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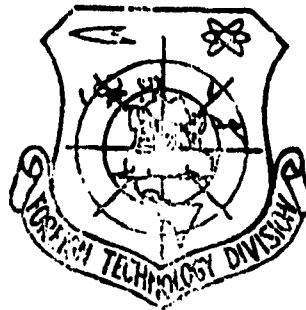
FOREIGN TECHNOLOGY DIVISION



INTERACTION OF POROUS ELECTRODE MATERIALS WITH
AN AIR PLASMA FLOW DURING THE BLOWING THROUGH OF
PROTECTIVE GASES

by

Yu. P. Kuketa, Yu. K. Lapshov, et al.



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13. ABSTRACT

A comparative study was made (in an air plasma flow) on porous electrodes (35-45% porosity) manufd. from the refractory compds. TIC, NBC and ZRB2, and destined for use in open cycle magneto-hydrodynamic generators. To protect the electrode material, a protective AR or N gas was blown through the boundary near electrode layer. Electrodes of ZRB2+LAB6, W+LAB6 and LAB6 were compared. The source of plasma flow was a 300 KW plasmotron with air arc stabilization and the following parameters at the inlet of the effective zone: mean mass temp., T=2700K, flow rate, U is approximately equal to 350 M-Sec.; AMT. of K addn. smaller than or equal to 1.2%. The electrode temp. was 1200-2400K. The expts. were conducted with and without the protective gas by detg. the phase compns. of the electrode material by X-Ray anal. When the electrodes were protected with neutral gases, they could be manufd. from TIC, NBC and ZRB2. AT1139112

KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Plasma Flow Porous Electrode Titanium Carbide Niobium Carbide Zirconium Boride Refractory Compound Magnetohydrodynamics Electrode Reaction Gas Property						

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А а	<i>А а</i>	A, a	Р р	<i>Р р</i>	R, r
Б б	<i>Б б</i>	B, b	С с	<i>С с</i>	S, s
В в	<i>В в</i>	V, v	Т т	<i>Т т</i>	T, t
Г г	<i>Г г</i>	G, g	У у	<i>У у</i>	U, u
Д д	<i>Д д</i>	D, d	Ф ф	<i>Ф ф</i>	F, f
Е е	<i>Е е</i>	Ye, ye; E, e*	Х х	<i>Х х</i>	Kh, kh
Ж ж	<i>Ж ж</i>	Zh, zh	Ц ц	<i>Ц ц</i>	Ts, ts
З з	<i>З з</i>	Z, z	Ч ч	<i>Ч ч</i>	Ch, ch
И и	<i>И и</i>	I, i	Ш ш	<i>Ш ш</i>	Sh, sh
Й й	<i>Й й</i>	Y, y	Щ щ	<i>Щ щ</i>	Shch, shch
К к	<i>К к</i>	K, k	Ъ ъ	<i>Ъ ъ</i>	"
Л л	<i>Л л</i>	L, l	Ы ы	<i>Ы ы</i>	Y, y
М м	<i>М м</i>	M, m	Ь ь	<i>Ь ь</i>	'
Н н	<i>Н н</i>	N, n	Э э	<i>Э э</i>	E, e
О о	<i>О о</i>	O, o	Ю ю	<i>Ю ю</i>	Yu, yu
П п	<i>П п</i>	P, p	Я я	<i>Я я</i>	Ya, ya

* ye initially, after vowels, and after ъ, ь; e elsewhere.
 When written as ѣ in Russian, transliterate as yě or ě.
 The use of diacritical marks is preferred, but such marks
 may be omitted when expediency dictates.

**INTERACTION OF POROUS ELECTRODE
MATERIALS WITH AN AIR PLASMA
FLOW DURING THE BLOWING THROUGH
OF PROTECTIVE GASES**

Yu. P. Kukota, Yu. K. Lapshov,
Ye. M. Prshedromirskaya,
V. M. Sleptsov, and L. A. Klochkov

The problem of creating reliable materials for the electrodes of open cycle MHD generators is still incompletely resolved. The accumulation of experimental data on the interaction of refractory electrode materials with aggressive flows is one of the pressing problems in seeking the necessary compositions, technology of separation and means of protection against electrode destruction.

Carbides and borides of transition metals from groups IV-VI of the periodic system, having high melting points, high hardness, high temperature-strength, wear resistance, high thermal and electrical conductivity, are of considerable practical interest in high temperature technology [1, 2], in particular when they are used as the electrode materials in MHD equipment.

This work studies the behavior of niobium and titanium carbides, and zirconium boride in a flow of air plasma. In order to protect the working surface of the electrodes from oxidation and erosion by means of blowing in argon in the near-electrode

layer, the materials were made with a porosity of 35-45%, which ensured the required gas permeability. The electrodes made from these materials were tested on a NII installation by maintenance engineers of the Moscow State University [3, 4].

The source of the plasma flow was a 300 kW plasmatron with air arc stabilization. The basic parameters at the entrance to the working section were: mean-mass temperature $T_w \sim 2700^\circ\text{K}$, velocity $U \sim 350$ m/s, up to 1.2% sodium addition; the electrode temperature varied from 1200 to 2400°K.

Results of studies on the tested electrodes made it possible to make a number of conclusions as to the behavior of the materials in flow from the point of view of erosion resistance and chemical interaction with the flow. Erosion resistance of these materials in an air plasma flow is unsatisfactory without special protective means. Considering the insufficient corrosion resistance of electrodes from carbides and borides together with the good electrical characteristics, they were tested with a supply of protective gas (argon or pure nitrogen) in the near-electrode boundary layer. It is known [5, 6] that blowing gases into a boundary layer through a porous wall results in a considerable reducing of the velocity, temperature and concentration profiles. A drop in the near-wall gradient of these quantities results in a decrease of the coefficients of friction, heat exchange and mass transfer, which is expressed in a rise of the erosion-collision resistance of the material.

Experiments with argon protection of porous titanium carbides, niobium carbides and zirconium boride in an air jet from a plasmatron showed that when the parameter of the blowing in $\frac{\rho_w V_w}{\rho_0 U_0} = 0,04$ the erosion resistance of these materials approaches the resistance of zirconium dioxide and in the same conditions surpasses the resistance of electrodes made of silicon carbide.

Linear measurement with correction for wear by weight determined the erosion wear of the electrodes. It must be kept in mind that the accuracy of determining the removal by this method is low ($\pm 100\%$), however the use of other methods, for example, the weight method, is difficult because of the presence on the electrodes of refractory concrete residues, a melt of the lining etc., removal of which without destroying the structure of the electrode material is practically impossible. Figure 1 graphs the values for removal of certain materials as a function of the parameter for the argon blowing. The graph also plots data on the erosion resistance of SiC [8] and ZrO₂ [9]. As is evident, the protection by means of blowing in argon (or high-purity nitrogen) permits the use of such materials as TiC, NbC, ZrB₂ in an aggressive plasma flow.

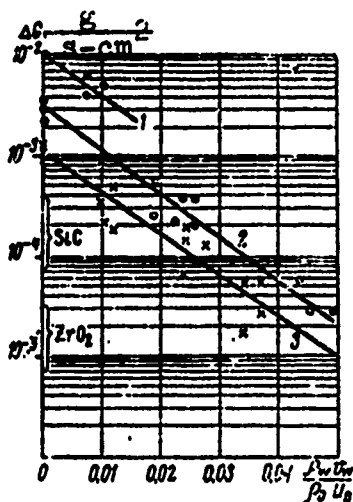


Fig. 1. Erosion wear of electrode materials:
 1 - W, W + LaB₆; 2 - TiC;
 3 - ZrB₂; ZrB₂ + LaB₆.

This blowing (injection) affects the purity of the electrode working surface, and as a result the electrical characteristics. In experiments with injection somewhat higher parameter values determining the voltage and ampere characteristics of the electrode were fixed. For example, Fig. 2 gives the relationship $\text{tg } \beta^* = f(T_w)$ and $j^* = f(T_w)$ [3] for ZrB₂ + LaB₆.

Electrodes of TiC, ZrB₂, NbC tested with protection through 3-4 triggerings (τ up to 10 min) showed practically no change in

geometry. According to data from microstructural analysis, on the surface of the electrode tested without protection a layer (up to 0.4 mm) is formed from the products of interaction of the material with the plasma flow. The surface of the electrodes with protection shows no such layer. Figure 3 gives the microstructural photographs of a $ZrB_2 + LaB_6$ electrode surface without protection (a) and with protection (b); the test time was 4 min, surface temperature $T_w = 0-2100^\circ C$.

In order to study the structural change in the electrodes, an X-ray metal analysis was made of the titanium carbide and the zirconium boride, which had been tested in an air plasma flow. Metallographic study of the electrode specimen showed that the interaction with the flow occurs directly on the surface. The microstructure of the layer on the titanium carbide is an alternating section of two types with a microhardness of 3160 ± 110 and $1430 \pm 200 \text{ kg/mm}^2$. These sections were identified by the authors as titanium carbide ($H_M = 2988 \pm 125 \text{ kg/mm}^2$) and a product of the interaction of titanium carbide with oxygen and nitrogen of the air plasma $H_M TiO_2 = 800-850 \text{ kg/mm}^2$ ($H_M TiN = 1994 \pm 137 \text{ kg/mm}^2$).

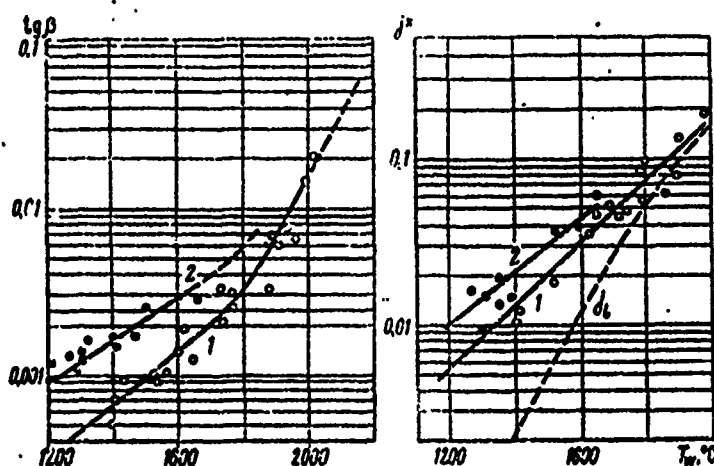


Fig. 2. Effect of surface purity on the electrical properties of a cathode from $ZrB_2 + LaB_6$ (0.3%K):
 1 - without protection; 2 - argon blowing
 $\left(\frac{j_w}{j_0} \frac{V_w}{V_0} \approx 0.0276\right)$



Fig. 3. Microstructure of the effective surface of an electrode from $ZrB_2 + LaB_6$ (magnification $\times 35$): a) without protection; b) with argon blowing.

The microstructure of the layer on the zirconium boride includes sections of two types with a microhardness of 1290 ± 30 and $1400 \pm 50 \text{ kg/mm}^2$, which the authors deciphered as zirconium boride ($H_M = 1520 \pm 85 \text{ kg/mm}^2$) and a product of the interaction of the zirconium boride with oxygen and nitrogen ($H_M ZrO_2 = 1013 \pm 104 \text{ kg/mm}^2$).

X-ray analysis was conducted on the specimens of TiC , ZrB_2 , $ZrB_2 + LaB_6$, $NbC + CO$, LaB_6 , $W + LaB_6$.

X-ray photographs were taken from the effective surface of the specimens and from their base in a cylindrical chamber 57.3 mm in diameter in filtered CuK_α radiation.

The phase composition of the specimens was determined by comparison with standard X-ray photographs taken from X-ray card indexes. The results of the analysis are given in the table.

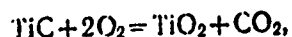
Table: X-ray phase analysis data

Specimen	Observed phases		
	Base	with protection	without protection
TiC	TiC	TiC	TiO ₂
NbC	NbC	NbC	Nb ₂
ZrB ₂	ZrB ₂	ZrB ₂	ZrO ₂
	ZrB		Monoclinic
ZrB ₂ + LaB ₆	ZrB ₂	ZrB ₂	ZrO ₂
W + LaB ₆	W	-	WO ₃ ¹
LaB ₆	LaB ₆	-	LaB ₆

¹High-temperature modification.

Comparative tests showed that by protecting the material with a blast of inert gases it is possible to use refractory compounds as open-cycle electrode materials.

Thermodynamic analysis of the possible titanium carbide oxidation reaction [7] testifies to the fact that in the temperature interval of 300-2000°K the most probable reaction is



since in this temperature interval this reaction has the greatest amount of change in free energy and correspondingly in the values of vapor pressure for the gaseous components.

Study of thermodynamic equilibrium in a titanium carbide-nitrogen system when different products of the CN and C reaction are obtained, showed that when titanium carbide interacts with nitrogen and carbon is obtained the free energy of the reaction decreases as temperature rises. As a consequence titanium carbide practically ceases to react with nitrogen at 926°K. A reaction of

titanium carbide with nitrogen and the obtaining of gaseous CN is impossible and theoretically can occur only at very high temperatures (12,500°C).

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