Progress in development and qualification of beryllium for ITER blanket first wall application in Russian Federation

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HIGHLIGHTS

• Russian beryllium of TGP-56FW grade has been accepted for the ITER first wall application.
• Experimental technology of TGP-56FW grade, has been successfully introduced to the industry.
• Further R&D will be directed on the cost reduction and increasing the efficiency of production.
• Performances of TGP-56FW grade and S-65C grade under ITER-like loads are very similar.

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ABSTRACT

Progress of R&D activities on the development and improvement of manufacturing technology of the billets and tiles made of TGP-56FW beryllium is traced and also some actions aimed on the preparation of mass production is reported. Additionally, the results of comparative study are presented on influence of transient plasma heat loads with the energy density of 0.3–1.0 MJ/m² at 250–500 °C (performed in QSPA-Be plasma gun facility), on the erosion and surface damage of beryllium tiles made of TGP-56FW grade (RF) and S-65C grade (USA).

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1. Introduction

Beryllium will be used as a plasma facing material for the ITER Blanket first wall (FW). The primary reasons for the selection of beryllium as an armor material for the ITER first wall are its low Z and also high oxygen gettering characteristics and also high thermal conductivity [1]. For the first wall panels beryllium is used in form of flat tiles (of 8 mm in thickness) joined to a CuCrZr alloy heat sink. Present FW design assumes that a total quantity of beryllium tiles is about of 10 tons. Two types of FW panels will be used in ITER: the “normal” heat flux (NHF) panels, which will be loaded by stationary heat flux of (1÷2) MW/m² and “enhanced” heat flux (EHF) panels, which will be loaded by heat flux up to 5 MW/m² [2].

Three beryllium grades have been accepted for application as the first wall armor: S-65C (USA), TGP-56FW (Russian Federation) and CN-G01 (China). This selection is based on the results of the ITER qualification program which includes material characterization and testing of their performance at transient heat loads [3,4]. According to the ITER Procurement Agreement the Russian Federation (RF) is responsible for manufacturing and delivering of 40% FW panels of ITER Blanket. The 60% of panels in the Russian share will be armored with Russian TGP-56FW beryllium that corresponds to ~2400 kg in form of final tiles (~180000 tiles with 50 × 16 × 8 mm in dimensions). It is expected that mass production of beryllium tiles will start in 2019–2020.

The status of R&D on the development and improvement of manufacturing technology of the TGP-56FW beryllium tiles and the activities aimed on the preparation to mass production are presented in this paper.

Additionally, this paper presents some recent results of comparative study on influence of transient plasma heat loads with energy...
density of 0.3–1.0 MJ/m² at 250–500 °C on the erosion, surface cracking and microstructure of beryllium tiles made of TGP-56FW grade (RF) and S-65C grade (USA).

2. Beryllium armor for the enhanced heat flux (EHF) first wall panels

In the FW beryllium is used in form of tiles joined to a CuCrZr alloy heat sink. According to the recent ITER estimations, ~50% (~350 m²) of FW surface will be exposed by scaled up stationary heat loads – up to 5 MW/m². All RF share is related to high loaded part of FW (EHF FW). During a few last years design of EHF FW panels was significantly changed, that resulted in a change of beryllium tiles dimensions.

Fig. 1 shows the FW panel of a new design (1.a), which consists of individual fingers (1.b) with the rectangular-shaped hypervapotron-type cooling channels and beryllium armor tiles of decreased dimensions. By the moment the tiles (Fig. 2) with dimensions of 16 × 50 × 8 mm³ and two transversal cuts (7 mm deep) are considered as the main type of tiles for the EHF panels.

3. Selection of the beryllium grade

As the result of ITER EDA activities [1] the reference beryllium grade S-65C (USA, Brush Wellman) and DshG-200 grade (RF, A.A. Bochvar Institute) were selected for armor of ITER FW. The main criterion of this choice was the highest resistance against High Heat Flux loading, which was shown by the results of thermal fatigue/shock test experiments carried out in 1994–1997 in SNL (USA) [5] and FZ J (Germany) [6].

Later, Russian and Chinese ITER Parties proposed new grades for application in the ITER FW. Then, to assess the performance of new grades the ITER qualification program was established [7]. This program included:

- Characterization of the main physical and mechanical properties and production technologies [8];
- Comparative tests of thermal performance (thermal shock resistance, vertical displacement event (VDE), heat load simulation, thermal cyclic fatigue tests after VDE simulation testing) with respect to the reference grade S-65C [3,4,8,9].

The TGP-56FW grades successfully passed the qualification and was approved by the ITER IO for the application as the armor material of FW [3,4].

4. Technical requirements to TGP-56FW beryllium grade

According to the specification for the supply of beryllium blocks [10], chemical composition, density, grain size and mechanical properties of TGP-56FW grade have to meet the requirements listed in Table 1. The data of S-65C grade [1] are also included in Table 1 for comparison.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>TGP-56 FW</th>
<th>S-65C [1]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical composition, % wt.</td>
<td>Be</td>
<td>99.0</td>
</tr>
<tr>
<td>BeO (max)</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>C (max)</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Si (max)</td>
<td>0.02</td>
<td>0.06</td>
</tr>
<tr>
<td>Fe (max)</td>
<td>0.12</td>
<td>0.08</td>
</tr>
<tr>
<td>Al (max)</td>
<td>0.04</td>
<td>0.06</td>
</tr>
<tr>
<td>Ti (max)</td>
<td>0.04</td>
<td>n/d</td>
</tr>
<tr>
<td>Cr (max)</td>
<td>0.06</td>
<td>n/d</td>
</tr>
<tr>
<td>Mn (max)</td>
<td>0.04</td>
<td>n/d</td>
</tr>
<tr>
<td>Σ(Mg + Cu + Ni) (max)</td>
<td>0.06</td>
<td>0.03</td>
</tr>
<tr>
<td>U (max)</td>
<td>0.013</td>
<td>0.003</td>
</tr>
<tr>
<td>Density (min), % of theoretical value</td>
<td>99.0</td>
<td>99.0</td>
</tr>
<tr>
<td>Average grain size (max), μm</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>Mechanical properties</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ultimate Tensile Strength (RT), (min), MPa</td>
<td>300</td>
<td>290</td>
</tr>
<tr>
<td>Yield Strength (RT), (min), MPa</td>
<td>220</td>
<td>207</td>
</tr>
<tr>
<td>Total Elongation (RT), (min), %</td>
<td>2.0</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Fig. 1. The views of the FW panel (a) and the individual finger (b).

Fig. 2. Beryllium tiles (16 × 50 × 8) mm³ of TGP-56FW grade for EHF FW panels.
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