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Publication date:
2018

Document Version
Publisher's PDF, also known as Version of record

Link back to DTU Orbit

Citation (APA):
Thermal stability of differently rolled, thin tungsten plates in the temperature range from 1300 °C to 1400 °C

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The thermal stability of thin tungsten plates of four different thicknesses achieved by warm and (in two cases) cold rolling is investigated in the temperature range between 1300 °C to 1400 °C. Hardness testing of annealed specimens allows tracking the degradation of the mechanical properties and, indirectly, the microstructural evolution. For all four tungsten plates, a concise description of both, isothermal and isochronal annealing treatments have been achieved using well-established models for the kinetics of recovery and recrystallization. A systematic dependence of the recovery kinetics at different temperatures on the hardness loss during recovery at a particular temperature has been identified. An Avrami exponent of 2 and activation energies energies for the progress of recrystallization ranging from bulk diffusion to grain boundary diffusion have been revealed. By extrapolating the observed kinetics of recrystallization, the temperatures for which half recrystallization would be expected to occur after two years range between 1000 °C and 1100 °C for these thin plates disqualifying them for use as divertor components.

Recrystallization in plasma facing applications

One of the most critical components of future fusion reactors is the divertor, the exhaust system responsible for maintaining the purity of the plasma while ongoing reactions produce heat.

The plasma facing components therein are exposed to high particle and high heat fluxes, requiring demanding performances in terms of heat and mechanical resistance.

Tungsten meets many of the requirements for plasma facing components: a high thermal conductivity (164 W/mK), high strength, high yield point and creep resistance at high temperatures, highest melting point of all metals (3422 °C), a low sputtering yield due to a high energy sputtering threshold. On the other hand, tungsten shows an intrinsic room temperature brittleness and a rather high Ductile to Brittle Transition Temperature (DBTT) in the annealed state.

Plastic deformation, however, confers tungsten ductility, extending the ductile range and hence, structural applications, to temperatures approaching RT. Within high heat exposure applications, operating with plastically deformed tungsten parts is hence limited by the occurrence of recrystallization replacing the ductile, deformed structure by an intrinsic brittle one.

The recrystallized condition is unfeasible for such a structural application, given the extremely high particle bombardment and high heat loads.

Kuhlmann and JMAK modeling

Microstructural evolution was obtained by mean of isochronal and isothermal experiments (Fig.1), respectively to study recovery and primary recrystallization.

Analysis of kinetics was performed respectively via Kuhlmann isochronal model for recovery and via JMAK model for recrystallization.

If the hardness of an annealed sample at the temperature \( T \) is \( H V_{\text{rec}} \), then its evolution with different annealing temperatures for a fixed time follows:

\[
HV_{\text{rec}} = HV_0^c - AT
\]

where the constant \( A \) is directly related to the microstructure through the constant \( c_2 \):

\[
A = \frac{k}{c_2} \ln \left( 1 + \frac{t}{t_0} \right)
\]

Recrystallization kinetics instead can be described instead by the JMAK model, where \( X_V \), the volume fraction of recrystallized material and \( b \) a material related constant:

\[
X_V = 1 - \exp(-b^n(t - t_0)^\alpha)
\]

Thin rolled tungsten behavior

These thin plates demonstrated to be microstructurally characterized by a typical elongated grains structure with a preferential rotated cube texture orientation upon rolling (Fig.2).

Recovery kinetics proved to be faster for thinner plates with the exception of one of the plates whose odd behavior is confirmed also within recrystallization.

Recrystallization kinetics revealed activation energies for the process to be ranging from bulk diffusion energy for the least reduced plates to grain boundary diffusion for the most thin rolled ones (Fig.3).

<table>
<thead>
<tr>
<th>TP2</th>
<th>TP1</th>
<th>TP05</th>
<th>TP02</th>
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<td>507±25</td>
<td>579±6</td>
<td>456±5</td>
<td>382±21</td>
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</table>

Fig.1: Isothermal Exp. on a 2mm thick plate at 1325 °C

Fig.2: EBSD orientation map of the RD of the as-received state for a 2mm thick plate

Fig.3: Arrhenius plot for the 2mm thick plate

Fab.1: Activation energies for the different plates.