Silicon carbide-based nanocomposite for anti-erosion coatings by chemical vapor deposition

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Introduction

Enhancing the erosion resistance of sliding and sealing components in pumps is a critical issue for ensuring the reliability and efficiency of energy systems such as pumped-storage hydroelectric power. Silicon carbide (SiC) is an attractive anti-erosion material for mechanical seals due to its notable properties such as high strength, high hardness and chemical inertness. However, its brittle nature renders SiC mechanical seals less reliable under severe slurry erosion involving sand and gravel. Moreover, the costly manufacturing process requiring high sintering temperature limits the widespread adoption of SiC mechanical seals. Therefore, the development of anti-erosion SiC coatings on mechanical seals of ductile and more cost-effective materials becomes significant to impart value-added characteristics to mechanical seals and extend the operational lifespan of pumps. To develop highly durable coating systems, it is important to maintain the hardness of SiC while reducing the elastic modulus of ceramic coatings. This study aims to develop coatings comprising SiC and tantalum carbonitride (TaCN) with high hardness and moderate modulus. The deposition of SiC– TaCN nanocomposite coatings on ceramics and metal substrates is demonstrated using laser chemical vapor deposition with metal-organic precursors.

Experimental Procedures

SiC–TaCN films were prepared using a custom-built cold-wall CVD instrument with high-power laser Hydridopolycarbosilane and alkylamino tantalum were used as precursors for SiC and TaCN, respectively. The precursor liquids were separately heated in precursor furnaces, and the precursor vapors were transported into the reaction chamber through gas lines with an Ar carrier gas. The silicon nitride (Si_3N_4) or SUS316 substrates were irradiated with a fiber laser, resulting in deposition temperatures of 800–1100°C. X-ray diffraction was used to identify the crystalline phases of the SiC–TaCN coatings. Scanning and transmission electron microscopes and X-ray photoelectron spectroscopy were employed to observe the surface and cross-sectional microstructure and to analyze the chemical bonding states and compositions. An instrumented indentation test was performed on the polished cross section of the SiC–TaCN coating using a diamond Berkovich indenter at room temperature. Erosion tests were carried out using a wet-blast-type erosion test machine at room temperature using spherical zirconia beads.

Results and Discussion

Dense and homogeneous coatings comprising low-crystallinity SiC and TaCN grains smaller than 10 nm, finely mixed and dispersed to form a nanometric mosaic structure were deposited on Si_3N_4 substrates at a deposition temperature of 1000°C (Fig.1). Cross-sectional nanoindentation tests revealed a reduced Young's modulus of 238.2 GPa and a hardness of 30.4 GPa. The SiC–TaCN nanocomposite film exhibited superior durability in erosion tests using a zirconia slurry under a pressure of 20 kPa [1]. For the deposition on SUS316 substrates, the high processing temperature, combined with the mismatch in thermal expansion coefficients, led to crack formation and delamination, hindering the formation of durable coatings. The presentation will cover the detailed structure and properties of the anti-erosion SiC–TaCN nanocomposite coating, as well as the solutions implemented to overcome the challenges of coating on metallic substrates by introducing a bond coat.

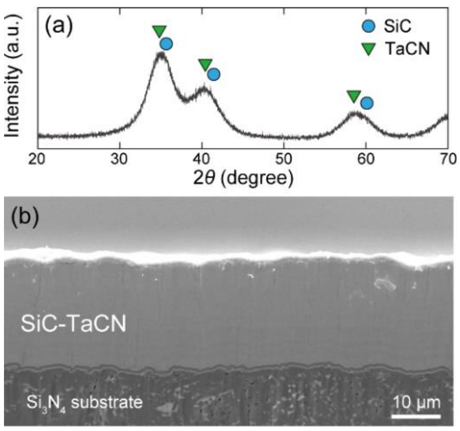

Figure 1 Typical XRD pattern (a) and cross-sectional SEM image (b) of anti-erosion SiC–TaCN nanocomposite coating.

References

[1] H. Katsui, K. Shimoda and M. Hotta, Ceram. Int. 49, 38813–38823 (2023)