Oxidation resistant tungsten-based alloys for high temperature application

CEIT-IK4 is a non-profit research centre located in San Sebastian, Spain, whose main task is to carry out industrial research projects under contract, in collaboration with R&D departments of companies. CEIT-IK4 works on the development of Self-passivating tungsten-based alloys for the first wall of fusion reactors and provides major safety advantage compared to pure W in case of a LOCA with simultaneous air ingress, due to the formation of a protective scale preventing the formation of volatile and radioactive WO3. Potential non-fusion applications are all those high temperature fields for which pure tungsten would be a good option but its poor oxidation resistance prevents its use or leads to short in service lifetime: electrodes, electrical contacts, balancing weights in gas turbine rotors, components in high temperature furnaces…

Description of the technology

CEIT has developed several W-based alloys for application at the blanket first-wall of DEMO within the EUROfusion project and during EFDA Work Programmes. The W alloys developed within EUROfusion belong to the W-Cr-Y system, being W-10Cr-0.5Y (in wt. %) the composition most deeply studied. The alloy is manufactured by powder metallurgy starting from elemental powders of W, Cr and Y, which are mechanically alloyed (MA) and subsequently compacted by Hot isostatic Pressing (HIP). After HIPing, a 100% dense material is obtained with extremely fine grained microstructure (average grain size 100 nm) consisting of two bcc phases with compositions in agreement with the W-Cr phase diagram: a (αW,Cr) main phase with minor presence of (αCr,W). The whole oxygen present after MA (0.15 wt.%) combines with Y to produce a Y2O3 nanoparticle dispersion contributing to inhibit grain growth and to reinforce the material. In this way, the grain boundaries (GB) are "cleaned" from oxygen avoiding the formation of brittle oxides and improving the mechanical strength. Subsequent to HIPing, a heat treatment (HT) at 1550°C is performed to obtain a single-phase bcc material, where the whole Cr amount is dissolved in the W-rich matrix. Thus, the presence of two phases with different thermal expansion properties is avoided, which is not beneficial in view of a high thermal shock resistance. The material obtained after HT exhibits a matrix grain size of 800 nm and coarsening of the Y2O3 nanoparticles.

The W-10Cr-0.5Y alloy has a linear oxidation rate 3–4 orders of magnitude lower than pure W at the C temperature range 800–1000°C due to the formation of a thin protective Cr2O3 layer. Oxidation tests performed at 1000°C under humid atmosphere for long exposure times reveal that the material would withstand a LOCA for at least 10 days. At 1200°C the protection cannot be maintained. The W-10Cr-0.5Y alloy after HIP + HT exhibits a high thermal shock resistance after 1000 ELM-like pulses of 0.38 GW/m2 and 1 ms duration at the electron beam facility JUDITH, where the alloy shows comparable performance to pure W. High heat flux tests up to 2 MW/m2 as well as 106 ELM like pulses at the ion beam facility GLADIS on W-10Cr-0.5Y samples brazed to a cooled component did not reveal the presence of cracks or any relevant damage. Aging tests performed at 650°C, the maximum temperature expected under normal operation conditions, resulted in an unchanged microstructure and hardness after 3000 h. There is also no appreciable changes in microstructure and hardness after 100 h at 700°C.

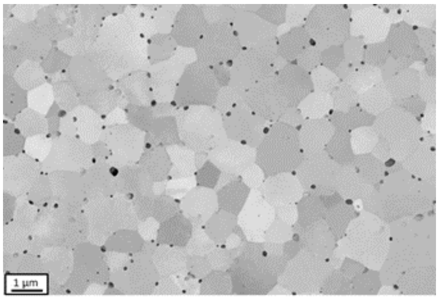

Fig. 1: Microstructure of W-10Cr-0.5Y alloy. The black dots correspond to Y2O3 particles.

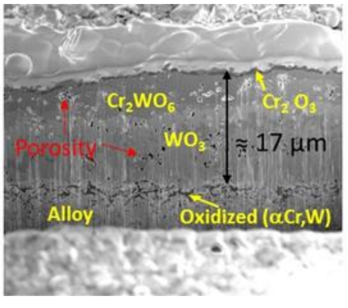

Fig. 2: Cross-section of W-10Cr-0.5Y alloy after 60 h isothermal oxidation at 1000°C.

EUROfusion
TECHNOLOGY TRANSFER PROGRAMME

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Innovation and advantages of the offer

Tungsten is a very attractive material for many applications under extreme conditions of temperature, heat load etc., due to its high melting point (3419°C), high strength and hardness at high temperature, good thermal conductivity and low thermal expansion coefficient. A drawback of tungsten is its high oxidation at temperatures above 500°C, which prevents its application in many fields where extreme conditions (high temperatures, high heat loads…) are expected. The material developed within this project consist of a W-based alloy which maintains many properties of pure W (high melting point, high mechanical strength, low thermal expansion coefficient, high Young modulus) while improving significantly its oxidation behavior, in such a way that the material would be able to work continuously under oxidizing conditions (even humid) up to 800°C and occasionally up to 1000°C. Even though the material is brittle, it exhibits a high mechanical strength, resulting in a thermal shock resistance comparable to or higher than pure W. As an alloy, the thermal conductivity is significantly lower than pure W. Nevertheless, the thermal conductivity in the range 500 – 800°C is about 55 W/mK, which is more than twice the thermal conductivity of standard Ni-base super alloys like Inconel-718 used currently in many applications under extreme environments.

Non-fusion Applications

The W-based alloy developed at CEIT can be applied in those areas where tungsten would be a good option (due to its high density, high strength, high temperature strength, etc.) but cannot be used because of its low oxidation resistance at temperatures above 500°C such as: electrodes, electrical contacts, balance weights in gas turbine rotors, components in high temperature furnaces

EUROfusion Heritage

As a Third party of CIEMAT, CEIT is involved in the work package WPMAT-HHFM, task Self passivating tungsten alloys of the EUROfusion project and previously in the EFDA Work Programmes MAT-HHFM. The motivation for this development was the fact that pure tungsten, the candidate first wall (FW) armor material for DEMO, oxidizes at high temperatures forming WO3, which is volatile above 750°C. This represents a potential safety issue in case of a loss-of-coolant accident with simultaneous air ingress into the vacuum vessel. As a solution for this important safety concern, the addition of oxide forming alloying elements to pure tungsten was proposed, resulting in the growth of a stable protective oxide scale at high temperatures in presence of oxygen, preventing tungsten from oxidation at high temperatures, thus avoiding the potential risk of radioactive release during such a scenario. The project involved EUROfusion WPMAT-HHFM group and WPPFC group with FZJ, CEIT, IPP and Polytechnic University of Madrid

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