# DEVELOPMENT AND STUDY OF THE NEW RUSSIAN CARBON-BASED MATERIALS FOR FUSION APPLICATION

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## Introduction

Carbon-carbon (C-C) composites and different graphites, like low-Z materials, are considered as one of the main plasmafacing materials for fusion application. During last years Russian activities were focused on the technological study of new carbon-based materials with high thermal conductivity, high strength, low ion and thermal erosion yields, low tritium diffusion, inventory and satisfactory neutron irradiation resistance.

Such complex approach was needed to produce carbon materials satisfying extremely rigid requirements imposed on divertor and other plasma-facing ITER components. Taking into account the selection criteria for candidate carbon-based materials [1], recrystallized graphites and C-C composites have been chosen for further technological study and investigation .

Table 1. Main materials studied and tested

| | |
|---|---|
| POCO-AXF-5Q<br>EK-98<br>MPG-6, MPG-8 | fine grain graphite (US)<br>fine grain graphite (Germ.)<br>fine grain graphite (RF) |
| RG-Ti-91 | recrystallized graphite (RF) (7.5$_{wt}$% Ti ) |
| RG-Ti-91-B | recrystallized graphite (RF) (7.5$_{wt}$% Ti, 0.1-0.8$_{wt}$% B) |
| UAM-92-5D | C-C composite (RF), PAN fibers, 5-directions, cell size: 1.5x1,5x0.75 mm$^3$ |
| UAM-92-5D-B | -"-, 2x2x0.75 mm$^3$, 0.2$_{wt}$% B |
| UAM-93-3D-Gr | C-C composite, "Granite" PAN-fibers, 3-direction, cell size 2x2x0.75mm$^3$ (RF) |

## Directions of Technological Study

First direction: recrystallized graphites are obtained by adding an organic binder and carbide-forming dopes (Ti, B, Si, Zr, etc.) into the charge, which serve as baking activators and carbon graphitization catalysts during a high temperature thermomechanical treatment. The main goals of this technological study are; produce RG-Ti graphite with maximum possible thermal conductivity (more than 600 W/m.K); try to find the optimum amounts of carbide-forming dopes (Ti - to obtaining maximum thermal conductivity and B - to form the barrier against tritium diffusion and inventory). To manufacture recrystallized graphite tiles for the divertor plates without surface impurities different methods for RG-Ti purification were studied.

Second direction: C-C composites. Among the variety of carbon fiber reinforced carbon composites, multidirectional (3-5 D) woven materials manufactured from special heat-treated pyrocarbon-saturated PAN fibers, coal tar pitch, with small amount of B or Ti dopes and subjected to high temperature graphitization were chosen and studied.

Well-studied fine grain isotropic graphites were taken for comparison as reference materials. Table 2 presents the main physical properties of the most interesting materials of each type.

## Experimental

To select candidate carbon-based materials for plasma facing components application and to determine their operation characteristics a set of experiments simulating the main damaging factors, such as plasma bombardment [2], high heat flux loads (plasma disruptions and thermocycling regimes [3]), neutron irradiation [4] and tritium diffusion and inventory [5], was performed. During last years the main activity was focused on investigations of carbon materials after neutron irradiation (physical properties changes, hydrogen isotopes retention/re-emission in irradiated materials) and on plasma disruption simulation experiments. Fission reactors, electron, ion and plasma accelerator [6] were used.

Detailed surface analyses after various impacts were carried out using different techniques: SIMS, SNMS, X-ray Diffractometry and SEM with X-ray Microanalysis.

## Results, Discussion and Conclusions

The most interesting carbon-based materials for such investigations were graphites with boron and titanium dopes. As the investigation showed, the boron migration in the composites and RG-Ti graphites was practically absent. Titanium in recrystallized graphites after ion, electron and plasma actions migrates to the sample surface and amounts to 15-20$_{wt}$% in the near-surface (some microns) layer.

Real influence of the B and Ti dopes on resistance of carbon-based materials for fusion reactor under different radiation fluxes was shown. Such properties as thermal shock resistance and material behavior during plasma disruption for fusion graphites strongly depends for fusion graphites on thermal conductivity. C-C composites seem to be more attractive in terms of high mechanical strength.

Experimental results reveal that the ion erosion of C-based materials is of "universal" character at exposure doses exceeding $1.10^{21}$ion/cm$^2$, under an other similar conditions the sputtering yields of different graphites differ slightly. Titanium added to material reduces the chemical sputtering of graphites.

Materials tests on electron and plasma accelerators under the conditions imitating thermal phase of plasma current disruption revealed a smaller thermal erosion on RG-Ti materials and UAM-92, UAM-93 composites than on other graphites. The results obtained a degree of modification of C-C composite matrix material.

New results demonstrate, that the presence of small amount of boron in graphite reduces deuterium trapping. For example, RG-Ti containing 0.5$_{wt}$% B retains only half as much deuterium as RG-Ti without B.

In view of neutron irradiation stability the preference should be given to titanium and boron contanining recrystallized graphites.

## References


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Table2.Physico-mechanocal characteristics[a] of the main Russian carbon-based materials for ITER application

| Materials | Thermal conductivity [W/mK] | Linear expansion coefficient [$10^6$K$^{-1}$] | Young's modulus E, [GPa] | Compression strength [MPa] | Density [g/cm$^3$] |
|---|---|---|---|---|---|
| RG-Ti-91 (7.5$_{wt}$% Ti) | 600/190 | 2/11 | 26/5 | 60/38 | 2.25 |
| RG-Ti-91-B (7..5$_{wt}$%Ti, 0.1$_{wt}$%B) | 395/ - | 3.1/10.5 | 25/4.8 | - | 2.25 |
| MPG-8 | 130/95 | 6/7.8 | 11.5/9.7 | 96/89 | 1.8 |
| UAM-92-5D | 430/ - | 0.5/ - | 20/ - | 105/ - | 1.92 |
| UAM-92-5D-B (0.2$_{wt}$% B) | 270/ - | 1.8/ - | 24/ - | 110/ - | 1.91 |
| UAM-93-3D-Gr | 425/ - | 0.5/ - | 23/ - | 150/ - | 1.82 |

[a] Characteristics are given for room temperature