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# Ductility Characterization of U-6Nb and Ta-W Alloys

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# Ductility characterization of U-6Nb and Ta-W Alloys

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## Introduction

We have previously evaluated the ductility behaviors of U-6Nb and pure Ta. One important observation was that both alloys have very stable necking ductility independent of test conditions. In contrast, uniform ductility varied significantly depending upon strain rates and temperatures. In general, higher strain rate and lower temperature reduce the uniform ductility. Using literature data, we have developed two dynamic ductility models to predict the ductility behaviors of pure-Ta and water-quenched U-6Nb respectively under extreme conditions.

In this study we further evaluate the aging effect on U-6Nb and the W-addition effect on Ta. For U-6Nb, the objective is to determine whether or not the ductility degradation by low-temperature aging mostly measured in quasi-static condition can still be observed under dynamic loading (high strain rate) condition. For Ta-W alloys, the focus is to identify the key control parameter so that the optimal condition of high-strength/high-ductility of Ta-10W can be achieved for certain defense-related applications.

## Test Materials

- U-6Nb: Y-12 metal with water-quenched and 200°C/48-hour aged conditions
- Pure Ta: As-received and LLNL induction annealed (1200°C/30 min.) conditions
- Ta-10%W: As-received and LLNL induction annealed (1500°C/30 min.) conditions

## Evaluation techniques

- Metallography for grain size characterization
- X-ray line-broadening to quantify the amount of residual strain in Ta and Ta-W alloys
- Uniaxial tensile tests ($10^{-3}$ to 7000 $s^{-1}$ strain rates) for strength/ductility measurement
- SEM for fracture surface examination

## Results

### *Aging effect on U-6Nb Ductility*

Uniform ductility of U-6Nb is moderately reduced from 28% to 23% after a 200°C/48-hour aging. Both aged and unaged U-6Nb suffer additional loss in uniform ductility as strain rate progressively increases from $10^{-3}$ to 7000 $s^{-1}$. But the detrimental aging effect on ductility still remains detectable at higher strain rates. In contrast, necking ductility of U-6Nb remains fairly stable at ~10% in all conditions, Figure 1.

### *X-ray line-broadening technique for residual strain measurement on Ta-W alloys*

The as-received pure Ta and Ta-10W alloys are obtained from Cabot Corporation as "annealed plates". Grain structure examination of the as-received plates shows equiaxed and recrystallized grains. But x-ray line-broadening measurement on (420) diffraction shows a poor resolution between the $K_{\alpha1}$ and $K_{\alpha2}$ spectra. This strongly indicates that the as-received plates have a substantial amount of residual strain (high dislocation density). A rapid induction annealing between 1200-1500°C can effectively remove most of the residual strain and results in an excellent resolution between the $K_{\alpha 1}$ and $K_{\alpha 2}$ spectra. We define a recrystallization index (RI) to quantify the amount of residual strain by the ratio of $K_{\alpha 1}$ peak-intensity to the valley-intensity between $K_{\alpha 1}$ and $K_{\alpha 2}$. A higher RI value (5.8) on induction annealed Ta-10W means a more complete recrystallization with less residual strain than as-received metal, Figure 2.

### *Ductility of pure Ta*

Pure Ta is a weak alloy (ultimate tensile strength ~280 MPa) and shows an excellent total ductility of ~64% at low $10^{-3}$ $s^{-1}$ strain rate. The total ductility is evenly distributed between the uniform ductility (31%) and the necking ductility (33%). As expected, the uniform ductility decreases rapidly to only 3-7% range as strain rate increases to 7000 $s^{-1}$, while the necking ductility remain fairly constant (31-39%) in the entire strain rate range ($10^{-3}$ to 7000 $s^{-1}$), Figure 3a.

The study also shows that the as-received and 1200°C induction annealed Ta have a similar ductility performance. This implies that pure Ta has a very forgiving ductility behavior as far as residual strain is concerned.

### *Ductility of Ta-10%W*

Ta-10W is a much stronger alloy (ultimate tensile strength ~540 MPa) than pure Ta. The alloy can have an excellent dynamic ductility if it is properly annealed. Our study shows that W-addition can have a major benefit in stabilizing the ductility at high strain rates.

Proper annealing is a critical parameter for the use of Ta-10W. The as-received Ta-10W shows an erratic ductility behavior with many premature failures during tensile tests. SEM examination shows that the erratic performance is primarily due to the inconsistent necking behavior. After a 1500°C/30 min. induction annealing, Ta-10W shows a very consistent and stable total ductility (~50%) even at the highest strain rate of 7000 $s^{-1}$, Figure 3b.

### *Fracture surface examinations by SEM*

SEM can be a useful tool to qualitatively evaluate necking behavior by examining the shape of fracture surfaces. The superior ductility on Ta and Ta-10W alloys to U-6Nb is obviously due to the excellent necking ductility of Ta-W alloys. Also, the erratic necking performance on the as-received Ta-10W can be easily identified by SEM, Figure 4.

### *Conclusions*

1. Low-temperature aged U-6Nb suffers uniform ductility loss, and the detrimental aging effect still remains detectable at higher strain rates. Necking ductility of U-6Nb is much smaller than Ta and Ta-10W alloys, but it remains fairly constant regardless of aging and strain rates.
2. Pure Ta shows a very forgiving ductility behavior as far as residual strain is concerned.
3. Ductility of pure Ta is very sensitive to strain rates. Most of its uniform ductility will disappear under dynamic condition. But the excellent necking ductility remains unchanged.
4. Ductility behavior of Ta-10W is sensitive to residual strain, and typical commercially annealed condition may not be adequate for ductility-sensitive applications.
5. Properly annealed Ta-10W shows excellent stability for both uniform and necking ductility, and it can be a material of choice for high strength/high ductility applications under ductility condition.
6. We developed an x-ray diffraction technique as a potential ductility control tool for Ta-W alloys.

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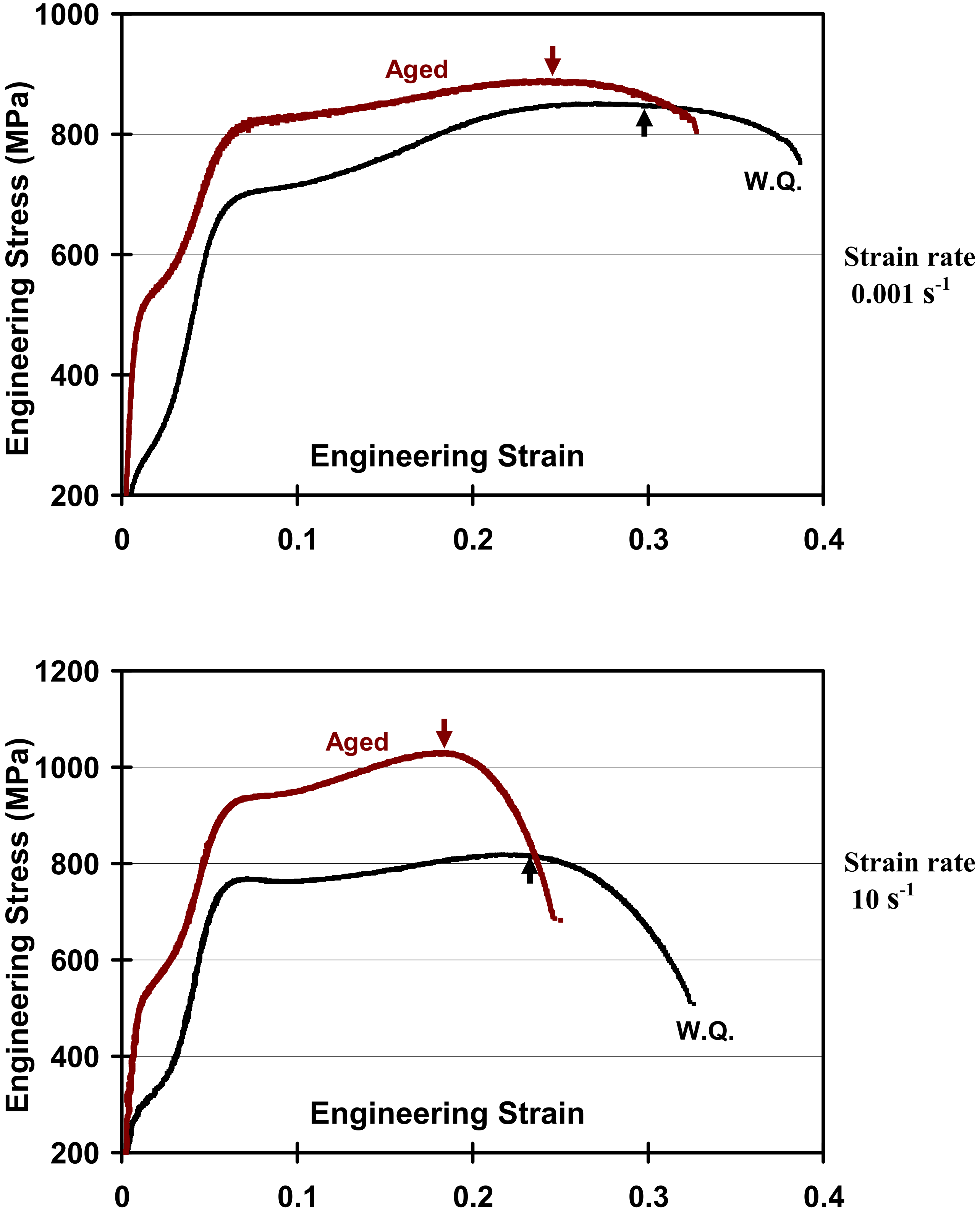

Figure 1: Engineering stress-strain curves of W.Q. and 200°C aged U-6Nb showing that the detrimental aging effect remains detectable at higher strain rates

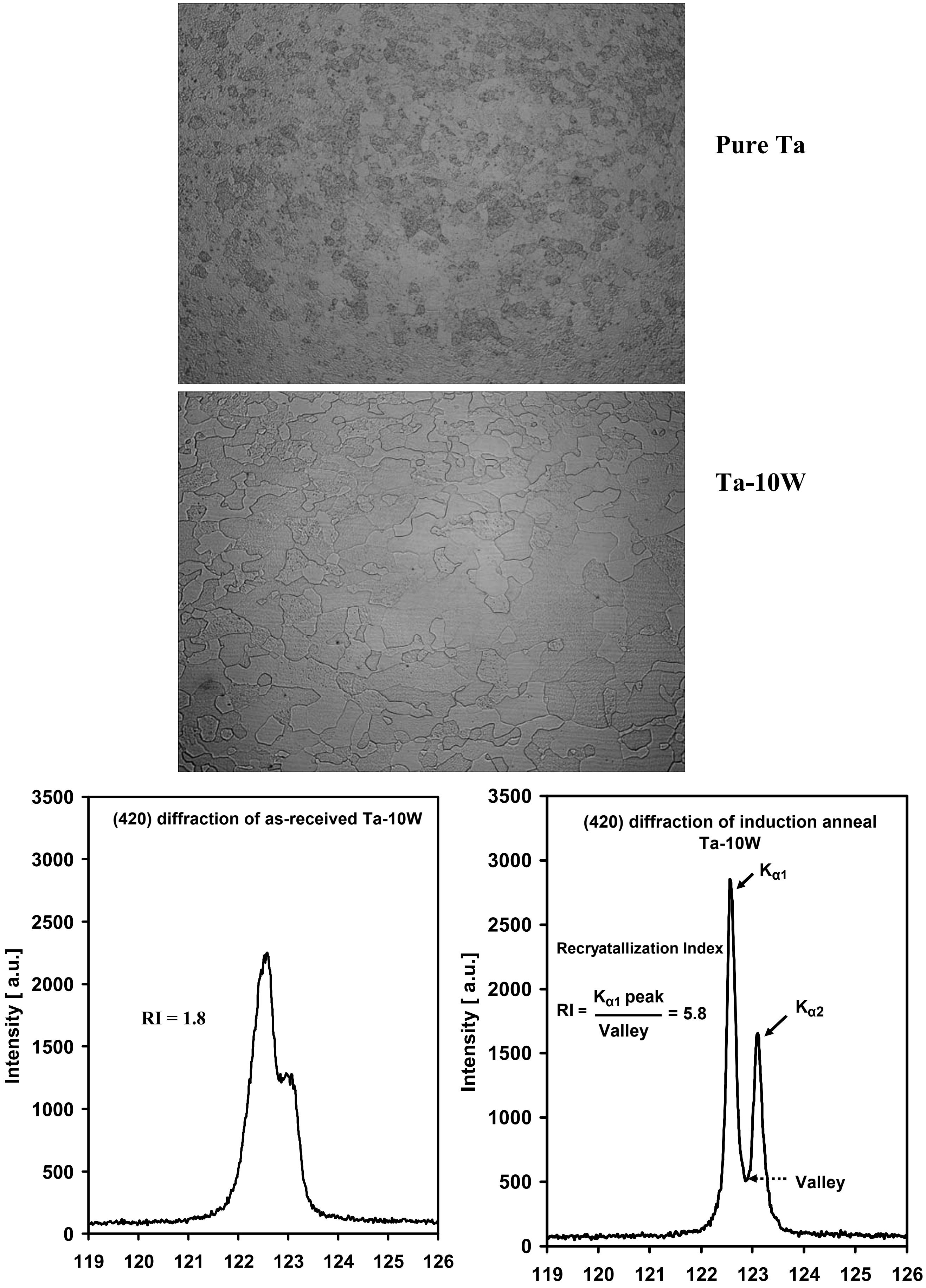

Figure 2: Recrystallized grain structures of as-received Ta and Ta-10W, and (420) diffraction spectra indicating substantial residual strain in as-received Ta-10W.

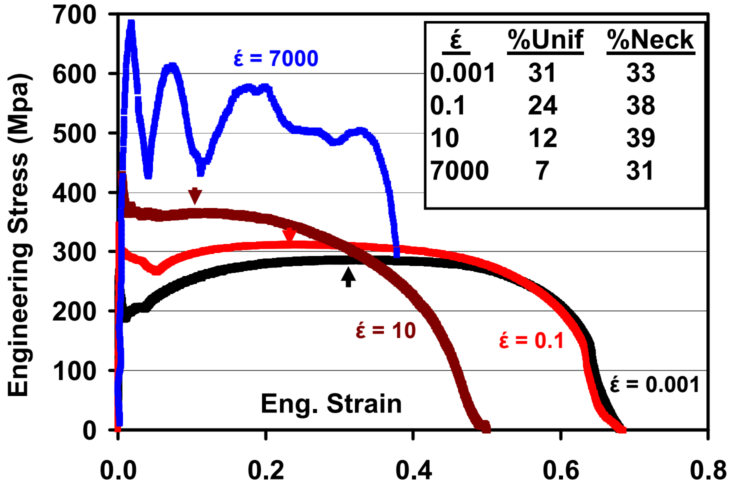

Fig. 3a: Stress-strain curves of pure Ta showing uniform ductility decreases at higher strain rates.

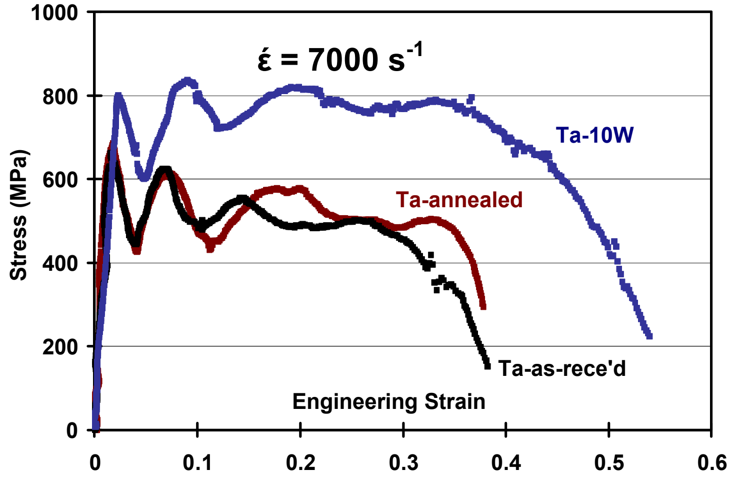

Figure 3b: Properly annealed Ta-10W can have higher strength and ductility than pure Ta under dynamic condition.

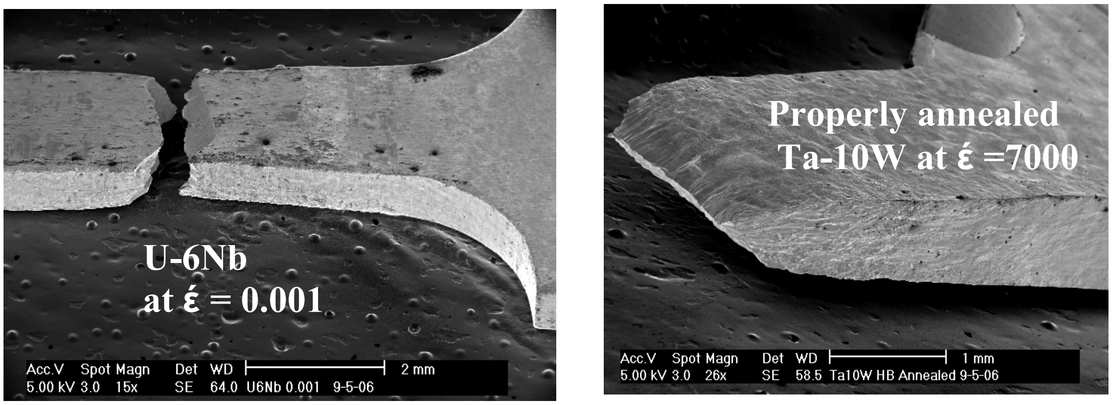

Fig. 4: SEM micrographs showing different necking behaviors of U-6Nb and Ta-10W.