PROTECTIVE COATINGS ON 316L STAINLESS STEEL FOR APPLICATION AS MOLTEN CARBONATE FUEL CELL CURRENT COLLECTORS

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Protective coatings on 316L stainless steel were investigated as interconnect candidates for molten carbonate fuel cells (MCFCs). Co-Cr-based PVD-deposited systems were studied for oxidation resistance and surface electrical conductivity after holding for 1000 h at 600°C in the air. Coatings based on Co-Cr-Mo and Co-Cr-Al-Ti-Fe-Cu retained conductivities above 10^5 S/m, whereas Nb- and V-containing coatings degraded severely. The Co-Cr-Al-Ti-Fe-Cu system showed the best balance of oxidation resistance and electrical conductivity.

Keywords: molten carbonate fuel cell, current collectors, protective coatings, oxidation resistance, electrical conductivity

Introduction. Molten carbonate fuel cells (MCFCs) operate at temperatures around 650°C, which enables the use of relatively low-cost electrodes and allows operation not only on hydrogen but also on hydrocarbon fuels [1]. However, under such conditions, the choice of current collector materials becomes a challenge, as they must remain stable both in reducing (anode) and oxidizing (cathode) environments, exhibit corrosion resistance, catalytic activity (to support electrochemical processes), low contact resistance, and, at the same time, be cost-effective [2]. Several main classes of materials are considered for current collector fabrication [3]: ferritic steels, which are inexpensive but lack sufficient corrosion resistance on both the anode and cathode sides; nickel-based alloys, which, despite their excellent corrosion resistance in anode environments, are not economically viable due to high cost; and austenitic stainless steels such as 316L and 310 [4], which offer adequate corrosion resistance on the cathode side at a relatively affordable price, making them promising candidates for large-scale application. One of the approaches to improving their properties is the use of functional protective coatings.

The aim of this work is to investigate oxidation resistance and electrical conductivity of the protective coatings on 316L stainless steel to identify coating systems capable of ensuring long-term stability and functionality of interconnects in molten carbonate fuel cells.

Experimental. 316L stainless steel specimens of sizes 0.4 × 20 × 20 mm^3 were used as substrates. The substrates were polished using abrasive silicon carbide paper to a roughness Ra of about 0.02 μm, then chemically degreased and ultrasonically cleaned in a hot alkaline bath for 10 min and dried in warm air. After cleaning, they were mounted on a rotating holder of a chamber (rotation speed of about 30 rpm). The distance between substrates and a cathode was about 300 mm. The chamber was evacuated to a pressure of 1×10^{-3} Pa. Argon gas was introduced into the vacuum chamber up to pressure 5×10^{-2} Pa for stable burning of the arc discharge [2]. Using the PVD method, 4 types of coatings with a thickness of 5-6 μm were deposited (Table 1).

Table 1. The studied coatings and their specific electrical conductivity

#	Coating system	σ_{in}, S/m
1	Co-Cr-Mo	$3\cdot10^6$
2	Co-Cr-Al-Ti-Fe-Cu	$1\cdot10^6$
3	Nb-Co-Cr-Al	$1\cdot10^6$
4	V-Co-Cr-Al	$1\cdot10^6$

The material microstructure was studied with a Carl Zeiss EVO-40XVP scanning electron microscope (SEM). The chemical homogeneity evaluation of materials was based on an energydispersive X-ray (EDX) microanalysis performed using an INCA Energy 350 system.

The oxidation resistance tests were divided into four stages, and each of them has duration of 250 h. Each stage consisted of heating to 600°C in air, exposition for a certain time, and cooling to room temperature. The weight of the specimens was measured before the test and after each stage by an analytical balance. The accuracy of the weight measuring was ± 10^{-4} g. The oxidation resistance of materials was characterized by weight gain per unit surface area Δm/S. Four-point probe measuring method and Ossila Four-Point Probe (UK) device were used after specimen cooling at each stage to characterize the electrical conductivity (σ) of the specimen surface in initial and post-oxidized states.

Results and discussion. The deposited coatings are homogeneous, without visible defects such as cracks or pores, while the EDX spectra confirm uniform distribution of the main alloying elements (Fig. 1).

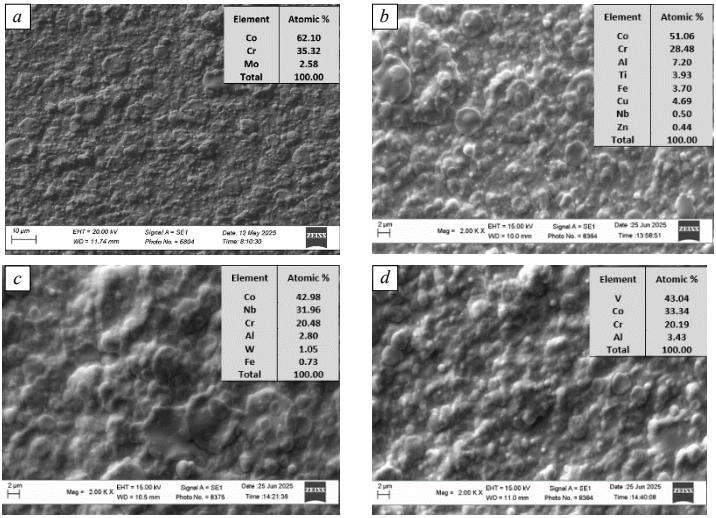

Fig. 1. SEM images and chemical compositions of coatings in the initial state: *a* – variant #1, *b* – #2, *c* – #3, *d* – #4.

After holding for 1000 h at 600°C in the air, coatings #1 and #2 largely preserved their structure, while coating #3 showed partial degradation and coating #4 suffered severe oxidation (Fig. 2).

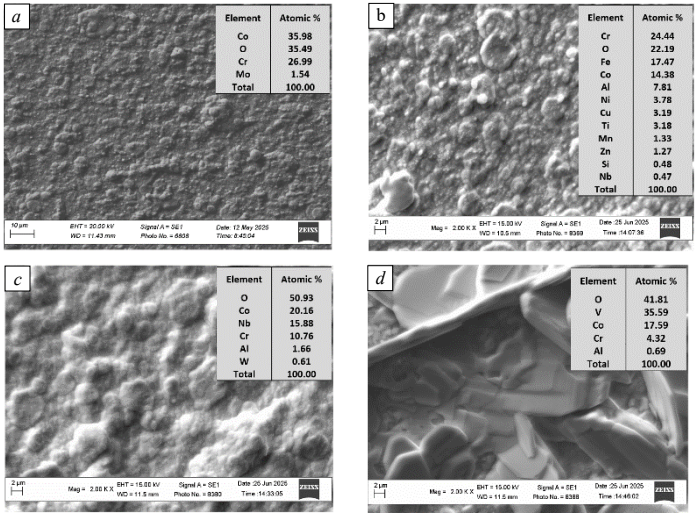

Fig. 2. SEM images and chemical compositions of coatings after holding for 1000 h at 600°C in the air: *a* – variant #1, *b* – #2, *c* – #3, *d* – #4.

As summarised in Table 2, after 1000 h at 600°C in the air coatings variant #1 and #2 retained surface conductivity at the level of 10^5 S/m, whereas the Nb-based coating (variant #3) showed a drastic decrease to ~50 S/m. The V-containing coating (variant #4) demonstrated almost complete loss of conductivity ($<10^{-5}$ S/m), making it unsuitable for interconnect applications.

Table 2. Electrical conductivity of deposited coatings after 1000 h thermal exposure at 600 °C in air

#	Δm/S, mg/cm^2	σ_{ox}, S/m
316L	0,027 [5]	$2\cdot10^5$ [5]
1	0,048	$1{,}4\cdot10^5$
2	0,012	$1{,}5\cdot10^5$
3	0,096	$5\cdot10^1$
4	1,34	$<10^{-5}$

The coating of variant 2 demonstrated twice the oxidation resistance compared to the substrate material, while maintaining a satisfactory level of electrical conductivity, which makes it a promising candidate for interconnects in molten carbonate fuel cells.

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1. *EG&G Technical Services, Inc. Fuel Cell Handbook (Seventh Edition). U.S. Department of Energy, Office of Fossil Energy, National Energy Technology Laboratory. – 2004. – 450 p.*
2. *Zhu B. Corrosion of current collector materials in the molten carbonate fuel cell. Doctoral Thesis. Department of Chemical Engineering and Technology, Applied Electrochemistry, Royal Institute of Technology, Stockholm. – 2000. – TRITA-KET R 128, ISSN 1104-3466, ISRN KTH/KET/R-128-SE.*
3. *Wang P., Du K., Yin H., Wang D. Corrosion and protection of metallic materials in molten carbonates for concentrating solar power and molten carbonate electrolysis applications. Materials Reports: Energy. – 2023. – 3:100118.*
4. *Frangini S., Loreti S.* The role of alkaline-earth additives on the molten carbonate corrosion of 316L stainless steel // *Corrosion Science. – 2007. – 49(3). – 1045–1057.*
5. *V.Ya. Podhurska, R.V. Chepil, M.M. Kuzmenko, O.P. Ostash Long-term oxidation resistance and electrical conductivity of materials in the cathode and anode environments of fuel cells. Mater Sci (2025). https://doi.org/10.1007/s11003-025-00921-y*