Impact bending tests on selected tungsten materials

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Overview

Tungsten or tungsten materials are considered to be the primary candidates for armour and structure of DEMO divertor designs. Present design outlines are based on a structural material with operation temperatures up to about 1300 °C. The most critical issues are ductile-to-brittle transition and recrystallization. The first defines the lower, the second the upper operation limit. Another problem consists in the fact that the microstructure of these refractory alloys depend strongly on the manufacturing history. Since mechanical properties are defined by the underlying microstructure, refractory alloys can behave quite different, even if their chemical composition is the same.

However, it has been shown that ductility is the most problematic criterion for a divertor structural material [1].

Therefore, a systematic screening study of impact bending properties of standard tungsten materials was performed to determine the influence of microstructure characteristics like grain size, anisotropy, texture, or chemical composition.

Results

Plansee provided five different tungsten rod materials: pure W, W-1%La_2O_3 (WL10) in two different conditions, potassium doped tungsten (WVM), and WL10 with 1% Re). Standard specimen (KLST type) were fabricated and tested.

The results of the tungsten materials may be compared to the results from specimens of a TZM (molybdenum, stabilized by Ti and Zr) rod. It can be clearly seen that only TZM shows the classical embrittlement behaviour which is typical for most body-centred cubic structured metals: (1) there is a clear transition from brittle (at lower temperatures) to ductile (at higher temperatures) fracture (DBTT), and (2) there is an extended regime of ductile fracture (area of almost constant energy, the so-called upper shelf).

Compared to TZM, the results of the tungsten materials look quite different. Only specimens of pure tungsten show an upper shelf starting at 900 °C. Potassium doped tungsten seems just to reach the upper shelf at 900 °C. But all other rod materials don’t show pure ductile fracture within the whole test temperature range. However, all tested materials tend to brittle fracture at temperatures below 500 °C. But above that temperature, the specimens show cleavage fractures which propagate along the rod axis, that is, parallel to the specimen’s long side and perpendicular to the notch.

In summary, there are three types of fractures (brittle, cleavage, ductile) which are linked by a brittle-to-cleavage transition and a cleavage-to-ductile transition. The brittle-to-cleavage transition temperature (defined in analogy to the DBTT) varies around 500 °C for all tungsten materials while the cleavage-to-ductile transition temperature is about 900 °C for tungsten and about 1000 °C for the potassium doped tungsten (comparable behaviour is also reported in [2]). For the other materials (WL10 and W1Re1La) the transition to ductile fracture starts probably at even higher temperatures.

Conclusions

For a given temperature, WL10 compared to pure tungsten may be stressed slightly more and still reaches the same life-time. So WL10 meets just the current divertor creep design criterion while pure tungsten does not. With that, the benefit of lanthanum-oxide in tungsten is an improvement of the processability, the suppression of recrystallization, and a slight strengthening effect. But at the same time, the already high ductile transition temperature of pure tungsten is still increased by the addition of lanthanum oxide.

The reason for the high ductile transition temperature is not brittle fracture but cleavage fracture. First examinations have shown that EDM fabrication produces microcracks at surfaces perpendicular to the rod axis. If such cracks could be avoided (by other fabrication methods) or sealed (by brazing, for example), the fracture behaviour should improve significantly.

This is part of the ongoing activities to determine the lowest possible ductile transition temperature of tungsten materials.

References

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