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Materials challenges for ITER – Current status and future activities

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Abstract

ITER will be the first experimental fusion facility, which brings together the key physical, material and technological issues related to development of fusion reactors. The design of ITER is complete and the construction will start soon. This paper discusses the main directions of the project oriented materials activity and main challenges related to selection of materials for the ITER components. For each application in ITER the main materials issues were identified and these issues were addressed in the dedicated ITER R&D program. The justification of materials performance was fully documented, which allows traceability and reliability of design data. Several examples are given to illustrate the main achievements and recommendations from the recently updated ITER Materials Properties Handbook. The main ongoing and future materials activities are described.

1. Introduction

ITER will be the first experiment to bring together the physics, materials and the key technologies of an operating fusion-power-generating reactor. The ITER project is now moving towards the construction phase. After selection of the construction site, Cadarache, France, extensive negotiations between the Participating Parties (the European Union, Japan, the Russian Federation, the United States of America, the Republic of Korea, People's Republic of China and India) are ongoing with the

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main goal to finalise an international agreement establishing the International Fusion Energy Organisation (ITER). The ITER will be responsible for the construction and operation of the ITER reactor and will be established in 2007.

The overall ITER design is complete to a sufficient degree to allow its cost to be accurately estimated, and a detailed description is published in the ITER Final Design Report, 2001 [1]. The status of the ITER project in recent years and the main design modifications and improvements are published in the proceedings of the previous fusion reactor materials conferences [2,3].

During the earlier ITER design phases, a rigorous materials R&D program in support of materials selection was carried out by the Participating Parties to address the unique operational conditions (4 K operational temperature for magnets, 14 MeV neutron irradiation for in-vessel components, high heat and particle fluxes for plasma facing materials etc.), and to provide the necessary materials properties databases for design justification. The results of the R&D program were summarized in the ITER materials documents [4,5] and reviewed in [6].

This paper will briefly describe the project-oriented materials activity and the selection of the materials for the various ITER components. The status of the main materials documents will be reviewed. Some examples of properties recommendations from the recently updated ITER Materials Properties Handbook for the vacuum vessel and in-vessel materials are presented. Finally, the main future activities will be briefly described.

2. Selection of materials for various components

From the beginning of the ITER project, the general strategy was to use conventional industrially available materials. The development of new industrial materials requires extensive effort and time for material qualification, which was not acceptable for the project. However, the specific ITER operational requirements (neutron irradiation, heat flux effect, low temperature, etc.) necessitated some modification of the existing materials. As an example, for the cryogenic magnet application, it was found that the steel 316LN, with a more narrowly specified concentration of elements such as nitrogen, nickel and chromium, within the conventional range, possesses significantly higher strength. This has led to the definition of a class of 'strengthened austenitic steels' for the magnet structures [7].

In a similar way, tightening the specification for the range of Cr and Zr concentrations in CuCrZr led to significant improvements in strength properties. Special thermomechanical treatments were introduced which led to improvements in the strength properties of DS Cu.

There are only a few examples of materials being specifically developed for the ITER application. The primary example is the development of new carbon fibre composites for high heat flux applications.

The ITER-specific safety requirements for material chemical composition have also to be taken into account. As an example, structural materials for the vacuum vessel and magnet have a limit on cobalt content in order to reduce contact dose, activated waste, and activated corrosion products.

The materials selection for some ITER components is summarized in Table 1. A list of materials for magnet and diagnostic components is included in [2]. The selection of materials was based on a general engineering approach, taking into account operational conditions, safety requirements, physical and mechanical properties, reliability, maintainability, corrosion performance, join-ability, etc. For some materials, detailed reasons will be discussed later in the paper. Several possible additional materials for some components are still under evaluation and their selection will be finalised together with the completion of the design.

3. Materials documentation

The main goal of the present materials activity in the ITER project is to provide qualified, reliable and traceable recommendations needed for the design assessment. The required properties data are specified in the design codes (ASME, RCC-MR, etc.) used for the different ITER components. However, ITER uses materials which are not included in the codes (e.g. Cu alloys, Ti alloys). Moreover, for the ITER operational conditions (temperature range, neutron fluence) the required data were not known.

To provide an efficient process for the preparation of the recommendations, the materials activity is currently organized as shown schematically in Fig. 1. The data from the ITER R&D reports and relevant open publications have been assessed by a Materials Expert Group and the data have been included to the ITER Materials Properties Database (MPDB). The Expert Group, which includes material scientists from the ITER International Team and from the Participating Parties, performs

Table 1
Materials for the several ITER components

Material	Forms
Thermal shield	
Steel 304L	Plates, tubes
Ti–6Al–4V	Plates
Steel grade 660	Fasteners
Alloy 718	Bolts
Al_2O_3 coatings	Plasma sprayed insulation
Glass epoxy G10	Insulation
Ag coating	Coating, 5 μm (emissivity)
Vacuum vessel and ports	
Steel 316L(N)-IG	Plates, forgings, pipes
Steel 304	Plates
Steel 660	Fasteners, forgings
Ferritic steel 430	Plates
Borated steels 304B7 and 304B4	Plates
Alloy 718	Bolts
Steel 316 (B8M)	Bolts
Steel XM-19 (B8R)	Bolts
Pure Cu	Clad
VV support	
Steel 304	Plates, rods
Steel 660	Fasteners
Alloy 718	Bolts
NiAl bronze	Rods
PTFE	Plates
First wall	
Beryllium (S-65C or equivalent)	Armor tiles
CuCrZr	Plates/cast/powder heart sink
316L(N)-IG	Plates, pipes
Blanket and support	
316L(N)-IG	Plates, forgings, pipes Cast, powder HIP
Ti–6Al–4V	Flexible support
CuCrZr	Sheets
Alloy 718	Bolts
NiAl bronze	Plates
Al_2O_3 coatings	Plasma sprayed insulation
CuNiBe or DS Cu	Collar
Divertor	
CFC (NB31 or equivalent)	Armor tiles
W	Armor tiles
CuCrZr	Tubes, plates
316L(N)-IG	Plates, forgings, tubes
Steel 660	Plates, bolts
Steel XM-19	Plates, forgings
Alloy 718	Plates
NiAl bronze	Plates, rods

the assessment and evaluation of the data and prepares recommendations. These recommendations are produced in accordance with internationally accepted code procedures (see for details MPH).

The detailed assessment is documented in the ITER Materials Properties Handbook (MPH). The recommended data from the MPH are included in the specific code documents (for example Appendix A to the ITER Structural Design Criteria) or directly used by the designers. This structure maintains traceability of the recommendations and allows for future modification of the recommended data.

Summarising, the currently available materials documents are as follows:

ITER Materials Properties Handbook [4]: A collection of design-relevant data on physical and mechanical properties of a large variety of the ITER-relevant materials. The Materials Properties Handbook forms the core of the materials documentation. Currently, the MPH consists of three parts:

- MPH-Magnet, which includes data for magnet materials at operational temperature, 4 K.
- MPH-Cryo, which includes data for thermal shield materials, operating at ~77 K–400 K.
- MPH-IC includes data for the vacuum vessel and in-vessel materials.

MPH includes physical properties such as thermal conductivity, thermal expansion, etc. Typically average values are specified for these properties. MPH also recommends average and minimum tensile properties. For some materials minimum tensile properties are already included in the codes (e.g. steel 316L(N)-IG in the RCC-MR), for others minimum values are calculated based on statistical analysis of the raw experimental data.

ITER materials assessment report (MAR) [5]: A description of the rationales for the selection of the specific materials grades for vacuum vessel and in-vessel components and an assessment of the materials performance.

ITER materials properties database (MPDB) [8]: A collection of raw experimental data providing a basis for further recommendations. The database maintains the data in an easily accessible form and it is an important tool for maintaining full traceability of the data, test details, data sources and other relevant information. The raw experimental data are being evaluated and only qualified data are used for further assessment.

Materials procurement specifications: A set of documents, describing the procurement of the materials for the various components. These documents

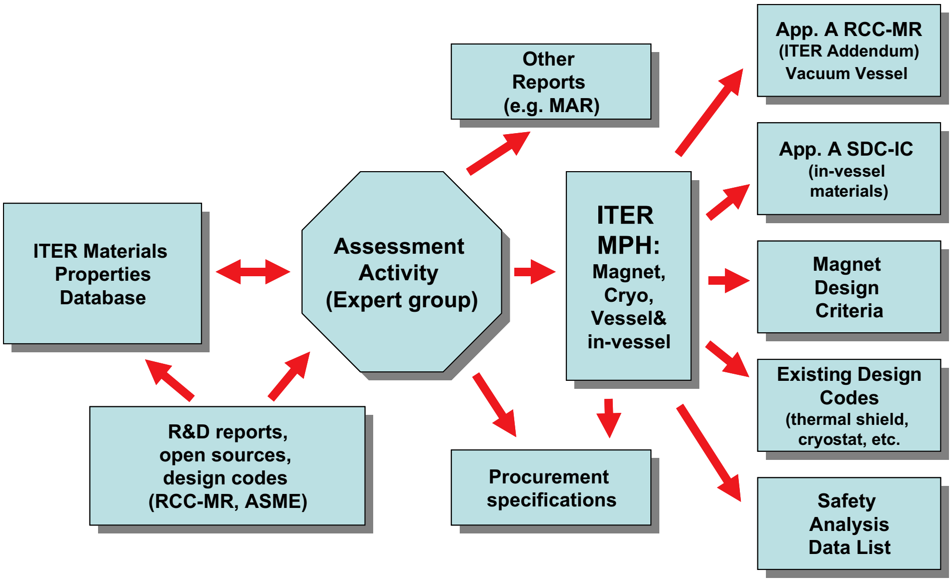

Fig. 1. Structure of the data flow and materials documentation for vacuum vessel and in-vessel components.

are being prepared in close collaboration with various Industries. They are based on the available technical specifications (ASTM, RCC-MR, EN, etc.) and include specific ITER requirements.

There are several additional design documents (Appendix A of the ITER Structural Design Criteria (SDC-IC) [9], Safety Analysis Data List (SADL) [10]) which are mainly based on MPH recommendations and include specific design properties.

4. Materials for vacuum vessel and in-vessel components

This chapter includes some illustrative information about materials, recent assessment and recommendations for materials for vacuum vessel and in-vessel components. The key issues for these materials are outlined. Not all materials used in ITER for these components are included in this paper. Further information can be found in the ITER materials documentation.

4.1. Materials for the vacuum vessel

The vacuum vessel is a double-walled torus-shaped water-cooled structure [11]. The materials operate at 100–200 °C, the expected damage dose is less than 0.02 dpa. The selected materials must provide reliable and safe operation for the planned 30 years of the ITER operation. The list of materials for the vacuum vessel and the vacuum vessel support is summarized in Table 1.

The vacuum vessel is a safety important class (in accordance with ITER classification) component, because it has a primary containment function. After selection of the construction site (Cadarache, France) it was decided that the appropriate design and construction code for licensing is RCC-MR [12] with the so-called ITER Addendum, which includes some new features not covered by the existing code. The major structural materials of the ITER vacuum vessel (316L(N)-IG, steel 304, steel 660, Alloy 718) are included in this code.

Austenitic stainless steel designated as 316L(N)-IG (IG means ITER Grade) has been selected as the main structural material for the ITER vacuum vessel and the in-vessel components [13,14] due to good corrosion resistance, weldability, availability and sufficient strength. The main driving force for the selection of this material versus similar austenitic steels (316L, 316LN, etc.) is its high minimum tensile mechanical properties (combined with good toughness), that results in higher maximum allowable stresses. These properties are achieved as a result of an optimal combination of the main alloying elements such as carbon, nitrogen, nickel, chromium, manganese and molybdenum, with a tight specification of their allowable range. Fig. 2 shows the minimum tensile strength of several materials specified for the vacuum vessel components. The 316L(N)-IG steel has a slightly modified chemical

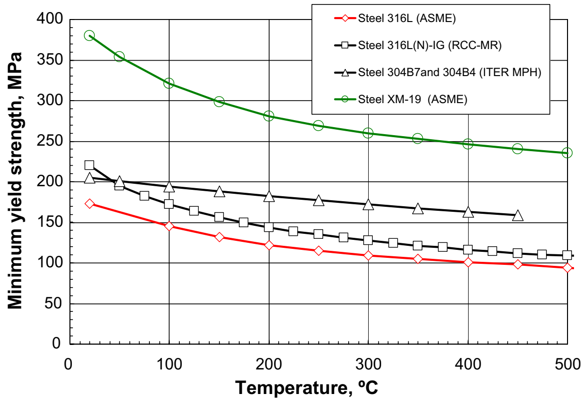

Fig. 2. Minimum yield strength of some vacuum vessel materials, for details see MPH.

composition taking into account the ITER safety requirements related to the limit of Co and Nb impurities, and the limit on boron content to provide reweldability of irradiated steel [5].

For this steel there is a comprehensive database on material properties, including heat-to-heat variations and the effect of product size, and the main design properties are included in the RCC-MR Code. However, the fracture toughness and crack propagation design data are not included in this code. For some specific analyses, fracture toughness data are needed for the evaluation of the performance of the design during operation and during off-normal events. A comprehensive analysis of the available experimental fracture toughness data for 316L(N)-IG steel was performed and included in the ITER MPH [4]. Fig. 3 shows the calculated minimum recommended J_{IC} toughness values for 316L(N) steel.

Several types of bolting materials are considered for the ITER vacuum vessel. Depending on the design application these materials are:

- Conventional bolts made from 316 steel (B8M grade); minimum yield strength at 150 °C is ~160 MPa.
- Bolts from precipitation-hardened steel 660 – this material has significantly higher minimum yield strength than 316 type steel (minimum yield strength at 150 °C is ~585 MPa).
- Bolts from nitrogen-strengthened austenitic stainless steel XM-19 (B8R grade) – this steel has approximately twice the yield strength at room temperature of most conventional steels but is lower than grade 660 bolts (minimum yield strength at 150 °C is ~298 MPa). This material has very good corrosion resistance and is proposed for use inside the water coolant.
- Bolts from Alloy 718. This alloy has the highest strength – minimum yield strength at 150 °C is ~970 MPa – but the lower coefficient of thermal expansion should be taken into account.

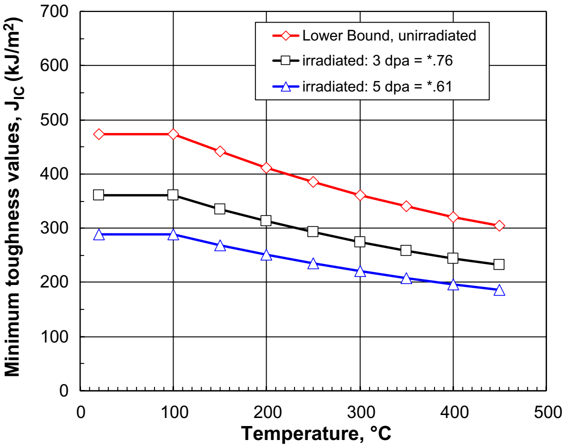

Fig. 3. Minimum fracture toughness values for un-irradiated and irradiated steel 316L(N)-IG.

Austenitic chromium-nickel stainless steels with the addition of ~1 and 2 wt% of natural boron (type 304B4 and 304B7, consequently in accordance with ASTM A887), are recommended for shielding parts inside the double shell of the ITER vacuum vessel, because of their high thermal neutron absorption efficiency. As relatively new materials there are no code-qualified recommended properties data. The ITER MPH includes a collection of the available data. The minimum mechanical properties values were assessed based on the available experimental data, see Fig. 2.

Ferritic steel 430 (ASTM A240) is a high chromium stainless steel. This material is being considered to reduce the magnetic field ripple that can occur between the magnets. It is proposed to insert the plates of this steel directly in the water between the double shells of the vacuum vessel. This steel has good corrosion resistance due to its high chromium content (16–18 wt%).

For the vacuum vessel support some non-metallic material such as polytetrafluoroethylene (PTFE) is also considered. The main issue is the sliding properties of steel against this material. The low dose neutron and gamma irradiation degrades the mechanical properties of the PTFE and this effect has to be assessed.

The design of the ITER vacuum vessel includes many different types of welds. Tungsten inert gas, electron beam, and laser welding are being considered for the manufacturing of the vacuum vessel. Some information about the selection of filler materials, properties of welds, etc. are included in the RCC-MR Code. However, further assessment of new welding methods and the relevant materials properties are still needed. The recent assessment of the weld properties can be found in [15].

4.2. Materials for in-vessel components

ITER in-vessel components are not ‘Safety Important Class’ and are not subject to licensing. However, the safe and reliable operation of these components is crucially important for the overall ITER performance. For the proper design of these components, which must withstand a neutron fluence up to 0.5 MW a/m^2 (~5 dpa in steel), high heat fluxes and mechanical loads, the full range of material properties has to be known. For the assessment of irradiated components in ITER, the SDC-IC [9] is being developed and the requirements for the materials properties are included in this document.

Among the various in-vessel components, the first wall, blanket and divertor are considered as the most challenging due to the high level of the neutron irradiation and high heat flux. The materials grades currently selected are summarized in Table 1. In some cases their performance under ITER operational conditions remains to be confirmed.

The design of in-vessel components includes a combination of the different type of joints of different materials (e.g. Be/Cu, CFC/Cu, W/Cu, SS/Cu) and these joints require adequate properties. Depending on specific requirements, different types of joining technologies were developed; see for example [5,6].

Some materials for the in-vessel components are well qualified in the un-irradiated condition and their properties can be found in various design codes (e.g. 316L(N)-IG in RCC-MR; Alloy 718, steel 660 – in ASME). For other materials (Cu alloys, Ti alloys, etc.) the main properties are not code qualified and they were assessed and included in the ITER MPH. For these materials, the effect of neutron irradiation must be assessed. The recent revision of the ITER MPH includes an assessment of the effects of neutron irradiation on tensile, fatigue and fracture toughness properties of 316L(N)-IG steel, the effects of irradiation on properties of Alloy 718, Ti–6Al–4V, pure Cu and Cu alloys.

A detailed assessment of the effect of neutrons on the tensile properties of 316L(N)-IG was performed recently [16]. The data from the ITER MPDB were assessed in accordance with the ITER SDC-IC requirements. Fig. 4 shows design curves for minimum yield strength of steel 316L(N)-IG as a function of neutron damage at a temperature range of 100–300 °C and also the minimum uniform elongation for different doses.

Data on the effect of neutron irradiation on fatigue were also assessed. As shown in Fig. 5, low temperature (less than 325 °C) data do not show a systematic deviation from the unirradiated data other than an increased scatter. All data fall above the RCC-MR design curve. The design rule (minimum value of $\Delta\varepsilon/2$ and Nf/20) has been applied to the trend curves to compare them with the design curve of the RCC-MR. It was concluded that it is unnecessary to incorporate additional safety factors for low temperature irradiated 316L(N)-IG up to about 10 dpa.

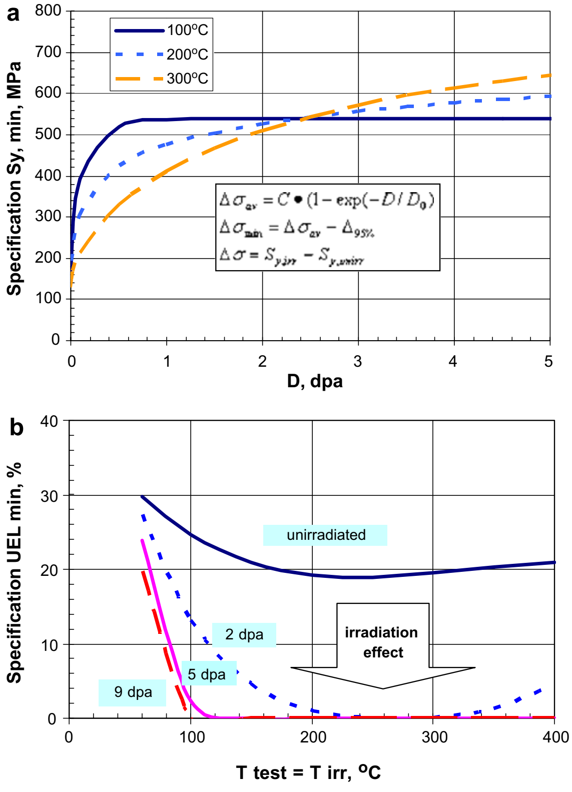

Fig. 4. Assessment of the effect of neutron irradiation on minimum yield strength (Sy) (a) and minimum elongation (UE) (b) of steel 316L(N)-IG.

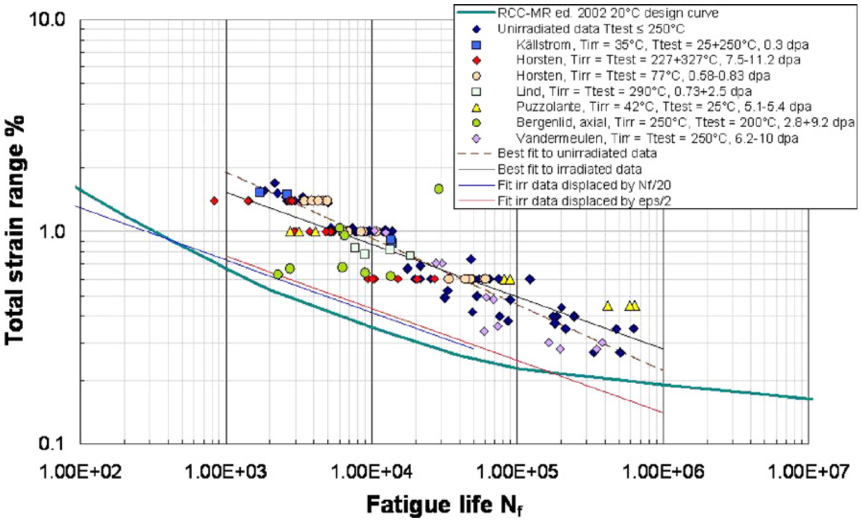

Fig. 5. Assessment of the effect of neutron irradiation on fatigue at temperatures less than 325 °C, for details see MPH.

The effect of neutron irradiation on fracture toughness is shown in Fig. 3. As was assessed in the ITER MPH, neutron irradiation leads to some reduction of the lower bound of J_{IC}, but the minimum values of the fracture toughness are still adequate for design performance.

316L(N) type steel can be used for in-vessel components after different types of heat treatment (e.g. HIP), or in the form of HIPed powder, or after casting. The acceptance of the properties after these types of treatments was demonstrated [5,6,14], however additional data are needed for the full characterization of the material after different treatments. The assessment of the effect of neutron irradiation on the properties of different welds, including rewelding issues, was presented in [5] and recently a new assessment is given in [15].

The issue of reweldability of irradiated 316L(N)-IG stainless steel was also extensively investigated with the available data included in the MAR [5]. Recently, the results of an additional study for thick (5 and 10 mm) plates with 2–7 appm He were published [17]. Summarizing the data, ITER makes the following recommendation for the maximum helium content in steel (at specified applied energy) which is acceptable for re-welding, as follows:

- $\leqslant$1 appm He for rewelding of thick plates (with multi-pass welding).
- $\leqslant$3 appm He for thin plate or pipe welding.

By restricting the boron content in steel to less that 10 wppm these low He levels can be easily achieved for the vacuum vessel and blanket manifold components.

There are several other issues related to materials for the blanket attachment system. A flexible support, in the form of a cylinder with axial slots, is screwed into the vacuum vessel on one side and bolted in the blanket. The material for this application is Ti–6Al–4V ($\alpha + \beta$) alloy, which can sustain a large elastic deformation due to the appropriate combination of a low elastic modulus and high strength. At the expected operational conditions (damage dose of ~0.1 dpa, temperature – 150–260 °C), the uniform elongation of Ti–6Al–4V alloy remains higher that 5%, as shown in Fig. 6 [18,19]. The fracture toughness values after irradiation,

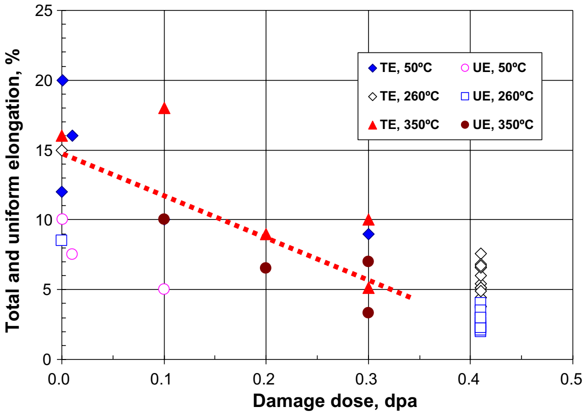

Fig. 6. Effect of neutron irradiation on total (TE) and uniform elongation (UE) of Ti–6Al–4V, [18,19].

including the appropriate levels of hydrogen, are also acceptable [20]. The Ti alloy elements are shielded from direct interaction with the hydrogen plasma. Nevertheless the possibility of ionization-enhanced hydrogen uptake and subsequent damage have to be further qualified (see Fig. 7).

The bolt material for the attachment of the blanket to the first wall is Alloy 718, because of its high strength. There are two main issues related to the effect of neutron irradiation on this material: stress relaxation and reduction of strength at the operational condition (damage dose ~0.1 dpa, temperature – 100–240 °C). Stress relaxation under neutron irradiation was extensively studied, and recommendations are summarized in the ITER MPH: the observed stress relaxation is ~20%, which gives an acceptable margin for the design [21]. A summary picture of the effect of neutron irradiation on the strength of Alloy 718 is shown in Fig. 8. A reduction of strength at low dose (~0.1 dpa) was observed and explained by the loss of coherency of the dispersed strengthening particles [21,22]. The degree of strength loss is ~15%. The ductility of irradiated Alloy 718 at this damage dose remains at the level of 10%.

Significant R&D efforts were devoted to the selection and characterization of copper alloys for the ITER first wall and divertor application. The main requirements for this application are high thermal conductivity, strength and radiation resistance. Several alloys (DS Cu Glidcop Al25, CuCrZr, CuNiBe, etc.) were considered and finally, due to its high fracture toughness, availability and cost, CuCrZr alloy was selected as the prime candidate. For the ITER application, the chemical composition of standard CuCrZr alloy was slightly modified (the recommended ranges of Cr – 0.6–0.9%, Zr – 0.07–0.15%, Cd <0.05%) to reduce the scatter of properties (mainly strength), and to improve toughness and weldability.

The properties of CuCrZr alloy strongly depend on its thermomechanical treatment, which may vary with the manufacturing cycle. Fig. 8 shows the yield strength of CuCrZr in the solution-annealed and aged (SAA) condition from various sources, average and minimum recommended curves, calculated based on SDC-IC recommendations (for details see the ITER MPH). In this figure, data for cast and solution-annealed CuCrZr and CuCrZr in overaged condition (580 °C, 2 h) are also shown. Clearly, depending on the details of the processing, a strong reduction of strength is observed. However, for the first wall application these reduced properties may be acceptable due to the low stresses in the design.

An important property for the design assessment is fatigue. The available data for CuCrZr were collected and assessed and the design fatigue curves were drawn up in the ITER MPH [4]. Fig. 9 shows the available data for CuCrZr and the proposed design fatigue curve for the temperature range of 20–350 °C. As seen from the Figure, CuCrZr has a

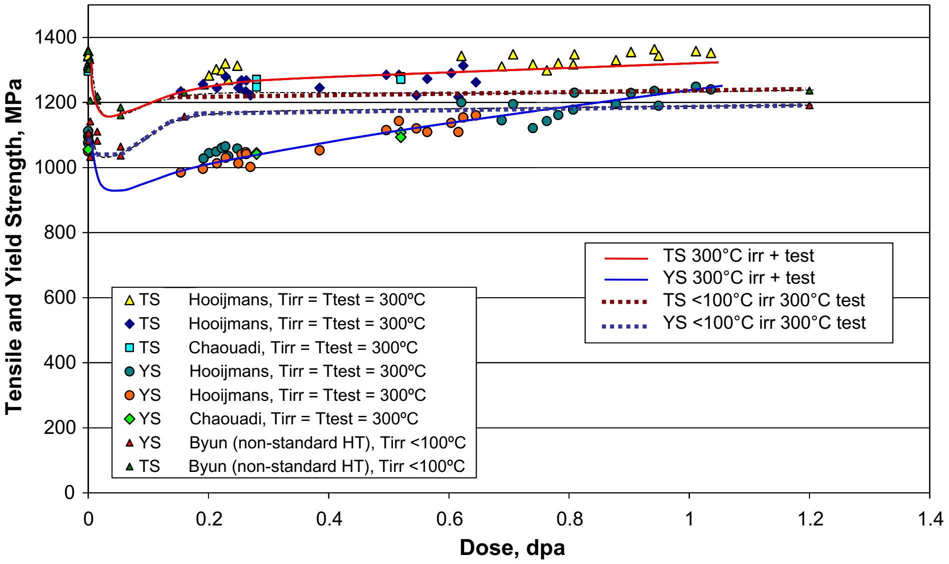

Fig. 7. Effect of neutron irradiation on yield (YS) and ultimate tensile strength (TS) of Alloy 718, for details see MPH.

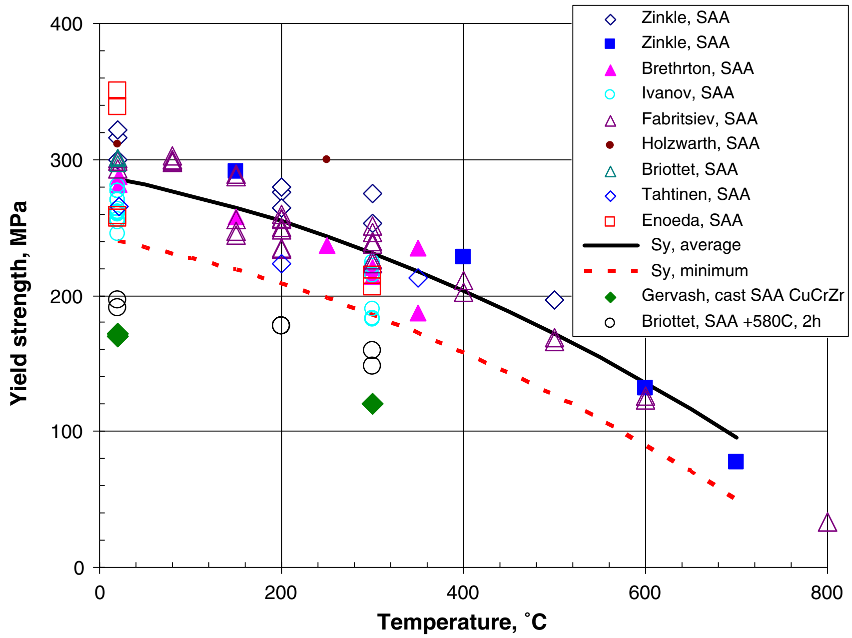

Fig. 8. Yield strength of CuCrZr in SAA condition, average, minimum curves and data for CuCrZr after different treatments, for details see MPH.

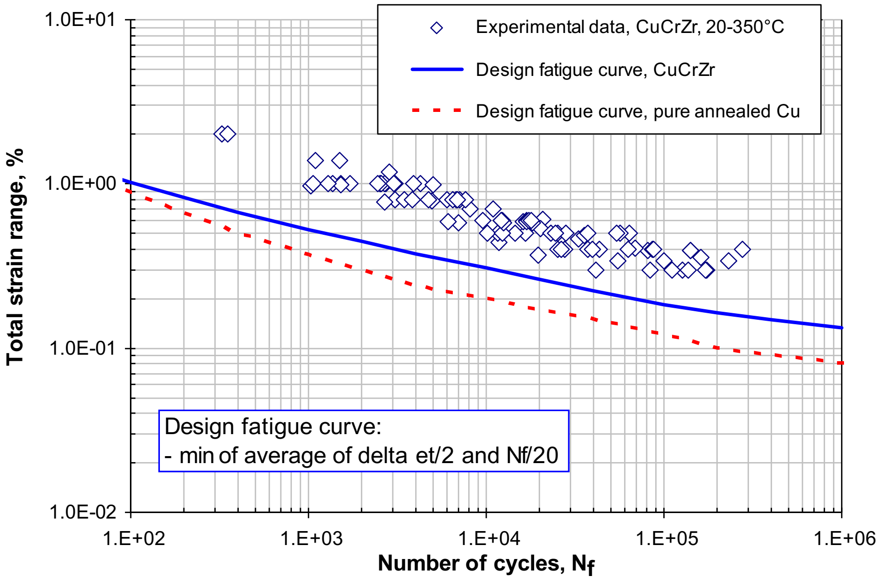

Fig. 9. Fatigue data for CuCrZr and design fatigue curves for pure Cu and CuCrZr, for details see MPH.

significantly higher resistance to fatigue damage compared to annealed pure copper. In addition, it seems that the fatigue behavior of CuCrZr alloy after different heat treatments is very similar.

The combination of fatigue with creep (also at ambient temperatures) has been shown to have a significant effect on the fatigue lifetime of CuCrZr alloy [23–25]. The data showed that the fatigue with a hold time at peak strains significantly reduced the fatigue lifetime compared with a standard fatigue test. This fatigue lifetime reduction is important for the design and should be further investigated.

There are only limited data about the effect of neutron irradiation on fatigue behavior of CuCrZr alloy at a damage dose of 0.3 dpa [24]. These data indicate that the effect on fatigue is not significant.

The effect of neutron irradiation on the tensile properties of CuCrZr alloy after different heat treatments is under assessment for the new edition of the ITER MPH. The previous assessments can be found in [5,6]. The effect of neutron irradiation depends significantly on the irradiation temperature. At irradiation temperatures below 250–300 °C radiation hardening occurs along with a reduction of ductility and loss of work hardening capability. At higher temperatures, radiation-induced softening occurs. In the irradiation temperature range of 100–300 °C saturation of hardening is observed at a damage dose of 0.1–0.5 dpa. At temperatures less that ~150 °C the uniform elongation is below 2%.

The fracture toughness data, including the effect of neutron irradiation were also assessed in the MPH. It was shown that there is some reduction of fracture toughness with increasing temperature. In addition, there is a tendency for fracture toughness to decrease with increasing CuCrZr strength. The neutron effect data are available only up to a damage dose of 0.3 dpa, and a reduction of fracture toughness is observed, especially at elevated temperatures. It was found that there is no correlation between loss of ductility (low temperature embrittlement) in tensile tests and fracture toughness, e.g. [26].

The effect of possible annealing during ITER operation (e.g. during bake-out regimes) on the properties of irradiated CuCrZr was recently studied in [27]. It was shown that repetitive annealing during irradiation at moderate temperatures (250 °C) reduces hardening and embrittlement of CuCrZr alloy.

The behavior of CuCrZr alloy in in-pile tensile tests was reported [28]. It was shown that during in-pile testing, the material deforms uniformly without a yield drop and plastic instability (i.e. low temperature embrittlement is suppressed compared to post-irradiation tests).

The assessment of the available database shows that further characterization for CuCrZr alloy is still needed. This includes, first of all, a characterization of the mechanical properties after the final manufacturing cycle, improved understanding of creep (thermal and irradiation) – fatigue interaction and an investigation of the effect of neutron irradiation to the goal neutron dose on fracture toughness and fatigue.

Different plasma-facing materials were selected for the different components in ITER; this selection was driven mainly by plasma surface interaction issues, such as materials erosion, plasma contamination and tritium retention. The detailed description of these issues can be found in [29,30]. Beryllium is used for the first wall and start-up limiter. Be grade S-65C VHP was selected as reference. Recently, several ITER Parties proposed their own grades of beryllium for the first wall application. A comparison of the properties and performance of these grades under ITER-relevant conditions (heat flux and transient events) should start soon.

Tungsten is the choice for the divertor baffle area. The standard powder metallurgical sintered tungsten grade with 99.94 wt% of W is the present reference material. The effect of radiation-induced embrittlement (shift of DBTT) on the performance of W armor is minimized by use of small tiles in the design.

Carbon Fiber Composite (CFC) is selected for the divertor vertical target. CFC SEP NB31 (production by SNECMA, EU) was identified as the most appropriate grade. Assessment of the properties of SEP NB31, after a series of industrial productions, has shown that deviation of properties from the average values is not acceptable. Further modification of industrial production to fulfill the ITER requirements is on-going. The final selection of the precise grades of armor materials remains to be completed before the start of the materials procurement.

5. Future work

At the current time, when the ITER construction is about to start, the materials activity is a truly multidisciplinary task focused on solving the various remaining engineering and scientific issues.

The most important task is preparing for the materials procurement for the various components and the first priority is materials for safety important and early procured components. A set of materials procurement specifications is currently under preparation. These specifications are primarily based on the main International Standards such as ASTM, EN, RCC-MR, but taking into account the ITER-specific requirement for chemical composition and properties.

The next task is the further consolidation of the materials properties data and modification of the ITER materials documents. Complete information about materials for the safety-important components is needed for the design site adaptation and licensing. For other components, e.g. for in-vessel, the completion of the materials properties recommendations are essential.

In some areas, the R&D program is still on-going with the goal to simplify design, reduce cost and increase reliability. Materials data to support these design modifications are needed. The missing data on the materials performance (some of them were mentioned in the paper), have to be generated.

Finally, materials for test blanket modules also have to be assessed to the same degree as other in-vessel materials. This task is ongoing among the ITER Parties and an adequate materials database is needed for the acceptance of these components.

6. Conclusions

ITER is ready to be built and its construction will start soon in Cadarache, France. The design and technical preparation for the construction of ITER are ready for implementation and inter-government negotiations are nearing completion.

This paper has presented an overview of the current ITER materials activity and has illustrated the organisation of the materials documentation in support of the ITER design. The results of the successful world-wide ITER materials and technological R&D program have indicated the feasibility of the selected materials and joining technologies to provide the required operational lifetime and structural integrity.

During the construction phase the materials activities will be focused on:

- Resolving the urgent remaining issues before starting the procurement of materials.
- Materials procurement and evaluation of the acceptance of the materials in the final components.
- Further consolidation of the data, which are needed for the licensing and for justification of the safe and reliable performance of materials during the ITER operation.
- Provision of supporting data necessary for assessment of the machine performance during operation.

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