

ABOUT THE MECHANISM OF BORON CARBIDE TRANSFER DURING ARC REGIME OF STB IN URAGAN-3M TORSATRON

G.P. Glazunov, E.D. Volkov, V.G. Kotenko, V.I. Lapshin, Yu.K. Mironov, N.I. Nazarov, I.M. Neklyudov, V.A. Potapenko, N.D. Rybal'chenko and Yu.A. Sizi

*National Science Centre "Kharkov Institute of Physics and Technology",
Akademicheskaya st., 1, 310108 Kharkov, Ukraine*

Abstract

The experiments in the arc regime of STB in the Uragan-3M torsatron with the employment of a movable B_4C -limiter and two channels for BI and BII spectral line intensity measurements and collecting probes placed on the plasma facing surfaces of protective housings of helical windings were carried out. The numerous damages in the form of craters, spallings and macro-spallings on the boron carbide target surface were observed after experiments. The metallographic studies of face-perpendicular cuts of the hot pressed in vacuum boron carbide plate used as a solid target for boronization during discharge cleaning, show that the cracks at the nearest surface bulk in the region of craters, being the result of local abrupt overheating caused by arcs, are the main reasons of spallings and macro-spallings. The arc erosion products are injected into the plasma confinement volume in various forms, such as vapors of boron carbide, plasma streams, small droplets of melted boron carbide, solid spalls. The latter ones can move for long distances through the plasma column that can be used as a boron carbide vapor source for boron carbide deposition onto the metallic surfaces far from the boron carbide target. The description of behavior of boron carbide material in plasma and some experimental arguments in such mechanism of material transfer favor are presented.

1. Introduction

The solid target boronization (STB) procedure is employed in many plasma devices to improve vacuum-plasma conditions. Recently, to get sufficiently high fluxes of boron on the plasma facing metallic surfaces during STB in the Uragan-3M (U-3M) torsatron the special arc-regime of a movable B_4C -limiter operation was suggested [1]. The radiation damages of boron carbide in such regime can be very different from physical sputtering by plasma ions: the new kinds of damages of the hot pressed boron carbide in the form of craters and macro-spallings were observed in [2, 3]. It was suggested [3] that the main cause of macro-spallings is the thermal stress cracking in the regions of cathode spots of arcs at the points of defect accumulations. However, to get the direct arguments in such mechanism favor, the additional investigations of irradiated samples were needed to be carried out. Also, the mechanism of boron carbide transport along the plasma column and possibility of its deposition onto the metallic surfaces far away from the boron carbide target are still not clearly understood. To elucidate the above mentioned

questions we have continued here the experimental studies of the B₄C erosion behavior under arc-regime of STB .

2. Experiment and discussion

The schematic sketch of the experiment is given in Fig. 1. There were two channels for BI and BII spectral line intensity measurements and eleven collecting probes placed on the plasma facing surfaces of helical winding housings. The sample under study was a B₄C-plate used as a head plate of a movable limiter during pulsed discharge cleaning (PDC) regime in the U-3M torsatron . The plate of a size 90×90×8 mm was made by hot-pressing in vacuum of a boron carbide powder with the particle size up to 1 μm and has the following characteristics: density is 2.44 g/cm³, (B 78.2 a.m.%, C 21.5 a.m.%), grain size is 2-5 μm, heat conductivity is ≈ 30 W/m.K and electrical resistivity is ≈ 10⁻² Ω.m . The typical plasma parameters near the plasma column center in the PDC regime were: hydrogen pressure $p = 1 \times 10^{-4}$ Torr, $n_e = 2 \times 10^{12}$ cm⁻³, $T_e = 10-15$ eV, $B = 0.035$ T, plasma pulse duration $t = 50$ ms, pulse frequency $f = 0.2$ Hz, total discharge power $W \approx 80$ kW with 5.4 MHz frequency of RF generator. The B₄C-plate was negatively biased up to -(120-200V) with a pulse duration of 10-50 ms, and an ion current amplitude during arc regime of STB was up to 2-10 A. After about 2×10^4 cleaning discharges the B₄C-limiter was removed from its position near the plasma edge region and, after finishing the experimental campaign, the head B₄C-plate was demounted for investigations.

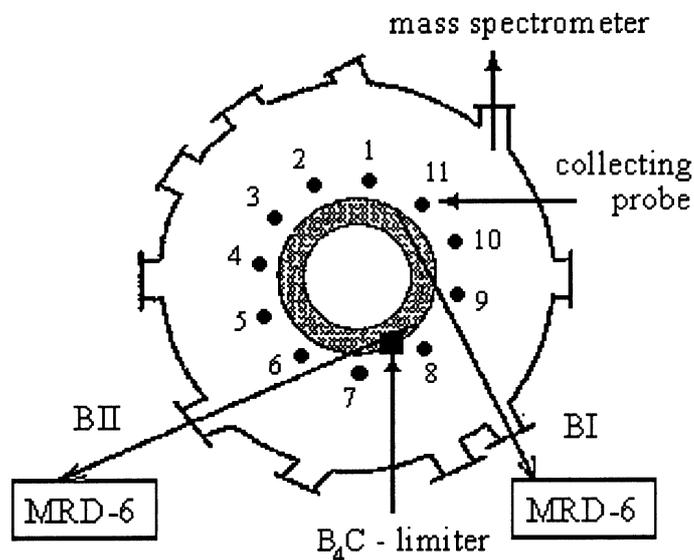


Fig. 1: Schematic top view of the experiment.

It was observed many craters of sizes up to 1.2 mm and spallings of different sizes on the sample surface area directly contacting with an edge plasma. Damages of similar kind but with lower intensity and density, are presented also on the sides and even on the back surface of the plate. The sizes of majority of craters are ranged between 0.1 and 0.5 mm [3] that is smaller than it was observed in work [2]. Probably, it is caused by the difference between grain sizes of

boron carbide used in different works. Also, the difference in boron carbide surface temperatures during the tests can play an important role.

The metallographic studies of face-perpendicular cuts of hot pressed in vacuum boron carbide plate have shown the presence of two kinds of cracks at the nearest surface bulk in the region of craters (Fig. 2). One part of them are "closed" cracks and another are "opened" to surface cracks. Both are the result of the local abrupt overheating caused by arcs and these cracks are the main reason of spallings and macrospallings. It is probable that at a starting stage of arcing the spalling of solid-phase boron carbide takes place. It can be said that in this case

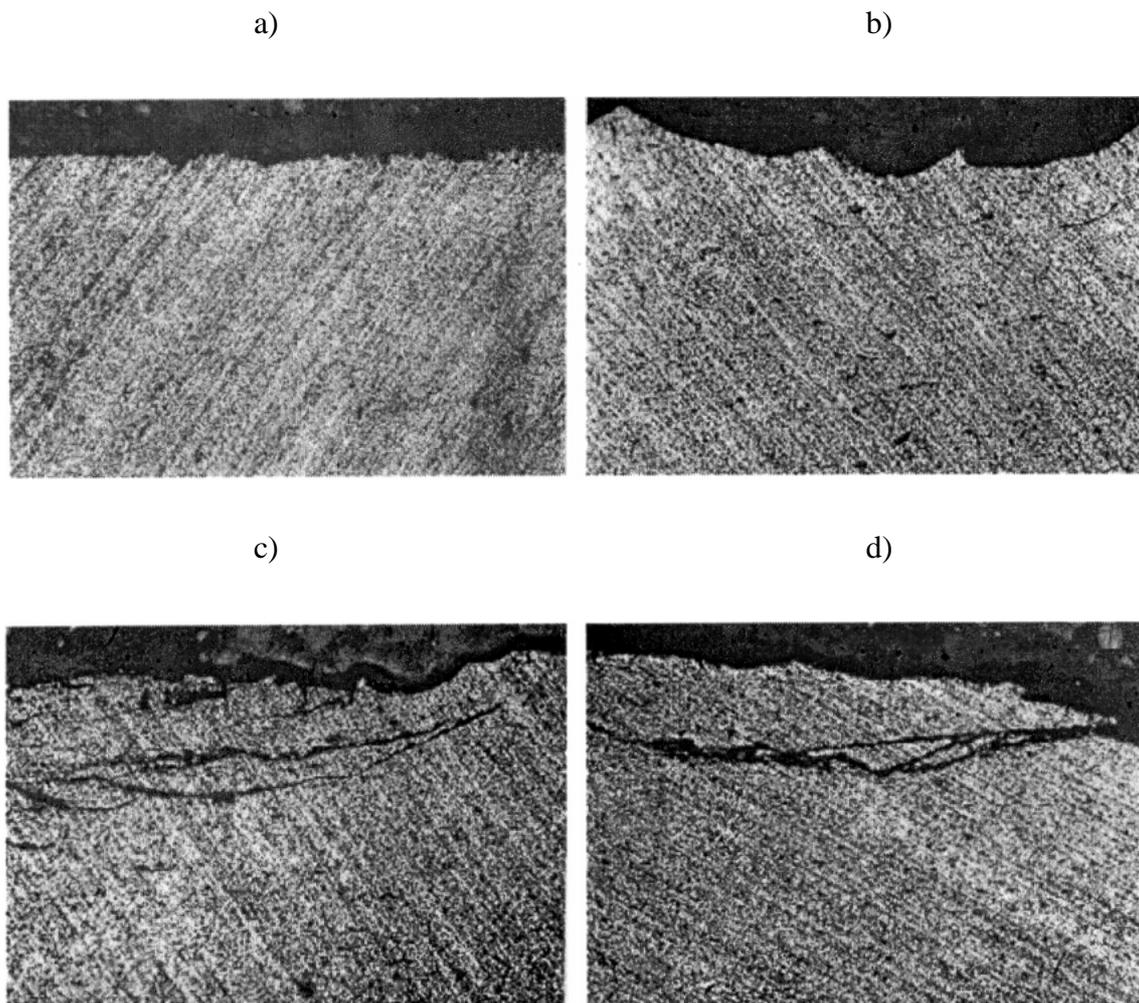


Fig. 2: Metallographic pictures ($\times 70$) of face-perpendicular cuts of hot pressed in vacuum boron carbide plate: (a) - undamaged part of sample, (b) - sample with craters after arcing, (c) - "closed" cracks at the nearest surface bulk, (d) - "opened" to surface crack.

the arcs work as original "chisels". It should be noted that earlier [4] we have observed the "spalling" kind of erosion for hot-pressed boron carbide after its exposure to high power microsecond fluxes of hydrogen plasma. Some spalls of different sizes and small droplets of melted boron carbide shot from the regions of cathode spots could move through plasma

column, and could be as a boron source in the plasma device similar to pellet injection. Such particles have high (~ 100 m/s) velocity [5] and can achieve far distances from the limiter. Note, that we observed visually through the optical window the light objects moving from the limiter. Besides, the neutral boron line intensity increase measured by BI channel was observed sometimes far from the limiter and we think that the vapor from droplets or melted spalls which achieve this distance is the reason of such increase. Note, also, that the chance character of the increase of the collecting probe weight (Fig. 3) shows in favour of such mechanism of boron carbide transfer.

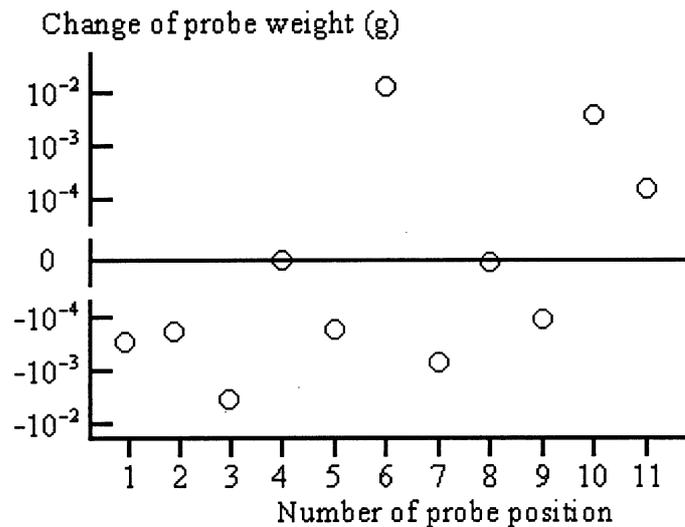


Fig. 3: The changes of collecting probes weights versus the positions on the surfaces of helical winding housings.

3. Conclusion

The cracks at the nearest surface bulk of boron carbide in the region of craters caused by arcing during arc regime of STB in the Uragan-3M torsatron are the main reason of spallings and macro-spallings of the boron carbide target. Some spalls or droplets shot from the regions of cathode spots of arcs can achieve far distances from the solid target and this phenomenon can be used as a boron carbide vapor source for boron carbide deposition on the metallic surfaces far from the target during STB procedure similar to pellet injection.

References

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