Tungsten Alloys

Andrea Bersani

INFN Sezione di Genova
Istituto Nazionale di Fisica Nucleare

Definition of Tungsten alloy

- Source: ASTM specification B777-07
- "Machinable, high-density tungsten base metal produced by consolidating metal powder mixtures, the composition of which is mainly tungsten"
- "For purposes of this specification, non-magnetic material is defined as material having a maximum magnetic permeability of 1.05"
- Classification in 4 classes
- Class 4 is not available in non magnetic form

Class	Tungsten nominal weigth (%)	Density (g/cc)	Hardness (Rockwell)
1	90	16.85-17.25	32
2	92.5	17.15-17.85	33
3	95	17.75-18.35	34
4	97	18.25-18.85	35

Mechanical properties

Class	Ultimate tensile strength		Yield strength at 0.2% offset		Elongation
	ksi	MPa	ksi	MPa	%
1	110	758	75	517	5
2	110	758	75	517	5
3	105	724	75	517	3
4	100	689	75	517	2

- Source: ASTM specification B777-07
- For non-magnetic alloys, ultimate tensile strength is reduced to 94 ksi (648 MPa)
- All data at room temperature
- Machinability is strongly dependent on class
  - number of hole a particular tool can drill is 8, 6, 4 and 2 for classes 1, 2, 3, 4 respectively

Commercially available example

Densalloy™ Grades		SD170	SD175	SD180	SD185	Dens 21	Dens 23	Dens 25	Uniperm 170	Uniperm 175	Uniperm 180
Characteristics		Standard Grades				Non-Magnetic Grades					
Density Classification	MIL-T-21014D	Class 1	Class 2	Class 3	Class 4	Class 1	Class 2	Class 3	Class 1	Class 2	Class 3
	AMS-T-21014	Class 1	Class 2	Class 3	Class 4	Class 1	Class 2	Class 3	Class 1	Class 2	Class 3
	AMS-7725E	Class 1 Type 2	Class 2 Type 2	Class 3 Type 2	Class 4 Type 2	Class 1 Type 1	Class 2 Type 1	Class 3 Type 1	Class 1 Type 1	Class 2 Type 1	Class 3 Type 1
	ASTM B777-15	Class 1	Class 2	Class 3	Class 4	Class 1	Class 2	Class 3	Class 1	Class 2	Class 3
Tensile Properties (typ.)	UTS (ksi)	125	125	125	130	110	110	110	110	110	105
	0.2% OYS (ksi)	83	85	90	95	80	80	80	75	75	75
	EL, min. (%)* @ 1"	5	5	3	2	2	2	1	2	2	1
Mag. Perm.	per ASTM A342	>1.05	>1.05	>1.05	>1.05	~1.01	~1.01	~1.01	~1.00	~1.00	~1.00
Density, nom.	(g/cc)	17.0	17.5	18.0	18.5	17.0	17.5	18.0	17.0	17.5	18.0
	(lb/in^3)	0.61	0.63	0.65	0.67	0.61	0.63	0.65	0.61	0.63	0.65
Hardness, typ.	(HRC)	28	28	29	30	28	28	29	28	28	29
W Content, nom.	(wt. %)	90	92.5	95	97	90	92.5	95	90	92.5	95
Modulus, nom.	($x 10^6$ psi)	50	52	54	56	50	52	54	50	52	54
Binder Elements		Ni + Fe	Ni + Fe	Ni + Fe	Ni + Fe	Ni + Fe	Ni + Fe	Ni + Fe	Ni + Cu	Ni + Cu	Ni + Cu

- From kennametal.com datasheet

Commercially available example

Grade	HA 190	HA 1925	HA 195	HE 390	HE 3925	HE 395	HE 397
Aerospace Industry Standards							
ASTM B777-15	Non-magnetic Class 1	Non-magnetic Class 2	Non-magnetic Class 3	Magnetic Class 1	Magnetic Class 2	Magnetic Class 3	Magnetic Class 4
AMS 7725E	Type 1 Class 1	Type 1 Class 2	Type 1 Class 3	Type 2 Class 1	Type 2 Class 2	Type 2 Class 3	Type 2 Class 4
Typical Properties*							
Nominal % Tungsten	90	92.5	95	90	92.5	95	97
Binder	Ni/Cu	Ni/Cu	Ni/Cu	Ni/Fe	Ni/Fe	Ni/Fe	Ni/Fe
Nominal Density							
g/cm^3	17.1	17.5	17.9	17.1	17.5	18.1	18.5
lb/in^3	0.62	0.63	0.65	0.62	0.63	0.65	0.67
0.2% Proof Stress							
MPa	675	650	680	645	645	660	660
ksi	100	95	100	95	95	95	95
Tensile Strength							
MPa	805	830	805	875	900	910	915
ksi	116	120	116	126	130	131	132
% Elongation on 25mm (1")	7	9	4	25	27	22	12
Hardness, HRC	24	24	24	27	24	24	25

- From wolfmet.com website

Commercially available example

EA Tungsten Alloy Grades	EA17	EA17M	EA17.5	EA17.5M	EA17.7	EA18	EA18M	EA18.5M
W Content, nom. (Wt%)	90	90	92.5	92.5	93	95	95	97
Binder Elements	Ni + Cu or Ni + Fe	Ni + Fe	Ni + Cu or Ni + Fe	Ni + Fe	Ni + Fe +Mo	Ni + Cu or Ni + Fe	Ni + Fe	Ni + Fe
Density Gms/cc	17 nom. (16.85-17.30)	17 nom. (16.85-17.30)	17.5 nom. (17.15-17.85)	17.5 nom. (17.15-17.85)	17.7 nom.	18 nom. (17.75-18.35)	18 nom. (17.75-18.35)	18.5 nom. (18.25-18.85)
Density Lbs./cu in.	0.61	0.61	0.63	0.63	0.64	0.65	0.65	0.67
Ultimate Tensile Strength	94ksi / 648Mpa min.	110ksi / 758Mpa min.	94ksi / 648Mpa min.	110ksi / 758Mpa min.	**Produced**	94ksi / 648Mpa min.	105ksi / 724Mpa min.	100ksi / 689Mpa min.
Yield Strength at 0.2% Offset	75ksi / 517Mpa min.	75ksi / 517Mpa min.	75ksi / 517Mpa min.	75ksi / 517Mpa min.	**to**	75ksi / 517Mpa min.	75ksi / 517Mpa min.	75ksi / 517Mpa min.
Elongation % min.	2% min.	5% min.	2% min.	5% min	**Customer's**	1% min.	3%	2%
Hardness (HRC) max. Unworked (As Sintered or Annealed)	32 max	32 max	33 max	33 max	**Specifications**	34 max	34 max	35 max
Coefficient of Thermal Expansion x 10^-6/◦C	4~6	4~6	4~6	4~6		4~6	4~6	4~6
Magnetic Properties	None	Slight	None	Slight	Slight	None	Slight	Slight
ASTM-B-777-15	Class 1	Class 1	Class 1	Class 2	N/A	Class 3	Class 3	Class 4
AMS-T-21014	Class 1	Class 1	Class 1	Class 2	N/A	Class 3	Class 3	Class 4
MIL-T-21014D	Class 1	Class 1	Class 1	Class 2	N/A	Class 3	Class 3	Class 4
AMS 7725E	Class 1 Type 1	Class 1 Type 2	Class 2 Type 1	Class 2 Type 2	N/A	Class 3 Type 1	Class 3 Type 2	Class 4 Type 2

- From eaglemetals.com website

Other things

- Other potential suppliers
  - Ed Fagan
  - Elmet
  - FB Tecno (in Italy)
  - Tungco
  - Wolfram-industrie
  - Midwets Tungsten Service
  - …
- Data I have not found
  - resilience
  - mech properties at low temperature
  - magnetic permeability is usually not measured accurately
- This material is intended for ballast and radiation screening, at room or high temperatures

Tungsten Molybdenum alloys

- Used mainly for high strength, high temperature and chemically challenging environments
- Up to 90% tungsten (some >17 g/cc)
- Very limited mechanical data
- Possibly too expensive to be worth thinking about

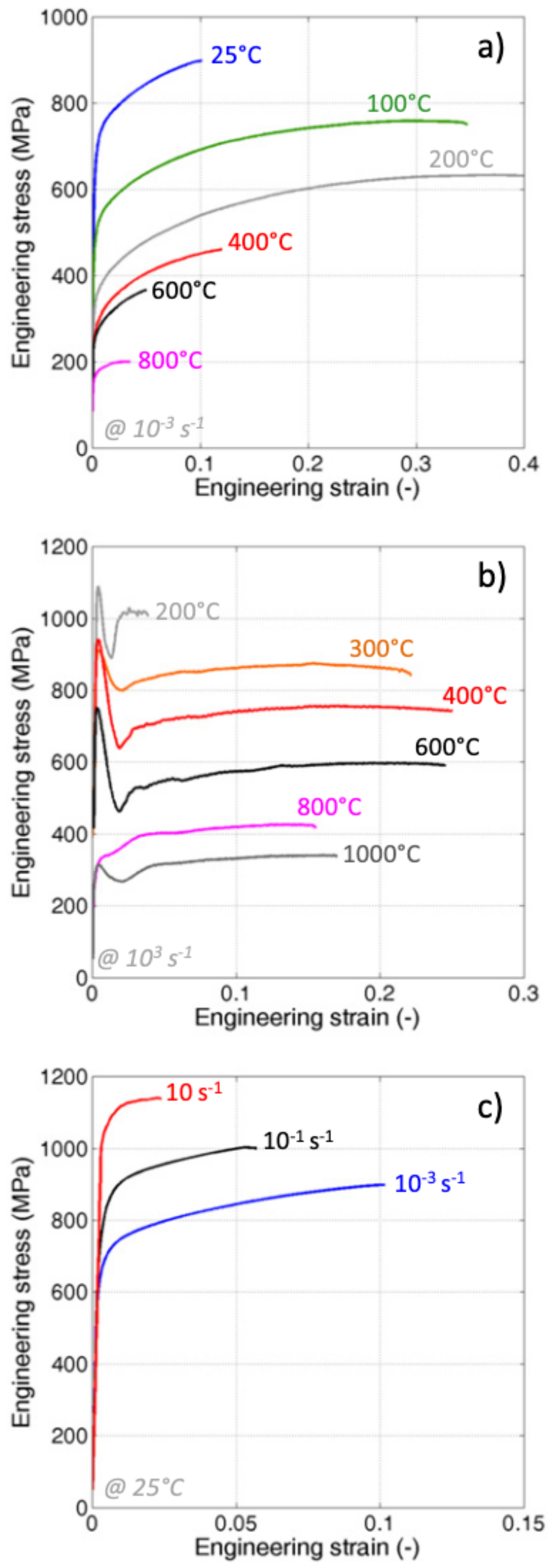


Figure 3. IT180 – Engineering stress vs. strain curves: a) quasi-static loading condition varying the temperature; b) dynamic loading condition varying the temperature and c) tests at room temperature varying the strain-rate.

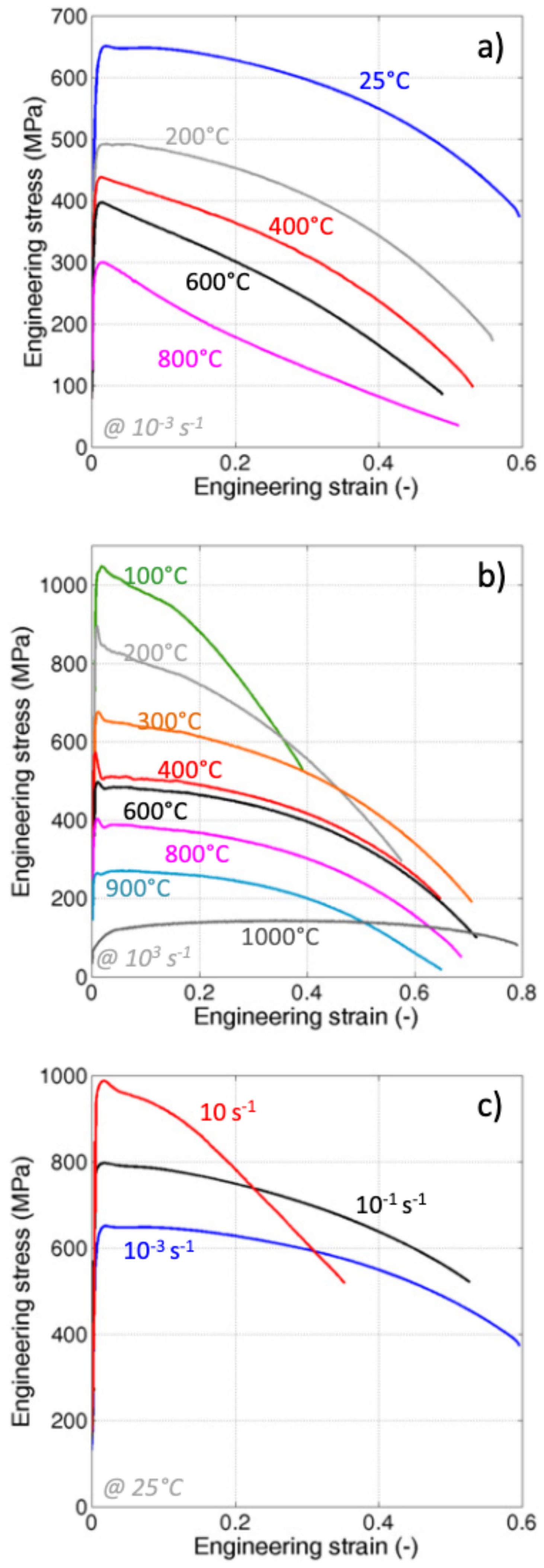


Figure 4. Mo1 – Engineering stress vs. strain curves: a) quasi-static loading condition varying the temperature; b) dynamic loading condition varying the temperature and c) tests at room temperature varying the strain-rate.

Tungsten Lanthanum Vanadium alloys

- Different alloys exist
- Specific gravity above 17 g/cc
- Data available down to 77 K
  - Young's modulus
  - flexure strength
  - fracture toughness
- Commercially available?
- Expensive?
- Machinable?

S280 T. Palacios et al. / Journal of Nuclear Materials 442 (2013) S277–S281

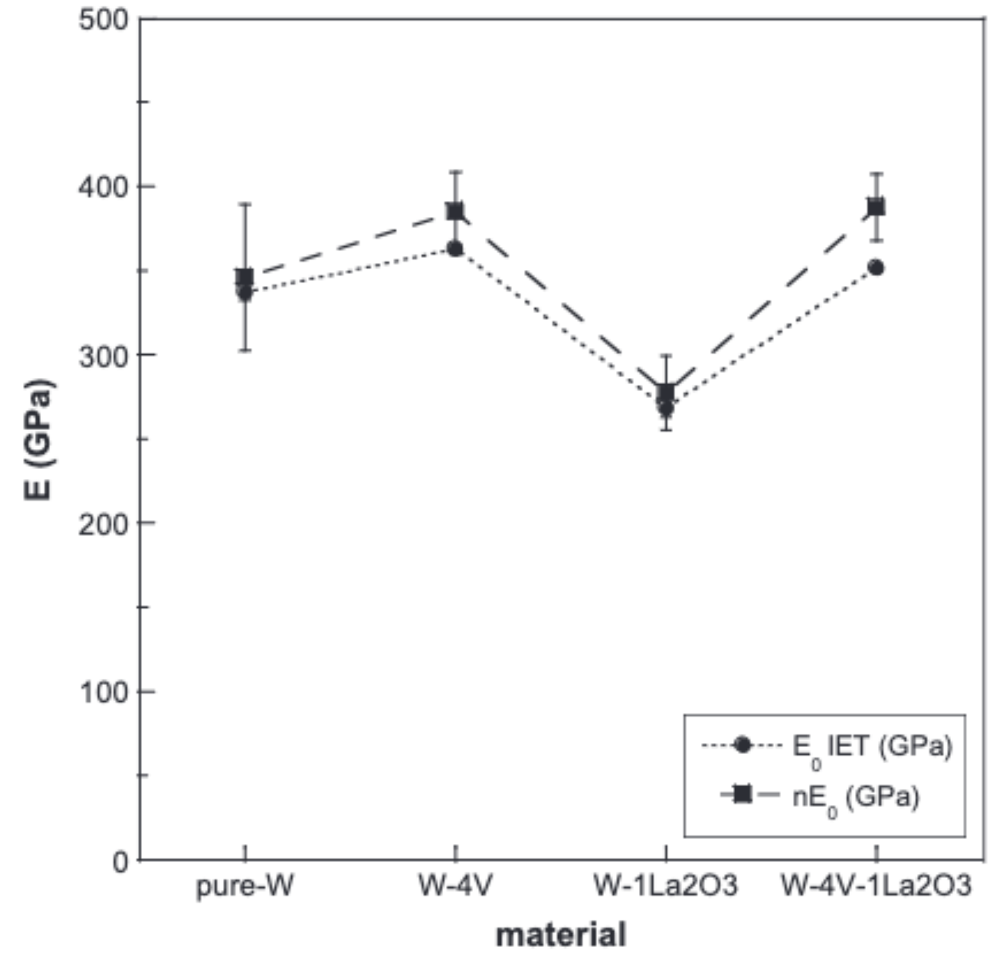


Fig. 5. Average elastic modulus of each material measured by IET and nanoindentation tests.

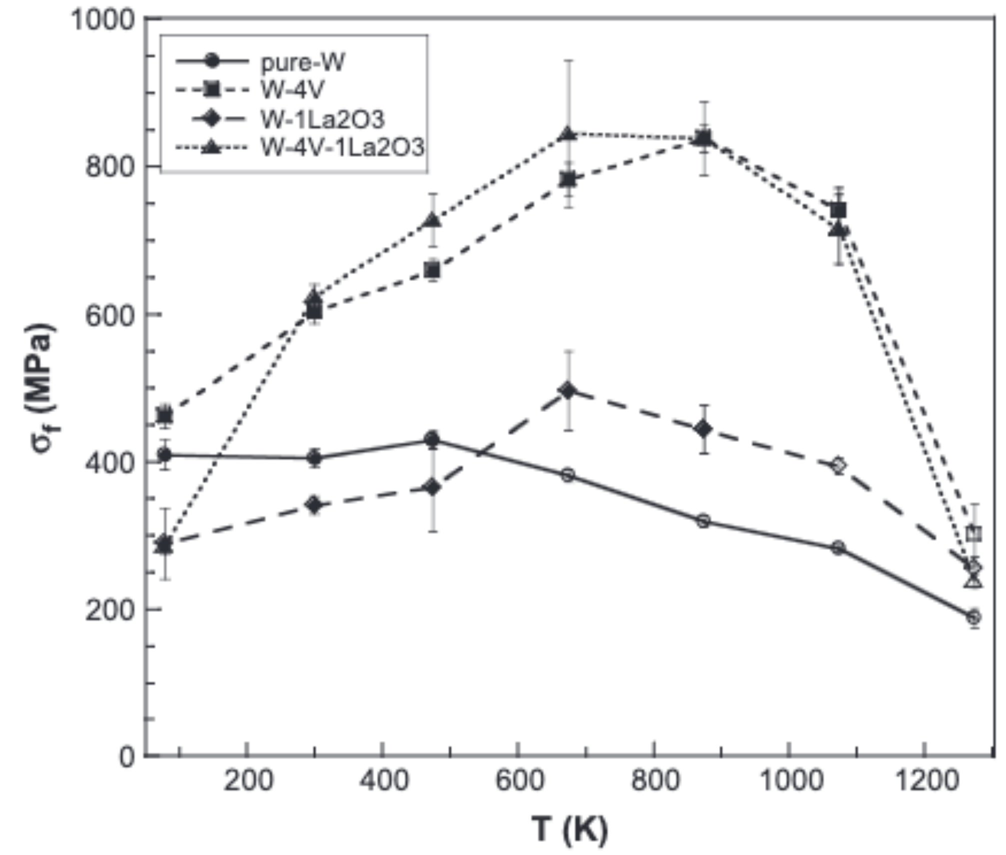


Fig. 7. Average flexure strength versus test temperature of each material. Open symbols represent the yield strength at 0.2%.

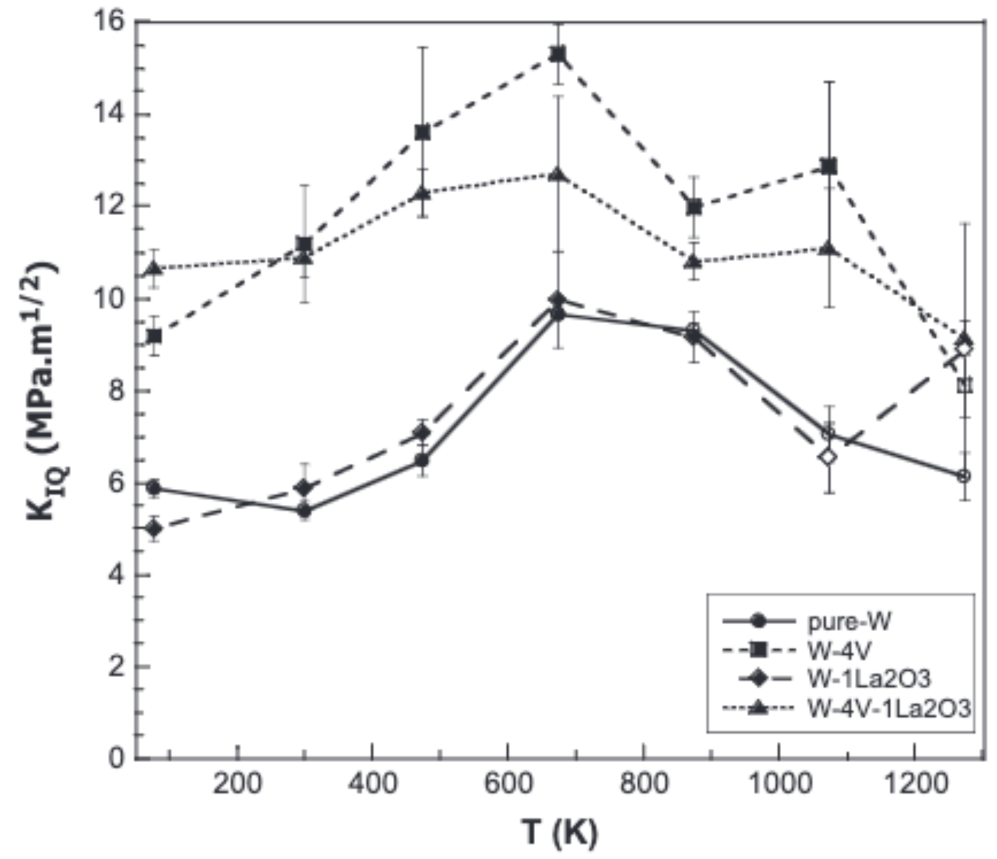


Fig. 6. Average fracture toughness versus test temperature for each material. Open symbols represent the apparent fracture toughness.

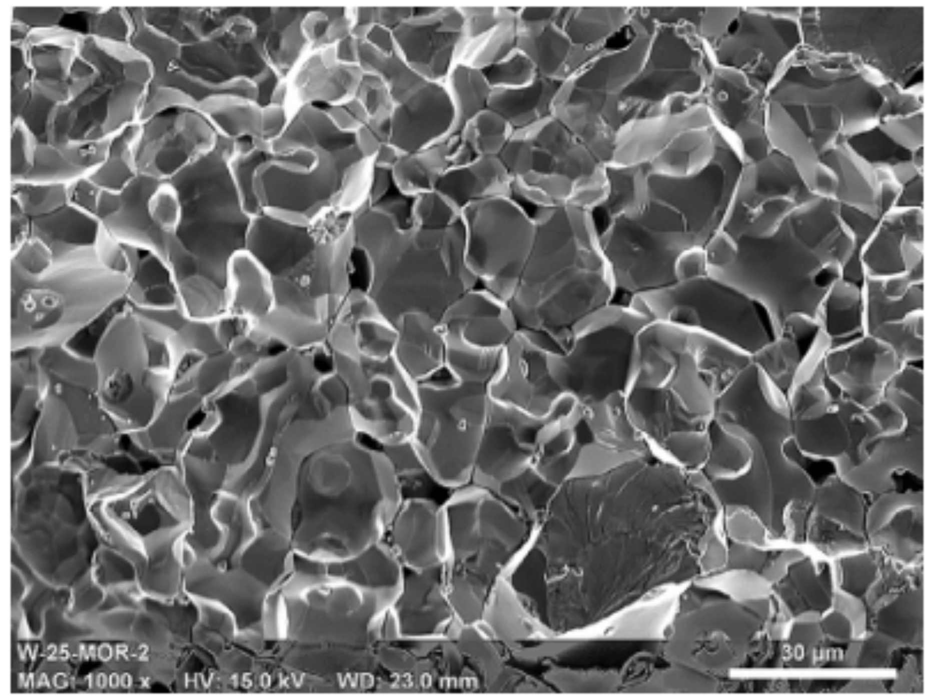
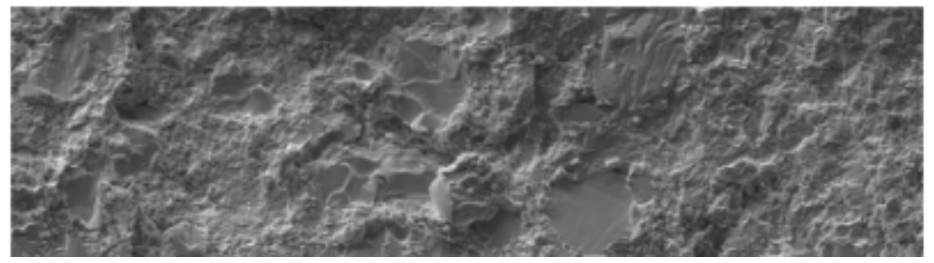


Fig. 8. Fracture surface at 298 K of pure-W.



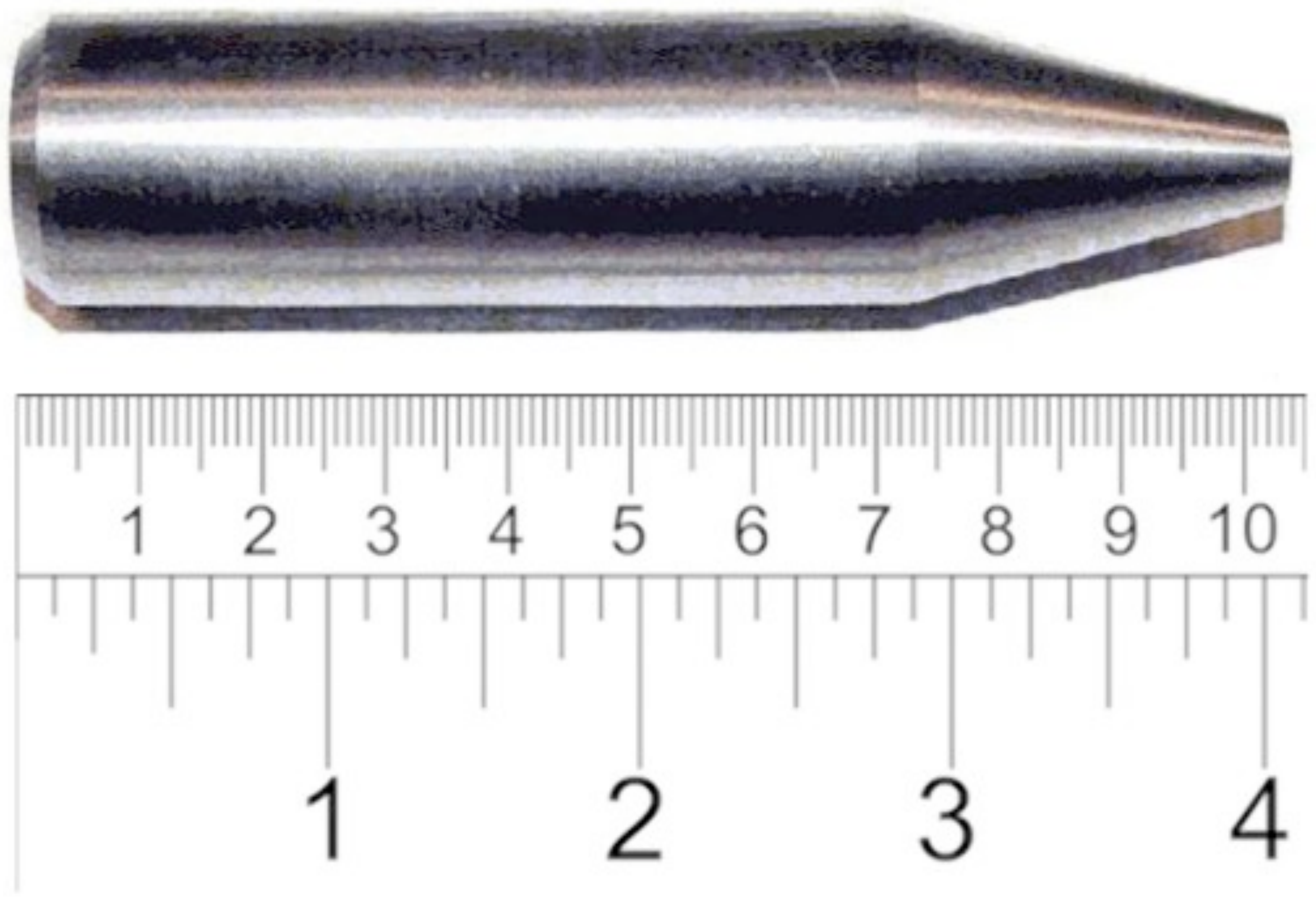
Tungsten Boride

- Good density, 15.3 g/cc
- Boron captures neutrons
- Mainly available as powder
- Expensive, O(100 €/100 g)
- Possibly available as solid bulk
- No mechanical data available
- Relatively new material
- Used mainly as abrasive
- Possibly useful in molten lead?

Tungsten Boride Properties (Theoretical)	
Compound Formula	BW
Molecular Weight	194.65
Appearance	Solid
Melting Point	N/A
Boiling Point	N/A
Density	15.3 g/cm^3
Solubility in H2O	N/A
Exact Mass	194.960238
Monoisotopic Mass	194.960205 Da

Depleted Uranium

- Very high specific gravity (19 g/cc)
- Mechanical data are available down to -40º C at least
  - not this good, possibly
  - thermal expansion similar to Nickel (in between Iron and Copper)
  - Young's modulus ~200 GPa
  - tensile strength at room temperature ~400 MPa
  - yield strength at room temperature ~200 MPa
- Good machinability
- "Widely available" (hundreds thousands tons in Western Europe)
- Used in ZEUS calorimeter at HERA
- Can be used as "pure" metal
- "Mildly" radioactive
- Slightly paramagnetic (μ ~ 1.000002)



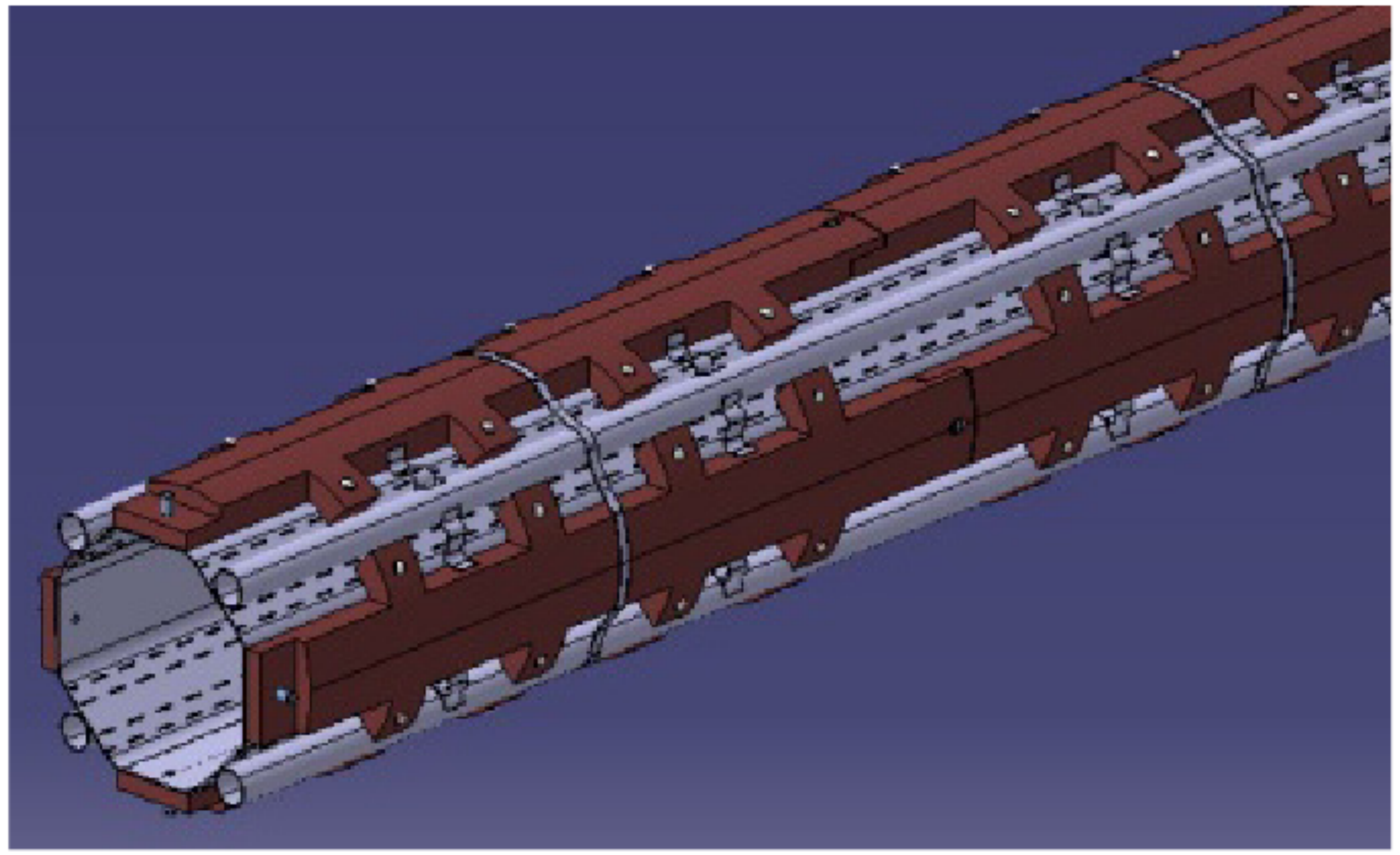
HL-LHC Beam Screen

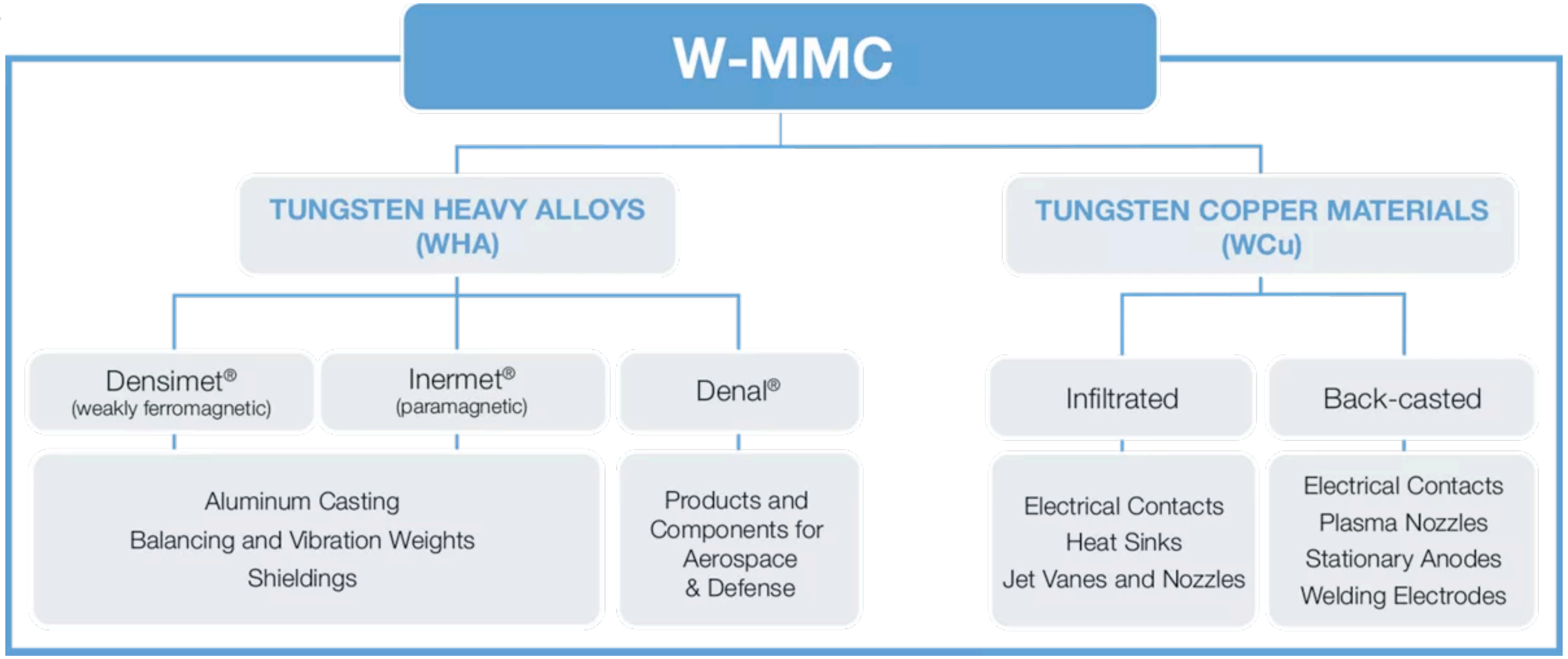
- For final focusing magnets composite beam screen are foreseen in HL-LHC
- INERMET 180 tungsten alloy is foreseen
- 18 km/dm3 density, paramagnetic, provided by Plansee (Italian company)

6th International Particle Accelerator Conference IPAC2015, Richmond, VA, USA JACoW Publishing
ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-MOBD1

PRELIMINARY DESIGN OF THE HIGH-LUMINOSITY LHC BEAM SCREEN WITH SHIELDING*

V. Baglin, C. Garion, R. Kersevan, CERN, Geneva, Switzerland





Conclusions

- I am not sure on which could be the best alloy to use
- WHA are the first choice, with some unknown on mechanical properties at low temperatures
- Some experience is anyhow available at CERN
- Other W alloys are nice, but with even less data available and it is not obvious if they can be purchased in solid bulk
- Depleted U is… depleted U

Links

- https://www.agescaninternational.com/images/ASTM_B777-07_%20Specs%20for%20Tungsten%20Based%20High-Density%20Metal%20(1).pdf
- https://www.kennametal.com/us/en/products/Metal-Powders-Materials-Consumables/tungsten-powders.html
- https://www.wolfmet.com/wp-content/uploads/2017/01/Wolfmet-Aerospace-brochure-NEW-version9_HR-.pdf
- https://www.eaglealloys.com/wp-content/uploads/2017/05/EA-Tungsten-Alloy-Data-Sheet.pdf
- https://cds.cern.ch/record/2155651/files/CERN-ACC-2015-0212.pdf
- https://www.sciencedirect.com/science/article/pii/S0022311513004121
- https://www.americanelements.com/tungsten-boride-12007-09-9
- https://inis.iaea.org/collection/NCLCollectionStore/_Public/14/760/14760887.pdf
- https://digital.library.unt.edu/ark:/67531/metadc1113266/m2/1/high_res_d/6087232.pdf
- https://www.sciencedirect.com/science/article/abs/pii/0168900287909521
- https://www.govinfo.gov/content/pkg/GOVPUB-C13-0db7cc6eaefa48f82095c56b41cabfc0/pdf/GOVPUB-C13-0db7cc6eaefa48f82095c56b41cabfc0.pdf
- https://accelconf.web.cern.ch/IPAC2015/papers/mobd1.pdf
- https://www.plansee.com/en/materials/w-mmc.html