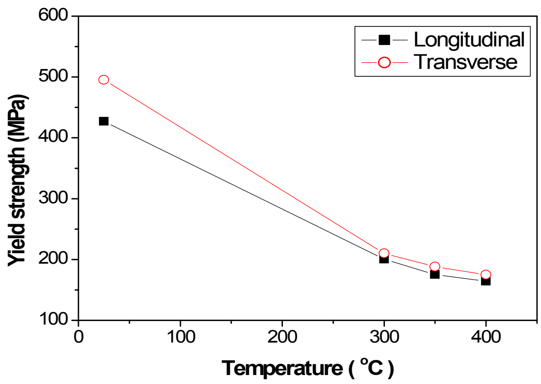


Fig. 2. Yield strength as a function of temperature

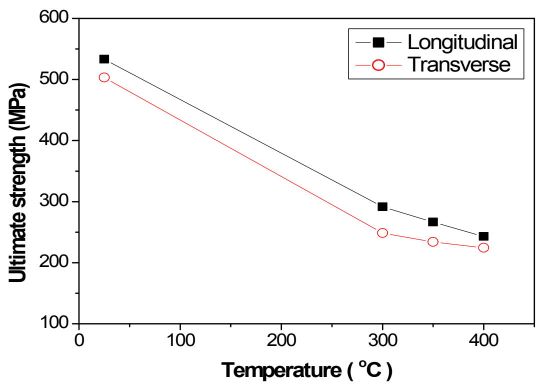


Fig. 3. Ultimate strength as a function of temperature

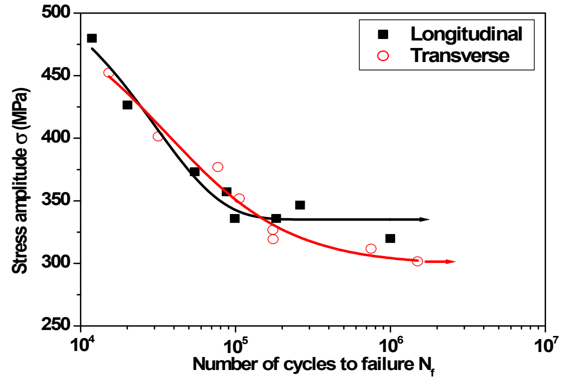


Fig. 4. Fatigue life curves of L and T specimen

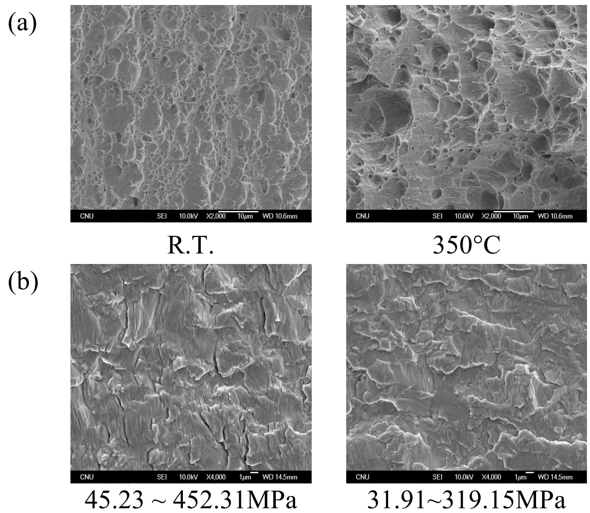


Fig. 5. SEM micrographs of fracture surface (a) tensile test and (b) fatigue test of L specimen

## 4. Conclusions

1. Yield and ultimate strengths significantly decreased with increasing of temperature.
2. Ultimate strength of L specimen was higher than that of T specimen. In the contrast, yield strength of L specimen was lower than that of T specimen.
3. The difference of fatigue life between L and T specimen is implied that zirconium alloy is the presence of anisotropy.

## 5. References

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