PHYSICAL MODEL FOR TESTING STRUCTURAL MATERIALS OF FUSION REACTORS UNDER PLASMA AND THERMAL IMPACT

[1,2] I.A. Sokolov, [3]M.K. Skakov

[1] Institute of Atomic Energy NNC RK, Kurchatov, Republic of Kazakhstan
[3] Shakarim University, Semey, Republic of Kazakhstan
[2] National Nuclear Center of the Republic of Kazakhstan, Kurchatov, Republic of Kazakhstan

Email: sokolov@nnc.kz

The choice of plasma-facing construction materials is still important engineering issue in designing of a fusion reactor (FR). The current choice of plasma-facing materials has been made at the ITER through a compromise between a number of physical and operational requirements: minimal impact of impurity contamination on plasma performance and operation, maximum operational flexibility, and minimal fuel retention for the operation in the deuterium-tritium reaction phase.

Recently, over many decades it was supposed to use beryllium as the material of the first wall (FWP) of the ITER, and tungsten as the diverter lining. Although to date it has been decided to replace beryllium with tungsten in the ITER, this material or its compounds are still used in other TOKAMAKs [1] and may be used in the future inside the FR vacuum chamber.

This paper contains the results of beryllium tests after simulating possible thermal and plasma impacts in the FR. The key idea of the research is the possibility of conducting similar studies for any structural material according to the developed algorithm of the physical model. The main research stages are analysis, computer modeling, preparing the test object, irradiation in a plasma beam installation (PBI) [2] and a set of methods of materials science research.

Based on the results of the references analysis, heat fluxes of 2 MW/m^2 (normal) and 4.7 MW/m^2 (elevated) were determined depending on the location of the PBI in the ITER chamber and a calculation model was built in the Autodesk CFD software package. The temperature distribution in the FWP structural materials has been obtained (Figure 1) and its maximum values for beryllium testing have been determined at a normal heat flow of 360 ° C, with an increased heat flow of 735 °C.

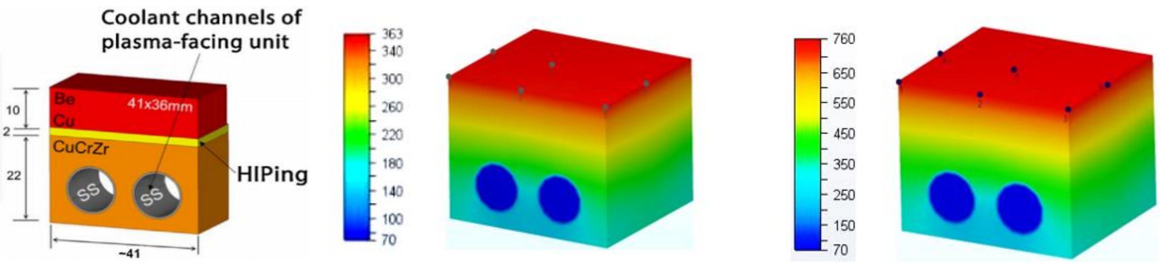

Fig. 1 – Temperature distribution in structural materials of the FW

For testing the material, TGP-56 beryllium samples were prepared with a perpendicular cutout to the material surface to simulate the effects of plasma and heat flow not only on the surface, but also on the edge between the FWP gaps. The samples were alternately tested in the PBI under the irradiation with hydrogen plasma with maintaining the calculated temperatures.

The measurement, calculation and recording of the technological parameters of the experiments were carried out using a set of measuring instruments, proprietary techniques and developed data calculation programs. The PBI has been equipped with an automated complex of plasma diagnostics based on Langmuir probes, optical spectroscopy, mass spectrometry, pyrometry, etc. This complex allows obtaining the plasma parameters (temperature, concentration, flow, fluence of charged particles) in real time mode. The irradiation process, the beryllium sample, and the PBI are shown in Figure 2.

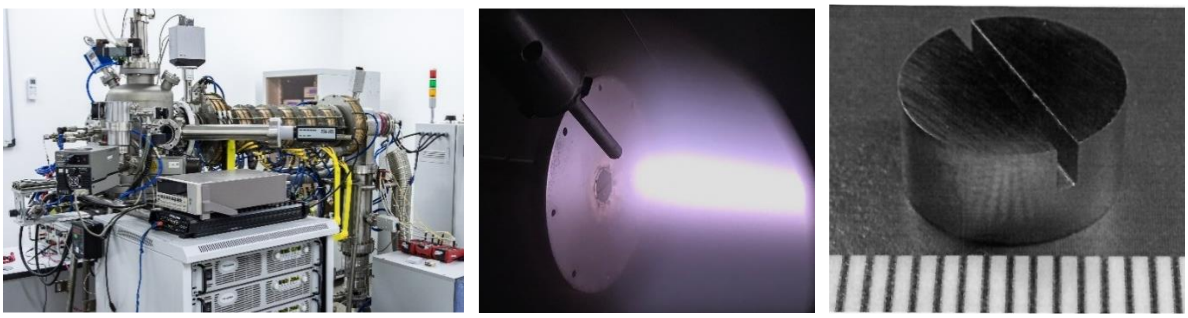

Figure 2 – PBI appearance and the process of the beryllium sample plasma irradiation

The following experimental research methods were used: microanalysis, X-ray diffraction analysis, transmission electron microscopy, determination of microhardness to study the changes in the microstructure and structural-phase states of the beryllium surface as a result of the tests. The images of the surface and fine structure of some samples are shown in Figure 3.

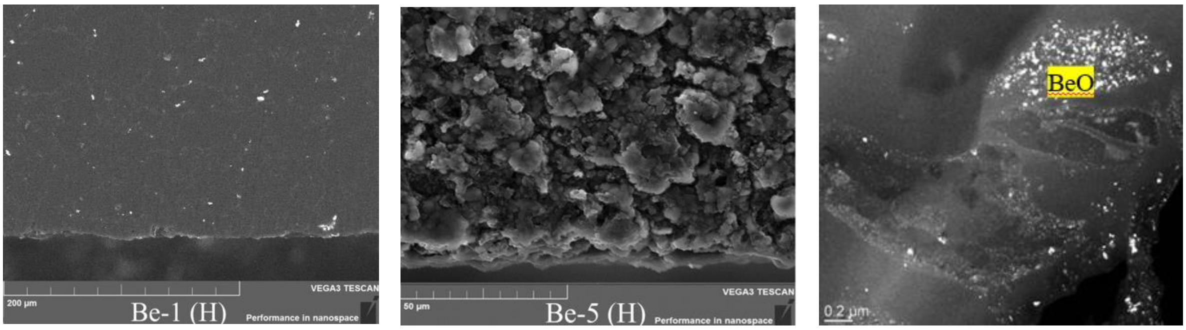

Figure 3 – SEM images of the initial beryllium Be-1(H) surface after the irradiation of plasma Be-5(H) with $3.56 \cdot 10^{26}$ hydrogen ion fluence and fine structure of Be-5(H) after 50,000 s at 760 ° C.

The effect of the hydrogen plasma and thermal loads did not have a critical effect on the structural change and destruction of the surface and edges of the beryllium samples after 50,000 seconds (100 pulses of 500 s each). An increase in the number of the irradiation cycles leads to an increase in linear pore sizes. According to the results of the phase analysis, BeO phases were detected in addition to beryllium, which is confirmed by the TEM results. Thus, this material has a high resource for its use in the FR. The physical model of simulating the experiments is used to study tungsten, beryllium, and titanium and can be used to evaluate the operational properties of any structural materials of the fusion installations.

ACKNOWLEDGEMENTS

This research was funded by the Science Committee of the Ministry of Education and Science of the Republic of Kazakhstan (grant no. AP08856026)

REFERENCES

[1] BREZINSEK, S., STAMP, M., NISHIJIMA, D. et al., Study of physical and chemical assisted physical sputtering of beryllium in the JET ITER-like wall, JET EFDA Contributors Nucl. Fusion Vol. 54 (2014) 103001.

[2] ZHANBOLATOVA, G., BAKLANOV, V., SKAKOV, M. et al., Influence of temperature on tungsten carbide formation in a beam plasma discharge, J. of Phys.: Conf. Ser. Vol. 2064 Iss. 1 (2021) 012055.