# Development of chromium for mid-flux region PFCs for DEMO divertor

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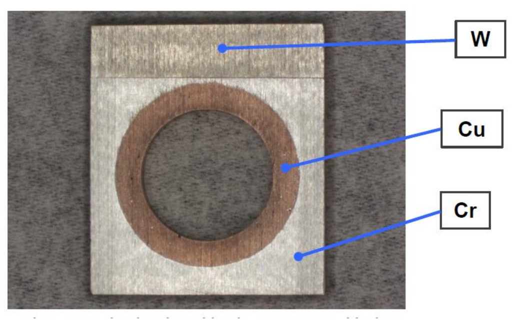
## Introduction

Designing of plasma-facing components (PFC) for DEMO divertor unravel new challenges to be met by the in-vessel materials. For designing mid heat flux PFCs, chromium (Cr) is currently considered as material for the main body connected to tungsten armour tile and cooling pipe.



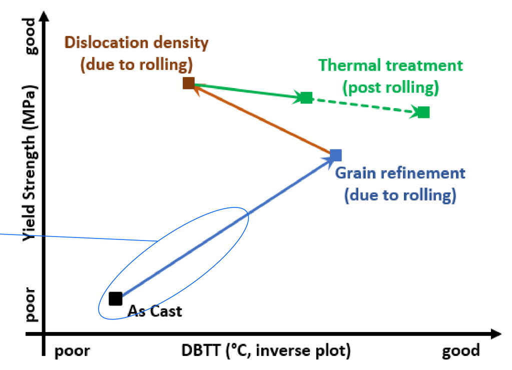

Cr has better toughness property in the low temperature range where the commercial tungsten (W) products are brittle. Cr is an excellent material to reduce the oxidation in case of loss-of-vacuum accident. Cr does not experience such harsh transmutation due to thermal neutrons unlike transmutation of Re and Os in tungsten. However, the mechanical properties of Cr are extremely sensitive to purity. Here, we employ vacuum arc melting (VAM) equipment for fabrication of Cr and Cr-W alloy suitable for PFCs. VAM represents new promising alternative route with a high upscale potential. VAM fabrication might improve Cr quality by avoiding the introduction of interstitial impurities, while the produced grades can be further mechanically treated to design dedicated microstructure and enhance the yield strength and toughness.

## Objectives

The main objective was to test and investigate mechanical properties as well as microstructure of pure Cr and Cr-10W alloy produced in Vacuum Arc Melter and compare them with commercial high purity Cr produced by Plansee™ with sintering and mechanical treatment.

- 3-point bending flexural test for determination of ductile to brittle transition region.
- Vickers hardness and nanoindentation. Estimation of $\sigma_{0.2}$ as $H \approx 3\sigma_{0.2}$.
- Fracture surface analysis with SEM and grain pattern analysis with EBSD.

Materials investigated in this work are on the first stage of future improvements by thermo-mechanical treatments.




## Materials and methods

### The Arc Melter

An innovative solution acquired by OCAS™ which uses principles of an electric arc furnace in combination with induction furnace:

- Allows on to melt W and Cr in order to create solid solution, instead of sintering;
- Vacuum chamber significantly reduces oxidation;
- Induction furnace involved in a melting process helps to cool down material slower, ensuring homogeneity of microstructure and mechanical properties.

### Arc Melter system

### Chromium flakes and tungsten lumps were used to produce tested materials.

Chromium flakes (99,97% purity)

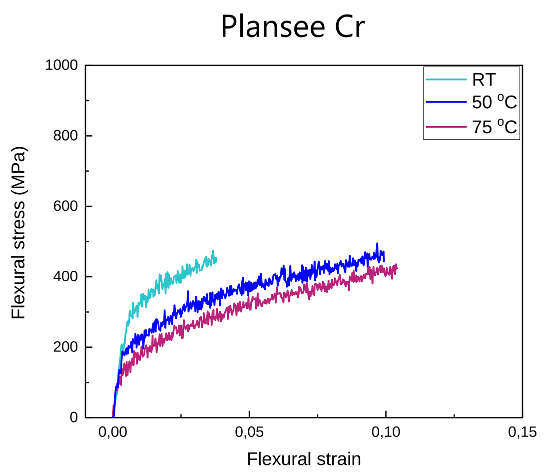
Tungsten lumps (99,99% purity)

Cr sample produced after melting (271 g)

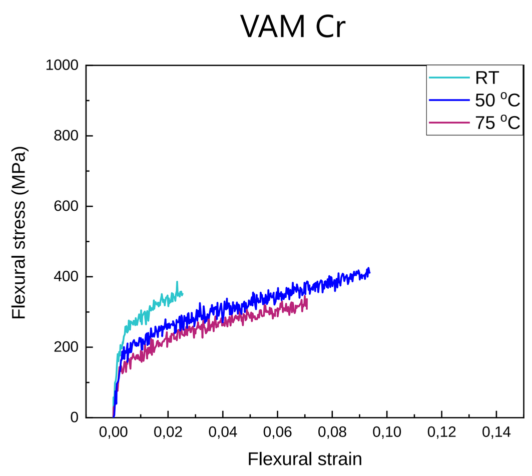
## Results

### Mechanical properties

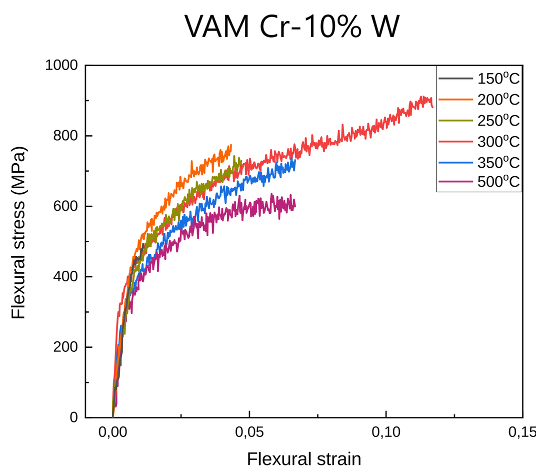
Plansee Cr



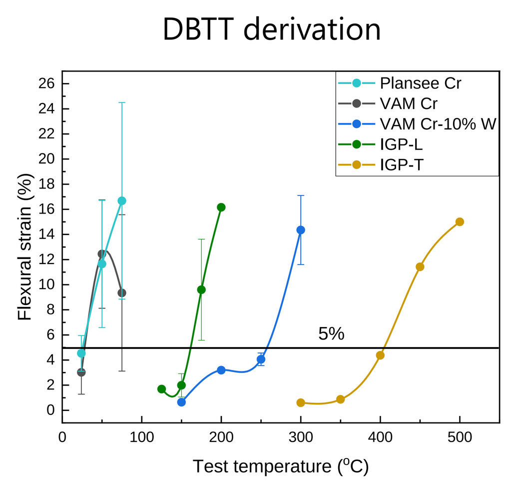

VAM Cr



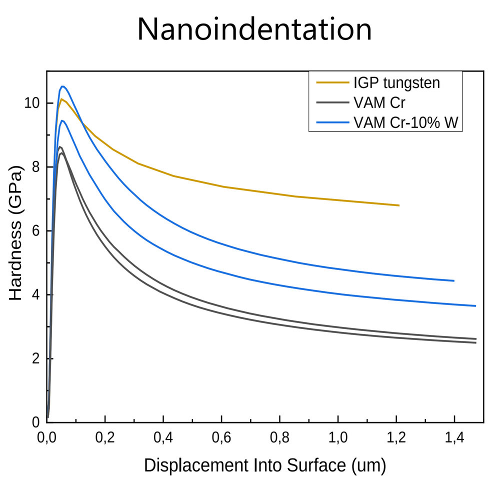

VAM Cr-10% W




DBTT derivation



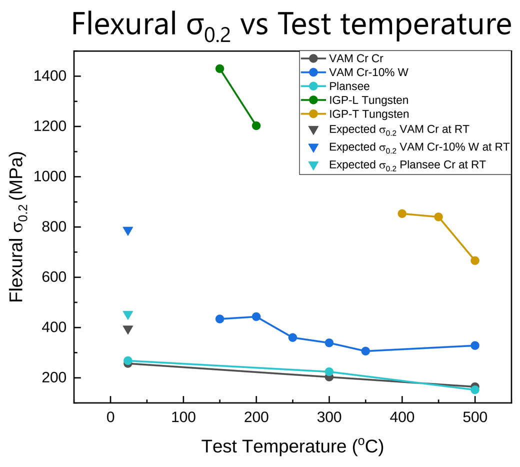

Nanoindentation



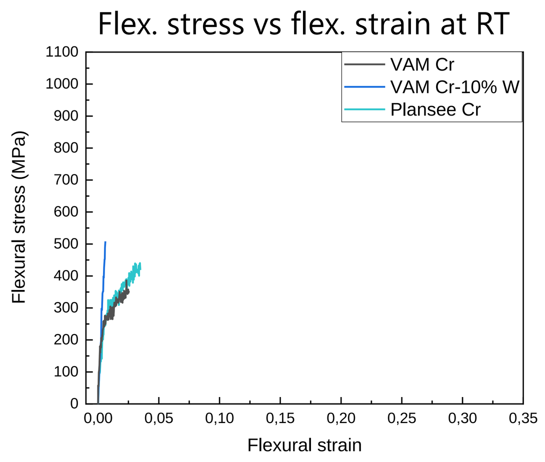

| Material | Flexural $\sigma_{0.2}$ at 300°C, MPa | Flexural $\sigma_{0.2}$ at 500°C, MPa | VH | $\sigma_{0.2} \approx$ 3VH, MPa | NI hardness, GPa | $T_{5\%}$ in 3PB test, °C |
|---|---|---|---|---|---|---|
| VAM Cr | 203 | 164 | 132 | 396 | 2,6 | 27 |
| Plansee Cr | 224 | 152 | 151 | 453 | TBD* | 27 |
| VAM Cr-10%W | 339 | 328 | 263 | 789 | 4 | 256 |
| IGP-T Tungsten | Brittle | 666 | 460 | 1380 | 6,8 | 405 |
| IGP-L Tungsten | TBD* | TBD* | 460 | 1380 | 6,8 | 162 |

TBD* - To be determined

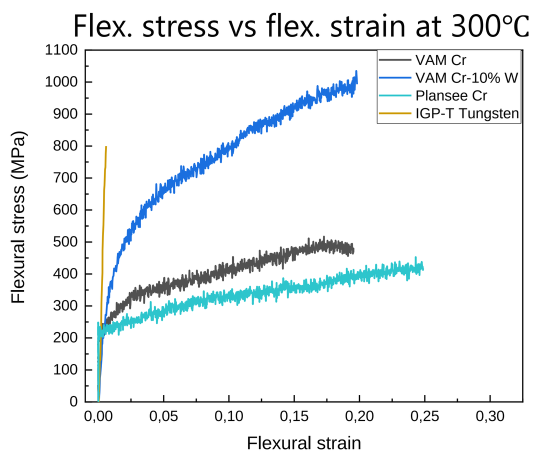
Flexural $\sigma_{0.2}$ vs Test temperature



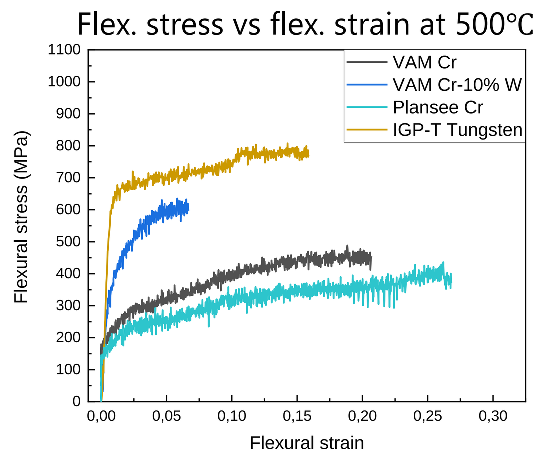

Flex. stress vs flex. strain at RT




Flex. stress vs flex. strain at 300°C



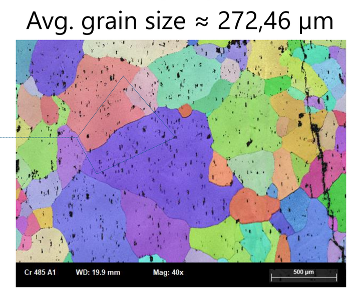

Flex. stress vs flex. strain at 500°C



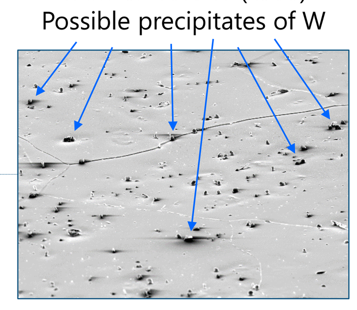

## Results

### Microstructure

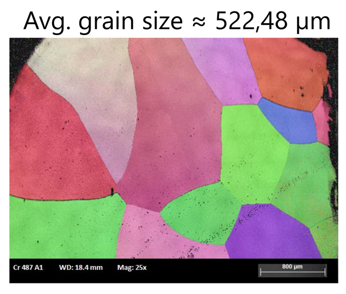
VAM Cr-10% W
Avg. grain size ≈ 272,46 μm

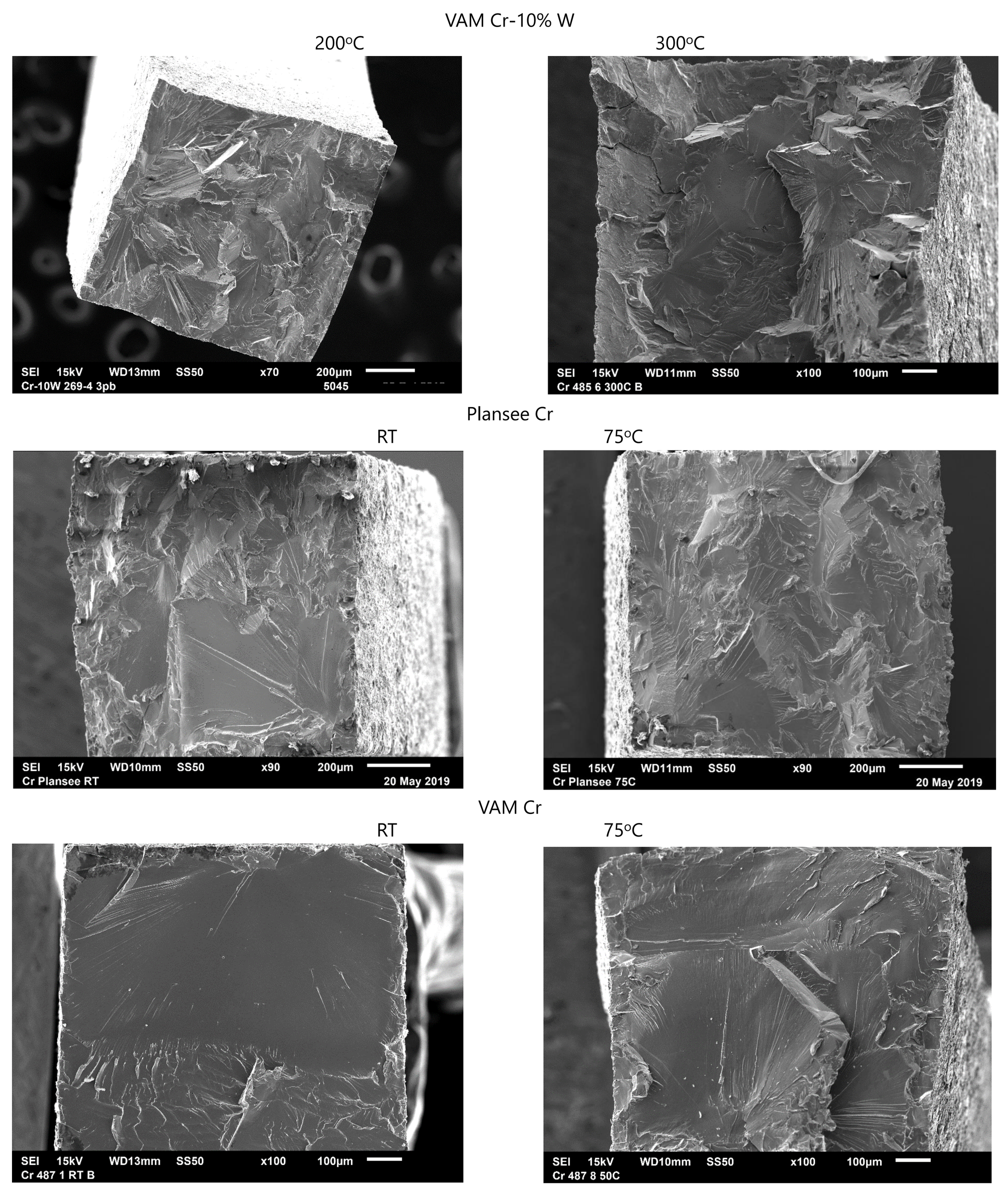


VAM Cr-10% W (x300)
Possible precipitates of W



VAM Cr
Avg. grain size ≈ 522,48 μm






## Results

### Chemical analysis by XRF and O contamination

| Material | Cr [mass %] | W [mass %] | Fe [mass %] | O [mass %] | O in raw material |
|---|---|---|---|---|---|
| VAM Cr | 99,5 | | 0,0025 | 0,005 | 0,003 |
| VAM Cr-10% W | 90,50 | 9,1 | 0,1 | 0,07 | 0,003 |
| Plansee Cr | 99,8 | | 0,078 | 0,05 | |

## Conclusions

- As-casted pure Cr (without any further treatment) produced by VAM has shown very similar mechanical properties to pure Cr of Plansee, which was produced by sintering and rolled into plate. The DBTT of VAM Cr is around room temperature.
  - Further thermo-mechanical treatment applied to VAM Cr should considerably improve its properties in terms of strength increase and DBTT reduction.
  - The Vacuum Arc Melter produces enough volume of chromium to fabricate a monoblock.
  - Due to the large grain size, the main fracture mechanism of VAM Cr is transgranular cleavage
- As-casted Cr-10W produced by VAM has shown much higher strength than pure Cr, capacity for significant work-hardening and DBTT around 250°C.
  - EBSD examination reveals the presence of W-rich particles, which implies that perfect solid solution was not reached.
  - Fracture mode is a mixture of trans- and intergranular cleavage.