Mechanical Characterization of PFC Candidate Fine-Grain Dispersion-Strengthened Tungsten Materials

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LOW ACTIVATION MATERIALS DEVELOPMENT AND ANALYSIS (LAMDA)

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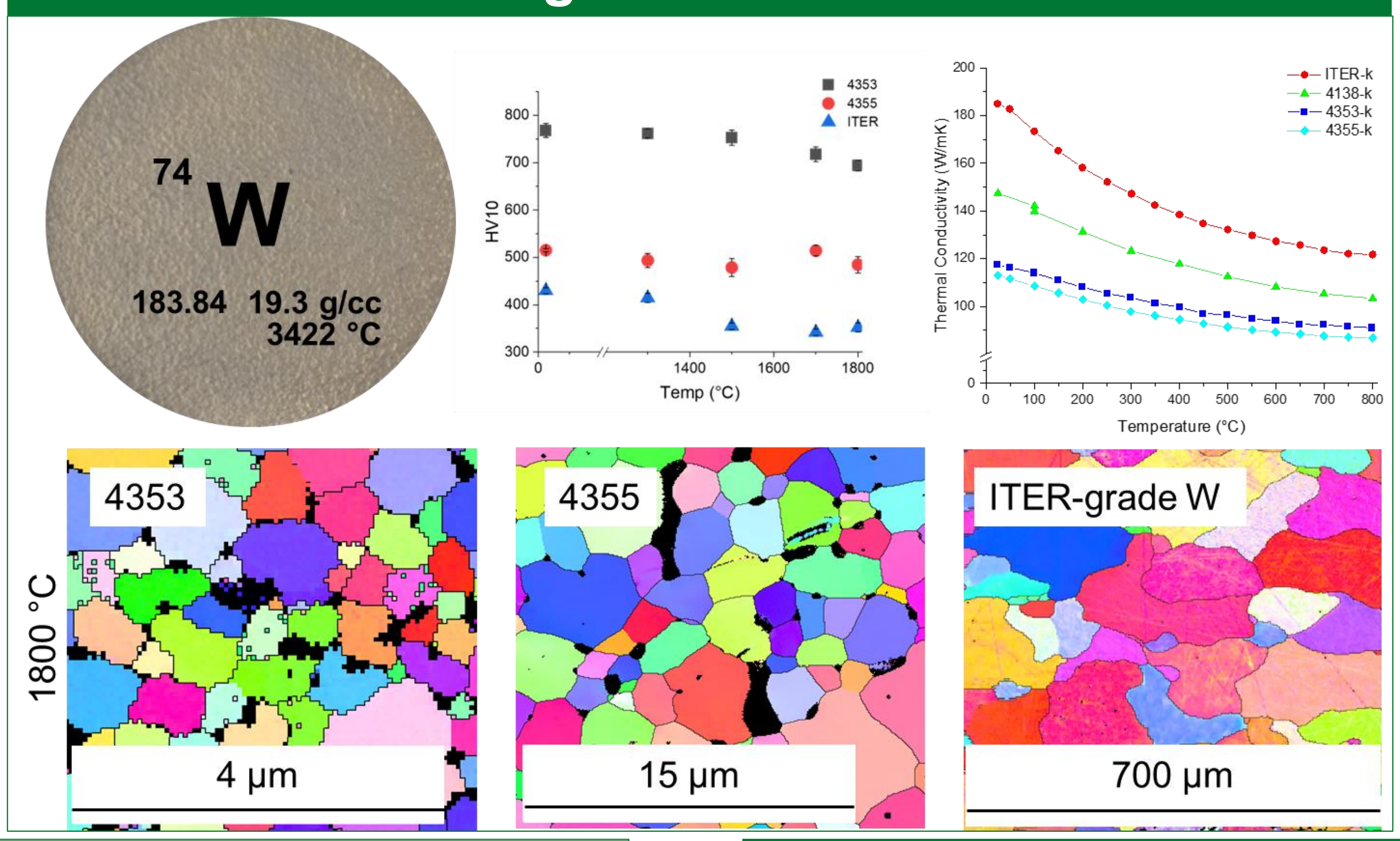
Background

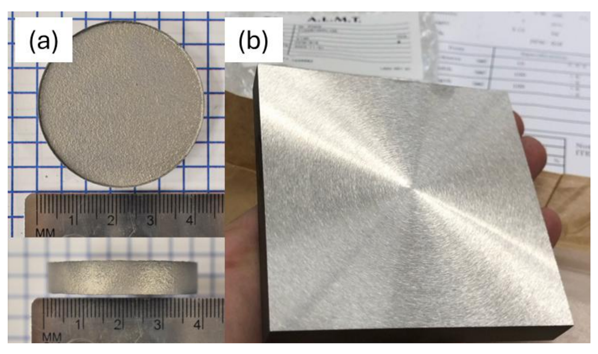
- Tungsten (W) is a promising material as plasma-facing components (PFCs)
- Conventional W suffers from serious drawbacks
- Advanced manufacturing technologies, like FAST, can provide a new solution
- FAST enables precise control over microstructure
- High temperature testing helps understand and validate W properties, performance, and durability of candidate plasma-facing materials (PFMs) in fusion pilot powerplants

Field-Assisted Sintering Technology (FAST) Produces Fine-Grained, Dispersion-Strengthened Tungsten Materials



FAST

- Sintering powdered materials into solid structures
- FAST-produced W: 4138, 4353, and 4355, using differing parameters
- ITER-grade W plate by A.L.M.T. Corp.



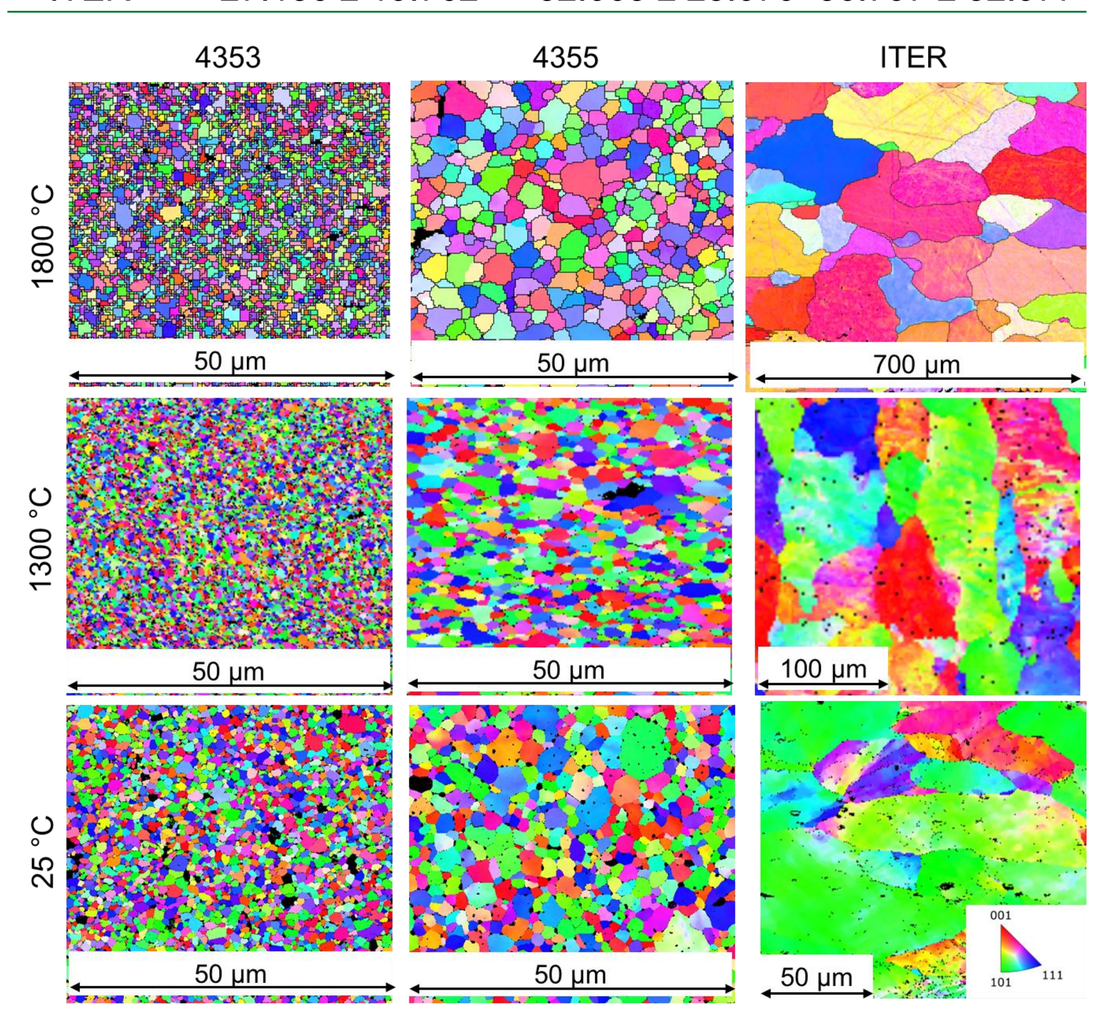
FAST-produced tungsten puck. Rough surface shows surface carbide layer (a). ITER-specification tungsten plate from A.L.M.T. Corp. (b).

Hardness, EBSD, and Grain Size Evaluation Show Sub-Micron Grains and High HV10 Values

- Hardness testing shows 4353 W has the highest HV10 values.
- Hardness values decrease as annealing temperature increased
- EBSD measurements illustrate the grain size differences
- 4353 W has the smallest grain sizes
- Grain size decreases at 1800 °C from 1300 °C, likely a result of grain size variation and inhomogeneity via recrystallization

Average grain size observed at 25 °C, 1300 °C, and 1800 °C for material 4353, 4355, and ITER-grade W

Material	25 °C	1300 °C	1800 °C
4353	0.437 ± 0.196	0.683 ± 0.144	0.372 ± 0.290
4355	3.666 ± 0.894	7.865 ± 0.948	1.16 ± 1.248
ITER	27.136 ± 19.762	32.063 ± 23.070	36.797 ± 52.977



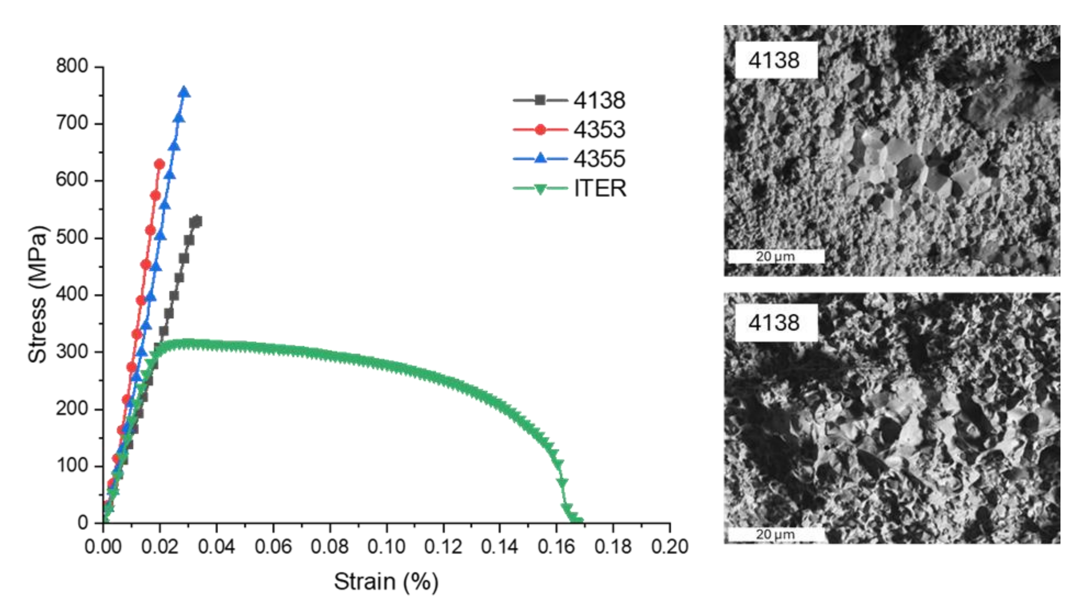
EBSD color maps of materials 4353, 4355, and ITER-grade tungsten as-machined, prior to annealing (25 °C) and after annealing at 1300 °C and 1800 °C, respectively, showing grain size and orientation

Vickers hardness values recorded for materials 4353, 4355, and ITER-grade W at annealed temperature values ranging from 25 – 1800 °C.

Temp	4353	4355	ITER
25	767.9 ± 14.8	515.0 ± 3.2	429.7 ± 6.5
1300	761.8 ± 9.6	493.6 ± 15.0	414.2 ± 9.8
1500	753.1 ± 16.0	478.4 ± 19.0	354.7 ± 6.8
1700	717.9 ± 15.4	514.2 ± 11.2	341.8 ± 6.9
1800	694.0 ± 11.2	484.5 ± 17.0	352.0 ± 9.9

Tensile Testing Evaluates FAST-Produced Tungsten as a Plasma Facing Material

- Elevated temperature tensile testing characterizes the mechanical behavior of the FAST-produced W materials
- Tensile testing did not show elongation or plastic deformation of materials 4138, 4353, or 4355 at 800 °C

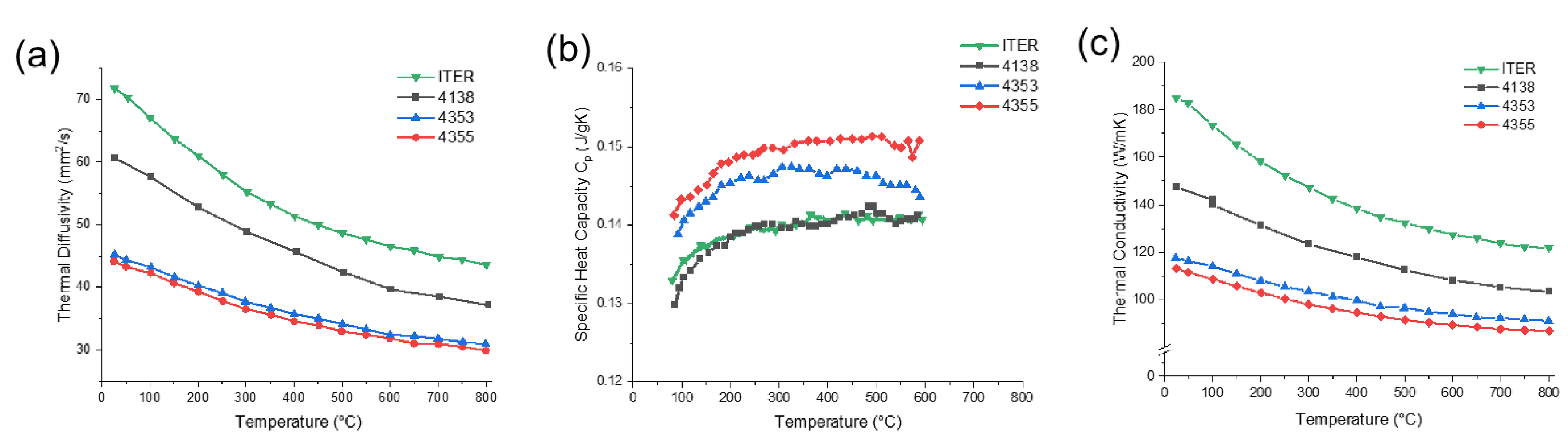


- SEM observes fractures along grain boundaries attributed to inhomogeneous grain sizes

Strain vs. stress curves of materials at 800 °C and SEM of material 4138 tensile sample fracture surface after tensile testing at 800 °C shows the fracture occurred along the grain boundaries.

Thermal Diffusivity Shows Values Similar To Oxide Dispersion Strengthened W Materials

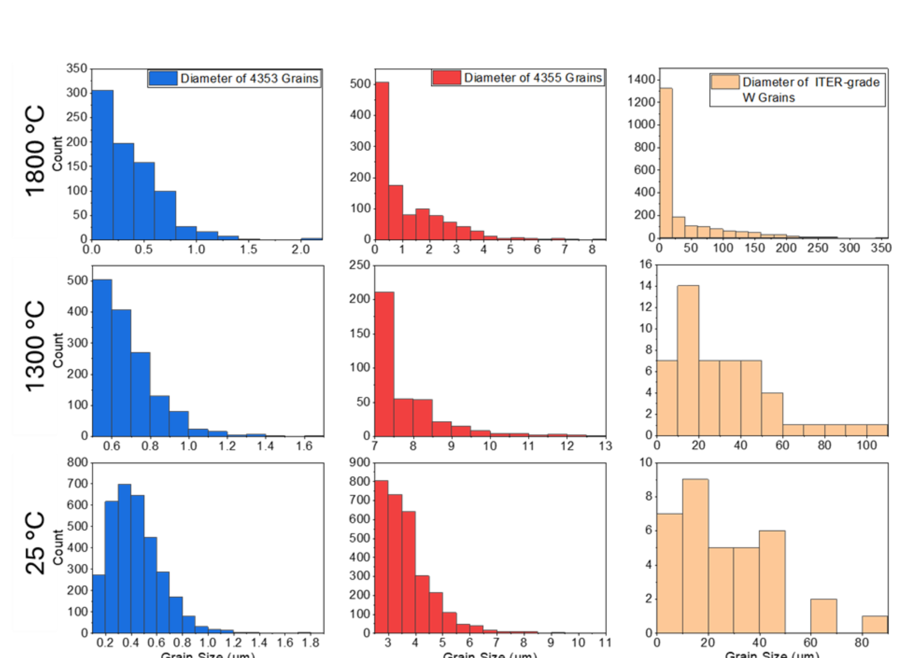
- The ITER-grade W has the highest thermal conductivity
- FAST produced W materials show similar thermal conductivity values to oxide dispersion-strengthened W materials [9,10].
- 4353 and 4355 W exhibit the smallest grains and lowest thermal conductivity



Thermal diffusivity (a), specific heat (b), and thermal conductivity (c) of material 4138, 4353, 4355, and ITER-grade W.

Conclusion

- FAST produces fine-grained, dispersion-strengthened W
- Tensile testing reveals likely oxygen contamination
- Hardness testing shows manufacturing conditions substantially alter hardness
- EBSD shows FAST produced substantially smaller grains than the hot-rolled ITER-grade W material
- FAST offers notable control over grain size



Grain size distribution finds material 4353 to have sub-micron grain values and material 4355 to have sub-10-micron grain size values compared to ITER having approximate 30 µm grain size on average

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Acknowledgement

- The authors would like to thank Thomas Muth, Anthony Guajardo, Stewart Marsh and Dr. Chad Parish for their contributions.
- Sponsored by Innovation Network for Fusion Energy (INFUSE) supported by the U.S. Department of Energy (DOE), Office of Science, Fusion Energy Sciences (FES) program.
- CRADA No. NFE-23-09503

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