TEM investigation of ultra-high purity tungsten for fusion application

G Cempura[1], C Thomser[2], M Wirtz[2] and A Czyrska-Filemonowicz[1]

1. AGH University of Science and Technology, International Centre of Electron Microscopy for Materials Science & Faculty of Metals Engineering and Industrial Computer Science, Al. A. Mickiewicza 30, 30-059 Krakow, Poland
2. Forschungszentrum Jülich, Institute of Energy and Climate Research 2, EURATOM Association, 52425 Jülich, Germany

cempura@agh.edu.pl
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The European conception studies of fusion power plant are based on tokomak concept, where the divertor in one of the main component of fusion reactor [1]. Its function is to extract heat and helium ash (products of fusion reaction) from the plasma. Currently, designed divertor (e.g. ITER's) compromises two main parts: supporting structure made of steel and plasma facing part. The plasma facing part of the divertor in ITER should be able to withstand high heat fluxes (5-20 MW/m^2 in steady state conditions) and very short transients up to 1 GW/m^2 and above in the sub-millisecond range as well as high particle irradiation such as hydrogen, helium and neutrons. Tungsten and its alloys are intended for use as a plasma facing material due to their high melting temperature, good thermal conductivity and low tritium retention [2]. However, the recrystallization temperature and the ductile-brittle transaction temperature (DBTT) are the limiting temperature range for structural application of the W-based alloys in fusion reactors.

In order to investigate an influence of high temperature exposure on recrystallization processes and the changes in the tungsten microstructure, two specimens of polycrystalline ultra-high purity tungsten (W-UHP) with a purity of 99.9999% were investigated by TEM. The specimens were prepared by so-called 'single forged' treatment [3] which reduces the anisotropy in the material. Additionally, one specimen was recrystallized at 1600 ºC for 1h after forging.

The microstructure of the specimens was investigated by TEM using the Tecnai G2 microscope of FEI. Thin foil preparation for TEM investigation of W-based materials was extremely difficult. Different methods of specimen preparation were elaborated in order to produce high quality specimens. FIB lamellas were not suitable due to high re-deposition of tungsten. The low ductility of the investigated tungsten was the main reason for difficulties of thin foil preparation for TEM analyses. It is the reason why no mechanical treatment at the last thinning steps was applicable. After many trials by various techniques, a method for thin foil preparation was successfully elaborated. Specimens for TEM observation were electrolytically cut in the NaOH solution to 3mm disks. Due to the high electron absorption of W, very thin specimens are required for TEM investigation. Therefore the 3 mm discs were subsequently slowly perforated by electro-polishing in the Tenupol 5 of Struers using 10% NaOH solution at room temperature.

The TEM analyses showed that a microstructure of the single forged specimen exhibited a high density of linear- and planar microstructural defects: high dislocation density, sub-grain boundaries and stacking faults within the elongated grains (Figs 1a,b). In the specimen heat treated at 1600 ºC for 1h after forging, the recrystallization effects were observed. Figs 2a, b show a microstructure of the recrystallized specimen: very large grains with much lower density of microstructural defects in comparison to the forged specimen. Very low dislocation densities within large grains were the typical microstructural features of the recrystallized UHP tungsten. Further studies of the microstructure and deformation mechanisms of tungsten and its alloys are in progress.

References

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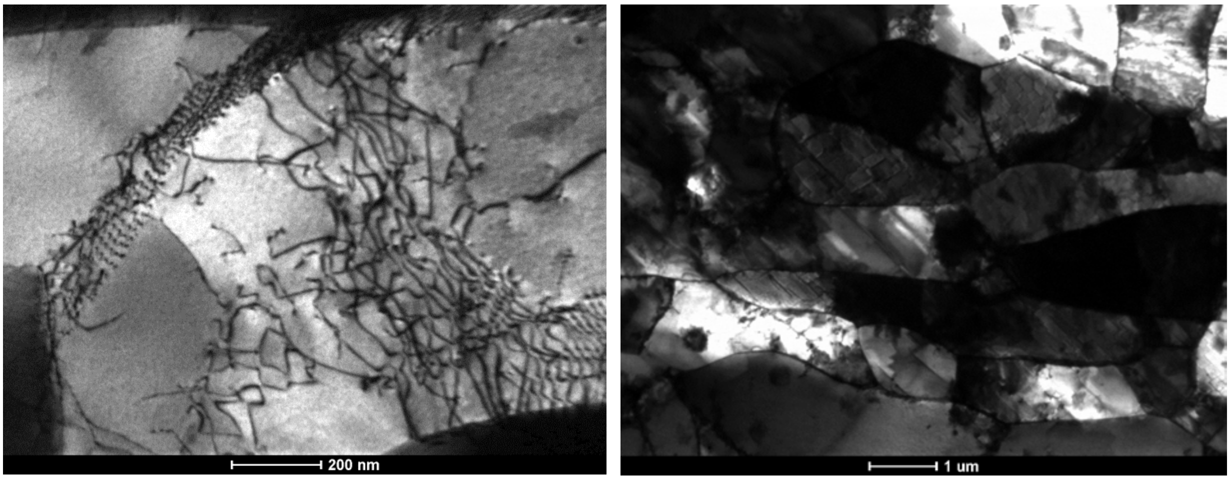
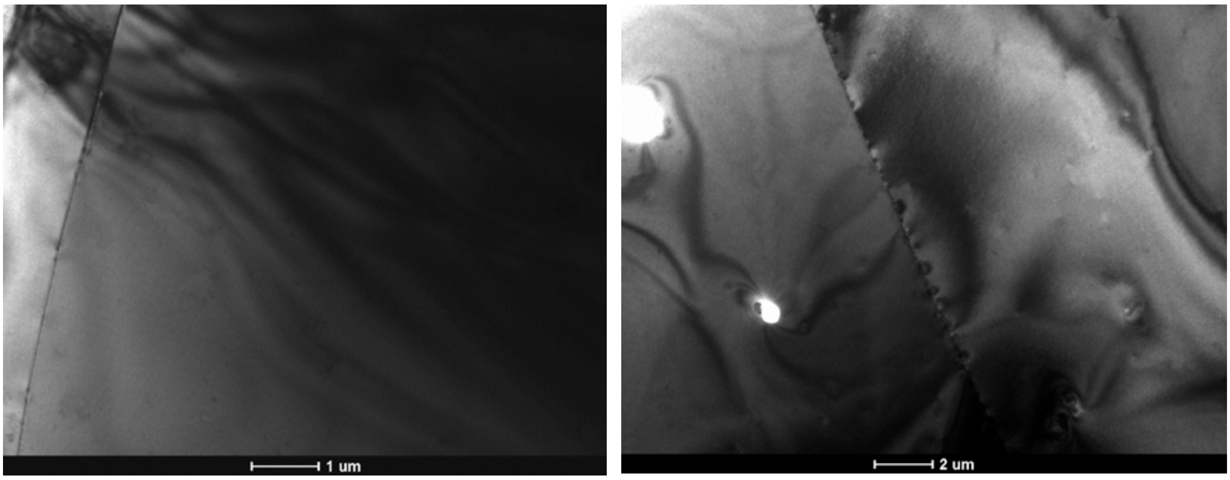


a) *b)*

Figure 1a,b. *Microstructure of UHP tungsten after single forging; dislocation structure and formation of sub-grains (TEM)*



a) *b)*

Figure 2a,b. *Typical microstructure of UHP tungsten after single forging and recrystallization at 1600 °C for 1h; very low dislocation density within large grains (TEM)*