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ITER Materials R&D Data Bank

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Abstract

To keep traceability of many valuable raw data that were experimentally obtained in the ITER Technology R&D Tasks related to materials for In-Vessel Components, and to easily make the best use of these data in design activities, the 'ITER Materials R&D Data Bank' has been built up, with the use of Excel™ spread sheets. Compared with existing material data banks, this data bank is unique in the following respects: (1) In addition to thermo-mechanical properties of single materials (beryllium, tungsten, carbon-based materials, copper alloys and stainless steels), thermo-mechanical properties (including neutron irradiation effects) for various kinds of joints between these materials, and the results of thermal fatigue tests of mock-ups are collected. (2) As for plasma facing materials (beryllium, tungsten and carbon), experimental data on plasma–material interactions such as sputtering, disruption erosion, and hydrogen-isotope trapping and release are collected.

1. Introduction

The 'ITER Materials R&D Data Bank' has been built up in order to keep traceability of many valuable raw data that have been experimentally obtained in the ITER Technology R&D Tasks related to materials for In-Vessel Components (divertor, primary wall, limiter, first wall, vacuum vessel, blanket, etc.), and to easily make the best use of these data in design activities such as (1) determination of operating window for each material, (2) selection of appropriate materials or grades for each component, and (3) numerical analysis of component design to evaluate its lifetime and performance limits, etc.

This data bank is unique compared with existing material data banks (including the Material Properties Handbook (MPH) compiled at ITER San Diego Joint Work Site), in the following respects:

1. In addition to thermo-mechanical properties including neutron irradiation effects of single materials similarly to the MPH, the experimental data for joining technologies and thermal fatigue tests of mock-ups fabricated using the developed joining technologies are included.
2. As for plasma facing materials (PFM), experimental data related to plasma–wall interactions such as sputtering, disruption erosion, and hydrogen-isotope trapping and release are included.
3. To support the engineering design, experimental data of hydraulics for various kinds of turbulence enhancers are also included.

The paper describes the Test Reporting Form (element of this data bank) and then the present status of experimental data collected in the data bank, and finally the summary.

2. Test Reporting Form

At the lowest branch of classification in the data bank structure, the Test Reporting Form (TR Form), which contains the real experimental information, can be found. The TR Form is an Excel™ (a software for personal computer) spread sheet, that is, this data bank is electronically written and can be used. In the TR Form, detailed information on data bank administration, test conditions, test results, specimen form and dimension, pre-test irradiation (if any), material production and chemical composition are provided.

In order to fit various kinds of tests/measurements in the ITER Technology R&D Tasks related to materials, different types of blank TR Forms are prepared.

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Table 1
Status of collected data on thermo-mechanical properties of plasma facing materials

Properties	Be	C		W	
		CFC	Graphite	W	W alloy
Thermal conductivity	**-unirrad.** S-200-F	**-unirrad.** CX2002U, MFC-1, NIC-01, NIC-02, U301, SEP N112, SEP N312A,B,C, SEP NS31, SEP NS11, Dunlop P-120 concept 1,2,3, LCL A05, FMI 1D, FMI 222, Hercules 3D	**-unirrad.** RGTi, H451	**-unirrad.** CVD-W	**-unirrad.** W–30Cu, W–Cu compo.
	-n-irrad. S-200-F	**-n-irrad.** CX2002U, MFC-1, SEP N112, LCL A05, FMI 1D, FMI 4D, FMI 222, DMS 678, Hercules 3D, UAM	**-n-irrad.** Pyro, S1611, 5890, S1260, RGTi, H451		
Tensile properties	**-unirrad.** S-65C VHP, S-65C HIP, S-200 VHP, S-200 HIP, S-200-F, DShG-200, TShG-56, HIPed H.P.Be **-n-irrad.** S-65C VHP, S-65C HIP, S-200 VHP, S-200 HIP, S-200-F, HIPed H.P.Be	**-unirrad.** CX2002U, SEP NS31			**-unirrad.** W–1% La_2O_3, W5Re, W–30Cu
Shear strength (Bend. streng.)	**-unirrad.** S-65C, B-26D	**-unirrad.** CX2002U, MFC-1, V1325, SEP N112, SEP A14, DMS 678	**-unirrad.** CL2508	**-unirrad.** P/M W, CVD-W	
	-n-irrad. S-65C, B-26D	**-n-irrad.** CX2002U, V1325, SEP N112, SEP A14, DMS 678	**-n-irrad.** CL2508		
Hardness	**-unirrad.** S-65C **-n-irrad.** S-65C				**-unirrad.** W–30Cu
Swelling (dimensional change)	S-65C, B-26D, S-200-FSP-200-F,HIPed H.P.Be	CX2002U, LCL A05, LCL A21 Novol-Tex, SEP N11, SEP N112, DMS 678, FMI A27-130	S1260, S5890	W	W–25Re
Physical prop. (density, spec. heat, CTE, elast. modul., etc.)	**-unirrad.** S-200-F	**-unirrad.** CX2002U, MFC-1, NIC-01, U-301, V1325, LCL A05, SEP NS31, DMS 678, SEP N312B, SEP N112, SEP A14	**-unirrad.** CL2508	**-unirrad.** P/M W, CVD-W	**-unirrad.** W–30Cu
	-n-irrad. S-200-F	**-n-irrad.** CX2002U, V1325, LCL A05, DMS 678, SEP N112, SEP A14	**-n-irrad.** S1260, CL2580		

3. Status of data collected in the data bank

3.1. Plasma facing materials

3.1.1. Beryllium (Be)

The available properties data on Be are listed in Tables 1 and 2. They contain not only thermo-mechanical properties, but also plasma–material interactions (PMI) data experimentally obtained in the ITER EDA.

3.1.2. Carbon-based material (CBM)

Many experimental data on CBM are stored in the data bank. As shown in Tables 1 and 2, CBM data in-

Table 2
Status of collected data on plasma–material interactions of plasma facing materials

Properties	Be	C		W
		CFC	Graphite	
Sputtering	Be^+ on Be (0–85°, 600–10 000 eV, RT–800°C) D^+, He^+ on Be (0°, 20–200 eV, RT) D^+ on Be (0°, 20–3000 eV, RT, 650°C) D plasma on Be and C poisoned Be	H^+ on B_4C/CFC (0°, 50 eV, 200°C)	H^+, D^+, He^+ on Pyro. (0°, 20–8000 eV, RT $\sim$ 727°C) D+ on RGTi (0°, 30–1000 eV, RT) D^+ on C/SiC (0°, 30–300 eV, RT) D^+ on USB15 (0°, 10–1000 eV, RT $\sim$ 527°C) O on graphite (0°, 1.55–10 000 eV, RT) H plasma on RGTi, POCO	D plasma on W
Disruption erosion (Simulative exp.)	**-by elec. beam**	**-by plasma gun**	**-by plasma gun**	**-by elec. beam**
	S-65C, TGP-56, TShG-200, TR-30, Baikov	UAM, MFC **-by elec. beam** SEP N112, LCL A05, UAM, B_4C coat	EK-98, RGTi, POCO, USB-15 **-by elec. beam** EK-98, RGTi, 5890PT, 1611PT **-by laser** EK-98, CL5890, POCO	MC-W, PS-W, CVD-W
Retention	**-unirrad.** S-65B, TIP-30, NGK (D_2^+ ion) Be (D^+ ion) TPG (H plasma) S-65 (T, D plasma) TIP-30 (D atom charge) TShG-56 (D_2 gas charge) Be (D co-deposit.) **-n-irrad.** S-65, S-200E, S-200FH, B-26 (T_2 gas charge)	**-unirrad.** LCL A05, SEP N112 (T_2 gas charge) **-n-irrad.** LCL A05 (T_2 gas charge)	**-unirrad.** Pyro (1.5 keV D^+ ion) RGTi, POCO (D plasma) RGTi, POCO (H_2, D_2 gas charge) Pyro, CL2239, CL5890, S1611, CLX, RGTi,POCO, C dust (T_2 gas charge) ETP-10 (H atom charge) Carbon (D co-deposit.) **-n-irrad.** Pyro, CL5890, S1611 (T_2 gas charge) **-C^+ irrad.** RGTi, USB, PGI, HOPG (D_2 gas charge)	
Permeation/ Diffusion	H in TPG, D in TShG-56			D in W

clude the data before and during the ITER EDA. Data on the degradation in thermal conductivity of CFCs as well as graphites due to neutron irradiation are also available.

Table 3
Status of collected data on thermo-mechanical properties of structural materials

Properties	Cu		SS
	Cu	Cu alloy	
Thermal conductivity		**-unirrad.** Glidcop Al-25, Glidcop Al-15, Glidcop Al-20, Glidcop Al-60, MAGT-0.2, CuCrZr, Cu–Mo, CuCrZrMg, YZC, MZC **-n-irrad.** Glidcop Al-25, Glidcop Al-20, Glidcop Al-60, MAGT-0.2, CuCrZr, CuCrZrMg, MZC, Cu–Mo	
Tensile properties	**-unirrad.** OFHC Cu **-n-irrad.** OFHC Cu	**-unirrad.** Glidcop Al-25, Glidcop Al-15, MAGT-0.2, MAGT-0.05, CuCrZr, CuNiBe, CuCrNiSi, Cu–2Be, Cu–Mo, Cu–Be, YZC, C08, ODS III **-n-irrad.** Glidcop Al-25, Glidcop Al-15, MAGT-0.2, MAGT-0.05, CuCrZr, CuNiBe, CuCrNiSi, Cu–2Be, Cu–Mo, Cu–Be	**-unirrad.** 316-SS(US), 316LN-IG(Cast/HIP)(US), SS316LN-PM130(EU), SS316LN-T5091(EU), SS316L(JA), 316LN-IG(RF), (ref, p.HIP, s.HIP) **-n-irrad.** 316-SS(US), 316LN-ERH, 316LN-ERH II-TIG deposit
Fracture toughness		**-unirrad.** Glidcop Al-25, Glidcop Al-15, MAGT-0.2, CuCrZr, CuCr1Zr, CuNiCrSi, CuNiBe **-n-irrad.** Glidcop Al-15	**-unirrad.** 316-LN, 316F, JPCA, 316LN-ERH II-TIG deposit **-n-irrad.** 316-LN, 316F, JPCA, 316LN-ERH II-TIG deposit
Crack propagation		**-unirrad.** Glidcop Al-25	
Impact		**-unirrad.** Glidcop Al-25, Glidcop Al-15	**-unirrad.** SS316L
Hardness	**-unirrad** OFHC Cu	**-unirrad.** Glidcop Al-15, YZC	
Fatigue		**-unirrad.** Glidcop Al-25, Glidcop Al-15, CuCrZr, CuNiBe	**-unirrad.** SS316L, SS316, 316LN-ERH II
Thermal creep		**-unirrad.** Glidcop Al-25, MAGT-0.2, CuCrZr, CuCr1Zr **-n-irrad.** MAGT-0.2	
Swelling	OFHC Cu	Glidcop Al-25, Glidcop Al-20, Glidcop Al-60, MAGT-0.2, CuCrZr, CuCrZrMg, CuNiBe, Cu–Mo	
Physical Prop. (spec. heat, CTE etc.)	**-unirrad.** OFHC Cu	**-unirrad.** Glidcop Al-25, Glidcop Al-15, CuCrZr, YZC	
Corrosion	Cu/water		

3.1.3. Tungsten

The experimental thermo-mechanical and PMI data on W are very limited, since it became a candidate in the late phase of ITER EDA. All available data on W are listed in Tables 1 and 2.

3.2. Structural materials

3.2.1. Stainless steel

Since sufficient data on unirradiated and neutron irradiated conventional stainless steels (SS) already exist in each Home Team, only data on mechanical properties shown in Table 3 of SS equivalent or close to SS316LN-IG (ITER Grade) are included in the data bank.

3.2.2. Copper alloys

During the ITER EDA, many thermo-mechanical properties of copper alloys were obtained through the ITER Technology R&D Tasks. The available data on Cu alloys are listed in Table 3.

3.3. Joining technologies

3.3.1. Joints between plasma facing materials and Cu alloys

The status of experimental data for various kinds of joints between PFM and copper alloys collected in the data bank is summarized in Table 4. Data for CFC/Cu alloy joints are limited to Ag and Ag-free brazing methods, and data on shear strength and bending strength are available. Up to now, only a few data are collected for W/Cu alloy joints.

3.3.2. Joints between structural materials

The status of experimental data for various kinds of joints between structural materials collected in the data bank is summarized in Table 5. Intensive R&D work to develop Cu alloy/SS joining technology for ITER has been conducted in the past years.

Table 4
Status of collected data on thermo-mechanical properties of joints between plasma facing materials and copper alloys or copper

Properties	Be/Cu		CFC/Cu		W/Cu
Tensile properties	Be/Al-15	by Ag braze			W/Cu by Ag free braze
	Be/CuCrZr	by HIP			(unirrad, **n-irrad**)
	Be/CuCrZr	by Diff. bond			W/Cu alloy by CVD
	Be/CuCrZr	by Ag free braze			
	Be/CuCrZr	by Ag braze			
	Be/CuCrZr	by Joint rolling			
	Be/CuNiBe	by HIP			
	Be/Cu	by HIP			
	Be/Cu	by Diff. bond			
	Be/Cu	by Electroplate			
	Be/Cu	by Explo.			
	Be/Cu	by Frict. weld.			
	Be/Cu	by Joint rolling			
	Be/Cu	by B-W meth.			
	Be/Cu	by Ag brazing			
Shear strength	Be/Al-60	by Diff. bond	CFC/Al-25	by Ag free braze	W-1% La_2O_3/Al-25
	Be/DSCu	by HIP	CFC/Al-15	by Ag braze	by HIP
	Be/CuCrZr	by HIP			
	Be/CuCrZr	by Diff. bond	CFC/CuCrZr	by Ag free braze	W-1% La_2O_3/Cu
	Be/CuCrZr	by Ag free braze	CFC/W-Cu	by Ag braze	by HIP
	Be/CuCrZr	by Joint rolling			
	Be/Cu	by HIP	CFC/Cu	by Ag free braze	
	Be/Cu	by Diff. bond	CFC/Cu	by Ag braze	
	Be/Cu	by Explo.			
	Be/Cu	by Joint rolling			
	Be/Cu	by Ag braze			
Bending strength	Be/Al-15	by Ag braze	CFC/DSCu	by Ag braze	
	Be/CuCrZr	by Ag braze	CFC/W-Cu	by Ag braze	
	Be/Cu	by Ag braze	CFC/Cu	by Ag braze	

Table 5
Status of collected data on thermo-mechanical properties of joints between structural materials

Properties	Cu/SS		Cu/Cu		SS/SS
Tensile properties	Al-25/SS316LN IG (unirrad, **n-irrad**)	by HIP	Al-25/Al-25	by HIP	316LN-PM130/316LN-PM130 by HIP
			CuNiBe/CuNiBe	by HIP	
	Al-25/SS316L	by HIP			316LN IG/316LN IG by HIP
	Al-25/316LNSS	by HIP			SS316L/SS316L by HIP
	(unirrad, **n-irrad**)				316LN-T5091/316LN-T5091 by HIP
	Al-25/SS316LN (unirrad, **n-irrad**)	by Frict. weld			
	Al-15/SS316LN IG	by HIP			
	Al-15/SS316L	by HIP			
	Al-15/316LNSS (unirrad, **n-irrad**)	by Explo.			
	MAGT-0.2/316LN (unirrad, **n-irrad**)	by HIP			
	CuCrZr/SS316LN (unirrad, **n-irrad**)	by HIP			
	CuCrZr/SS316LN IG	by pHIP			
	CuCrZr/SS316 (unirrad, **n-irrad**)	by Frict. weld			
	CuCr1Zr/316LN IG	by Explo.			
	CuNiBe/316LNSS	by HIP			
	CuCrNiSi/316LN (unirrad, **n-irrad**)	by HIP			
Shear strength	Al-25/316LNSS	by sol. HIP			
	Al-25/316LNSS	by pow. HIP			
	Al-25/316LNIG	by HIP			
	Al-15/316LNSS	by sol. HIP			
	Al-15/316LNSS	by Explo.			
	CuCrZr/316LNIG	by HIP			
	CuCr1Zr/316LNIG	by Explo.			
	CuNiBe/316LNSS	by sol. HIP			
Bend.str.			Al-25/Al-25	by HIP	SS316L/SS316L by HIP
Impact	Al-25/SS316L	by HIP	Al-25/Al-25	by HIP	SS316L/SS316L by HIP
Tension-compres. fatigue	Al-15/SS316L	by HIP			SS316L/SS316L by HIP
	Al-25/SS316LN IG	by HIP			316LN/316LN by HIP
	Al-25/SS316L	by HIP			316LN-ERH/316LN-ERH by HIP
	Al-25 with SS tube/SS316L	by HIP			
	Al-15/SS316LN IG	by HIP			
	Al-15/SS316L	by HIP			
	CuCrZr/SS316LN IG	by HIP			
	CuCrZr/SS316LN IG	by pHIP			
	CuCr1Zr/316LN IG	by Explo.			
Tor. fatigue	CuCrZr/SS316	by Frict. weld.			

Table 5 (Continued)

Properties	Cu/SS		Cu/Cu		SS/SS
Bending fatigue	Al-25/SS316L	by HIP	Cu/Cu	by HIP	
	Al-25/316LNSS	by sol. HIP	Cu/Cu	by Explo.	
	Al-25/316LNSS	by pow. HIP			
	Al-15/316LNSS	by HIP			
	Al-15/316LNSS	by Explo.			
	CuNiBe/316LNSS	by sol. HIP			
Creep	CuCr1Zr/316LN IG	by Explo.			
Fracture toughness	Al-25/SS316LN IG	by HIP			
	Al-25/316LN SS	by sol. HIP			
	Al-25/316LN SS	by pow. HIP			
	CuCr1Zr/SS316LN IG	by HIP			
	CuNiBe/316LN SS	by sol. HIP			
Crack prop.	Al-25/SS316L	by HIP			

3.3.3. Thermal bond layer

As for thermal bond layer, data on drawability and wettability of rheocast alloys (Pb–Cu, Al–Ge), tensile properties of Al–Ge, and results of a concept feasibility test using Pb are collected in the data bank.

3.3.4. Coating technology

Data on Be coating technology are predominantly obtained from the plasma spray Be experiment at Los Alamos National Laboratory in US. Recently, data on W coating by plasma spray and CVD methods have also become available in the data bank.

3.4. Thermal fatigue test of integrated mock-ups

As the progress in the technology for joining PFM and Cu alloys, the power handling capability of mock-ups, which simulate the heat removal structure of divertor or primary wall for ITER, has increased year by year. Thermal fatigue tests are conducted in such a way that mock-up(s) cooled with water flowing through channel(s) is (are) heated repeatedly from one side by a heat source (electron beam, ion beam or lamps) at a constant heat flux and a fixed heat loading time (longer than thermal equilibrium time of the mock-up) and a fixed dwelling time, until the planned number of cycles is reached or any failure occurs prematurely.

The Data Bank provides the results of thermal fatigue tests for Be/Cu, CFC/Cu and W/Cu mock-ups in three main parameters of thermal fatigue tests: (1) the incident or absorbed heat flux (in MW/m^2), (2) the heat loading time (in s) for each cycle and (3) number of attained cycles without any failure on the mock-up.

Although hydraulics is not directly related to material properties, experimental data on critical heat flux (CHF) and pressure drop for various kinds of turbulence enhancers (swirl tubes, screw tubes, finned tubes and Hypervaportron, etc.) are collected in the data bank.

4. Summary

The ITER Materials R&D Data Bank, a collection of the materials data on In-Vessel Components obtained in the ITER Technology R&D Tasks, has been established, as one of the ITER JCT activities. This Data Bank covers thermo-mechanical properties of plasma facing materials (PFM: Be, CBM and W), structural materials (SS and Cu alloys), PFM/Cu alloy joints and joints of structural materials together with plasma–material interactions on PFM. Data Bank also includes data on in situ repair techniques, thermal fatigue of mock-ups, and CHF and pressure drops for various kinds of turbulence enhancers. Established Data Bank is a useful tool for a comparative assessment of R&D results of materials for a selection of the In-Vessel Components. A CD-ROM of the Data Bank will be published as a supplement of the Materials Assessment Report in near future.

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