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SILICON CARBIDE COATINGS ON ZIRCONIUM ALLOY FOR LIGHT WATER REACTOR FUEL CLADDING STUDIES

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ПОКРЫТИЯ ИЗ КАРБИДА КРЕМНИЯ НА ЦИРКОНИЕВОМ СПЛАВЕ ДЛЯ ИССЛЕДОВАНИЙ ТЕПЛОВЫДЕЛЯЮЩЕЙ ОБОЛОЧКИ ЛЕГКОВОДНЫХ РЕАКТОРОВ

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Аннотация. *Нанесение покрытий на циркониевые сплавы является перспективным подходом для повышения различных свойств оболочек тепловыделяющих элементов, включая физико-механические свойства, устойчивость к коррозии и снижение радиационных повреждений. В настоящей работе покрытия SiC с толщинами 100, 200 и 300 мкм были осаждены методом селективного лазерного спекания (SLS) на подложки из сплава Zr-1Nb при мощности лазера 150 Вт. Сканирующая электронная микроскопия (СЭМ) показала среднюю шероховатость поверхности от 3,5 до 7 мкм. Однородность и небольшая пористость покрытий наблюдается на поперечных шлифах. Анализ фазового состава покрытия выявил образование фаз карбида кремния и оксидов Al2O3, Y2O3, SiO2 и YAlO3. Результаты скретч-тестов показали отсутствие отслоений и высокую адгезию покрытия, однако наблюдались частичные откалывания и поперечные трещины. Полученные результаты указывают на необходимость дальнейших исследований по улучшению пористости поверхностной структуры покрытия и проведения других необходимых испытаний.*

Introduction. Since 2011 following the tragic Fukushima Daiichi Nuclear Power Plant accident, the quest for Accident Tolerant Fuel (ATF) has become extremely essential towards shaping the safety path of future nuclear industries. Though zirconium-based alloys have gained acceptance over decades in the nuclear industry, the submissiveness of zirconium during Loss of Coolant Accident (LOCA) event in which the oxidation response of zirconium at a higher temperature speedily deteriorates in its integrity under such condition calls for the need in enhancing the next generation of cladding materials [1]. One of the approaches in enhancing the fuel cladding tube includes protective coatings on zirconium based alloys. Thin coatings are anticipated to have marginal importance in terms of the thermomechanical properties of zirconium based claddings [2]. Also, these coatings do not exceptionally change the central physics in LWRs [3] but are likely to improve the heat transfer performance of the cladding [4]. Some studies have proven various depositions on zirconium based alloy substrates effective in overcoming oxidation, resisting corrosion and minimizing the vulnerability of grid-to-rod fretting failures.

According to published researches, ATF coating material composition should have at least *Cr, Al* or *Si* in order to form one of the protective oxide phases (*Cr2O3*, *Al2O3,* and *SiO2*) in strengthening the underlying material.

Ceramic coatings involving *TiN*, *TiAlN*, *Ti3SiC2*, *Ti2AlC* and *SiC* have been investigated in recent times, however, *SiC* has more outstanding properties than most ceramics. Hence, there is the need to further investigate *SiC* depositions with several 3D printing techniques to compare their various properties in order to make the right choices of factoring cost, time and efficiency of the fabrication methods engaged. Therefore, this study aimed at depositing *SiC* composite coatings on *Zr-1Nb* alloy substrates using the SLS technique, followed by microstructural and scratch adhesion investigations and analysis.

Research methods. A sample of dimensions (40 mm × 25 mm × 2 mm) of the E110 (*Zr-1Nb*) alloy substrate was polished and cleaned with acetone on all faces and measured at an average roughness of 0.3 µm with the Hommel tester T1000. The SLS system was equipped with the Ytterbium fiber laser (IPG Photonics, Moscow, Russia) of 1070 nm output wavelength and 500 W maximum power. *SiC* powder (grade: SIKA DENSITEC L, Norway) was used in this research. Deposition of the *SiC* on the substrate was performed at coating thicknesses of 100 µm, 200 µm, and 300 µm, respectively, as indicated in Table 1.

Table 1

Parameters followed in the SLS fabrication

Laser power (W)	Scanning time (µs)	Laser speed (mm/s)	Deposition thickness (µm)			Atmosphere
150	600	25	100	200	300	Air

Results. Fig. 1 is a micrograph showing the weakest portions of the coating variants a, b and c corresponding to 100, 200 and 300 µm thick deposition respectively using the TESCAN VEGA3 SEM system. These surfaces were characterized by fewer shallow trenches, coarse-grained structures with few micro-cracks in the 100 µm deposition. It was observed that thicker coatings present more uniformity compared to the 100 µm thick variant. Fig. 2 shows a cross-section of 100 µm thick deposition. It can be observed that about 50 µm coating layers were embedded into the substrate to keep the coating firm into the zirconium substrate. Nano to micro scratch tests were incompatible to the coating due to the higher level of adhesiveness exhibited by the coatings, hence macro-scratch test was carried out involving constant loads of 50 N to 100 N. Fig. 3 shows the scratch paths and its associated features. SEM observations along the coating paths reveal less degradation despite the higher magnitude of load exerted by the diamond stylus during the test. No major spallation was observed but chippings along both sides of the groves. EDS taken along the scratch path shows the presence of some remains of the coating material composition such as *Si, O, Al*, and substrate material *Zr* being the majority.

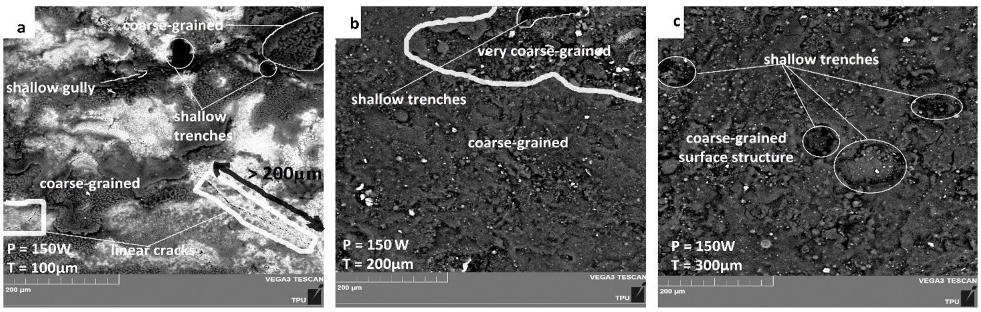

Fig. 1. Micrograph of the surface morphologies of coated samples

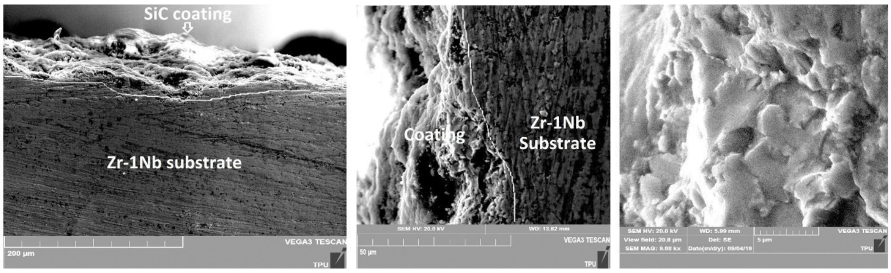

Fig. 2. Micrograph showing the cross-sections through coating and substrate of 100 µm deposition

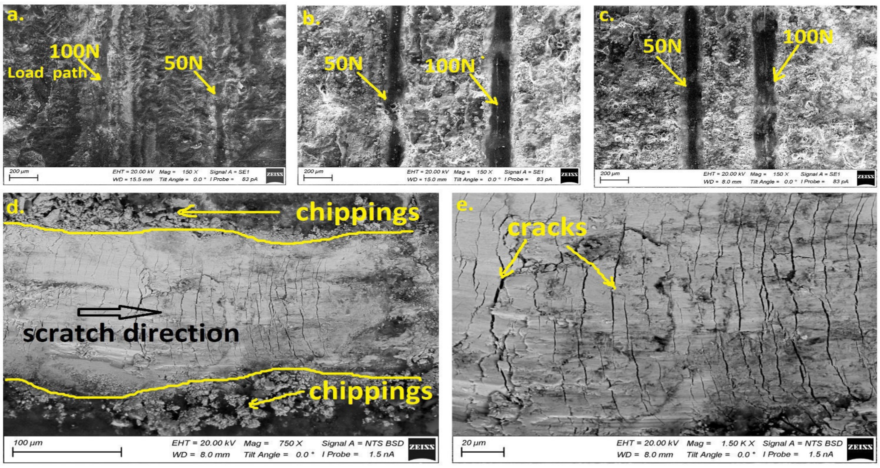

Fig. 3. Scratch paths created by a stylus with constant loads of 50 N and 100 N on (a) 100 µm, (b) 200 µm, (c) 300 µm thick coating specimen, (d) a typical scratch path and its associated features (d, e)

Conclusion. *SiC* micro-composites were deposited on *Zr-1Nb* alloy substrates at 100, 200, and 300 µm for cladding material studies. Experimental investigations and analysis involving SEM surface structure, XRD phase composition, EDS elemental composition and scratch adhesion of the coating were carried out to understand the major changes in the coating properties. SEM surface structures reveal coarse grained, shallow trenches in all variants but higher uniformity was achieved in the higher layer thick variants. Uniformity and less porosity are established in the cross-sections as observed at 5 µm magnification. Phase compositions include *β-SiC (6H)*, *SiC (4H), Si* and essential oxides such as *Al2O3*, *Y2O3*, *SiO2* and *YAlO3* were recorded in the coating. Macro scratch test results show fewer deteriorating effects when observed at a microscale. Finally, results from microstructural features to scratch adhesion details exhibit promising results which guarantee further research in order to absolutely establish the necessary details required.

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