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EFFECT OF INPUT POWER ON THE PHASE COMPOSITION AND MICROSTRUCTURE OF AIR PLASMA-SPRAYED YTTERBIUM DISILICATE ENVIRONMENTAL BARRIER COATINGS

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ABSTRACT

Ytterbium disilicate ($Yb_2Si_2O_7$, YbDS) is the current state-of-the-art environmental barrier coating (EBC) topcoat for protecting SiC/SiC ceramic matrix composites (CMCs) from rapid surface recession caused by high-temperature water vapor in gas turbine combustion environments. YbDS is widely deposited by air plasma spray (APS) due to its cost-effectiveness and high deposition rate. However, the resulting coating phase composition and microstructure are directly affected by process parameters, particularly input power. Excessive input power can induce silica volatilization and the subsequent formation of the undesirable ytterbium monosilicate (Yb_2SiO_5, YbMS) phase, resulting in increased coating CTE and crack formation during service. Conversely, increased particle melting at higher power reduces coating porosity and enhances microhardness, but also produces an amorphous as-sprayed deposit that requires post-deposition heat treatment to crystallize. Therefore, this article examines the influence of input power on the phase composition and microstructure of YbDS coatings, and its consequent effect on coating properties and durability.

KEYWORD

Environmental barrier coatings, Ytterbium disilicate based coating, SiC, Air plasma spray, Input power

INTRODUCTION

The most effective approach to improving the efficiency of gas turbine engines is to increase the inlet temperatures or reduce the weight of structural components (Paksoy & Xiao, 2023). Ni-based super-alloys protected with thermal barrier coatings (TBCs), currently used in gas turbine hot-section components, have reached their operational temperature limit, requiring a shift to next-generation materials (Tejero-Martin et al., 2021). To address this challenge, SiC/SiC ceramic matrix composites (CMCs) are among the most promising candidates due to their lower density, higher temperature capabilities, and greater mechanical strength at elevated temperatures (Lee et al., 2021). Despite these advantages, water vapor in combustion environments reacts with CMCs to form volatile silicon hydroxide ($Si(OH)_4$), causing rapid surface recession (dos Santos e Lucato et al., 2011). To overcome this limitation, environmental barrier coatings (EBCs) are applied to CMC components to provide a protective barrier against water vapor attack, as shown in Figure 1. Among current EBC materials, ytterbium disilicate ($Yb_2Si_2O_7$, YbDS) is the state-of-the-art EBC topcoat due to its CTE (3.62–4.5 $\times10^{-6}$ °C^{-1}) closely matching that of SiC (4.5–5.5 $\times10^{-6}$ °C^{-1}) and single-phase stability up to its melting point of 1850 °C (Turcer & Padture, 2018; Xu et al., 2017).

Air plasma spray (APS) is currently one of the most industrially attractive techniques for YbDS deposition owing to its high deposition efficiency and cost-effectiveness. However, APS deposition of YbDS involves several interdependent challenges that are strongly controlled by input power. First, elevated input power drives silica volatilization from the YbDS feedstock, shifting the coating composition toward ytterbium monosilicate (Yb_2SiO_5, YbMS) (Bakan et al., 2019). The presence of YbMS is undesirable because it has a high CTE (7.2 $\times10^{-6}$ °C^{-1}) that promotes crack formation during service (Wang et al., 2025; Xu et al., 2017). Second, while higher input power promotes complete particle melting, increases coating density, and enhances microhardness, it simultaneously generates a mainly amorphous microstructure requiring post-deposition heat treatment (Di Iorio et al., 2023; Garcia et al., 2019). This review brings together recent findings on how APS input power influences the phase composition and microstructure of YbDS coatings and how this affects properties and durability.

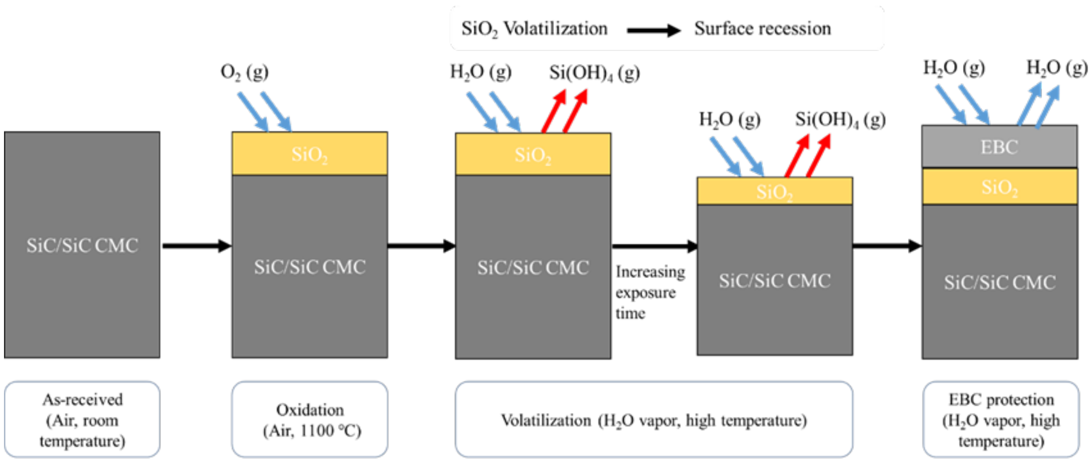

Figure 1: Schematic of the degradation mechanisms of SiC/SiC CMCs in high-temperature water vapor and the protective role of EBCs.

EFFECT OF APS INPUT POWER ON PHASE COMPOSITION

During APS deposition, silica volatilization occurs at high plasma temperatures driven by the high vapor pressure of silica, shifting the stoichiometry of the feedstock powder. The first systematic investigation of the relationship between APS process parameters and YbMS phase formation was reported by Richards et al. (2015), who deposited YbDS coatings across a range of input powers using a Praxair SG-100 torch. The volume fraction of the YbMS phase in the annealed coatings increased from approximately 15 to 24 vol% with rising input power from 9.3 to 13.3 kW. Subsequently, Lynam et al. (2023) used the same torch and studied the effect of a higher input power from 12 to 24 kW. The YbMS content in annealed YbDS coatings increased progressively from 13.0 wt% to 52.0 wt%, with a small fraction of Yb_2O_3 (4.8 wt%) appearing at the highest power level, indicating excessive silica loss. Chen et al. (2021) demonstrated the effect of YbMS on coating performance, reporting that the coating CTE increased from 5.01 $\times 10^{-6}$ °C^{-1} to 6.37 $\times 10^{-6}$ °C^{-1} as the YbMS phase fraction increased from 32.8 to 65.3 vol% using a different APS torch (SinplexPro). This increase in CTE was the main reason for the reduction in thermal cycling life in a steam environment, which decreased from 576 to 355 cycles, highlighting the critical importance of minimizing YbMS content in APS YbDS coatings. Despite the use of different torch models and power ranges across these studies, the trend is consistent: increasing input power systematically increases YbMS content through accelerated silica volatilization. Therefore, APS input power is the primary determinant of YbMS secondary phase content in deposited YbDS coatings, with direct consequences for coating CTE and long-term durability.

EFFECT OF APS INPUT POWER ON COATING MICROSTRUCTURE

Input power is considered one of the primary parameters governing the coating density during APS deposition. Elevated input power generates a plasma with higher enthalpy and velocity, thereby enhancing heat and momentum transfer to in-flight particles and promoting more complete melting, which results in a denser coating microstructure. Lynam et al. (2023) demonstrated this effect in YbDS coatings across four power levels (12, 16, 20, and 24 kW). As shown in Figure 2, at the lowest input power of 12 kW, the coating exhibited the highest porosity of 9.8%. As input power increased to 24 kW, the degree of particle melting improved significantly, producing the lowest porosity of 5.6%, an approximately 43% reduction. This reduction also improved the microhardness of YbDS coatings, which increased from 463 HV to 736 HV, an improvement of approximately 59%.

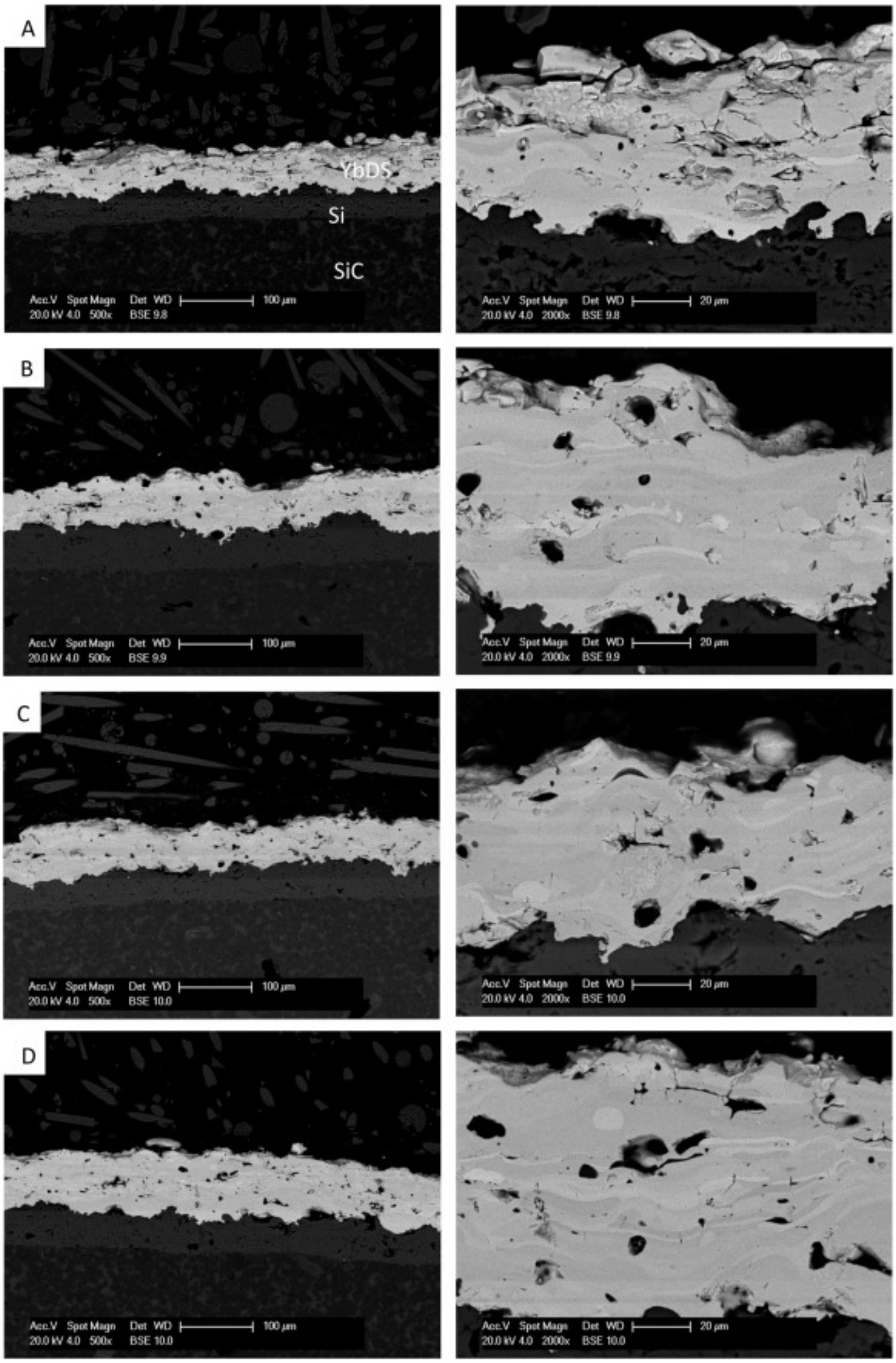

Figure 2: BSE SEM images of heat-treated YbDS coating microstructures deposited using four input power levels of (a) 12, (b) 16, (c) 20 and (d) 24 kW (Lynam et al., 2023).

In addition to porosity, input power also influences the crystallinity of the deposited coating (Di Iorio et al., 2023). The amorphous structure is caused by extremely rapid cooling rates, ranging from 10^4 to 10^8 K/s, which inhibit crystallization (Fan et al., 2023). Wang et al. (2022) demonstrated the effect of power on as-deposited coating crystallinity, reporting that at the lowest input power, the as-sprayed coating retained visible crystalline YbDS diffraction peaks attributed to the presence of partially unmelted particles alongside a broad amorphous hump. However, with increasing input power, the amorphous hump became more visible, indicating a progressively higher amorphous fraction due to more complete particle melting. At the highest input power, additional YbMS peaks appeared, indicating excessive silica volatilization at this elevated power level. Therefore, post-deposition annealing at 1300 °C for 4 h is commonly applied to crystallize as-sprayed amorphous YbDS coatings (Harder & Gildersleeve, 2026).

CONCLUSION

This review establishes that APS input power is the key processing variable for YbDS EBC fabrication because it controls phase composition and microstructural development. The evidence reviewed shows that input power has both beneficial and detrimental effects. Increasing input power achieves more complete particle melting and reduces porosity by approximately 43%, resulting in an approximately 59% improvement in microhardness. The same increase shifts the coating away from the target YbDS phase through silica volatilization, first toward a YbDS/YbMS mixture, and at the highest powers, further to Yb_2O_3. The presence of YbMS raises the coating CTE, promoting cracking that reduces both coating durability and performance. The more complete particle melting that reduces porosity also produces a mainly amorphous as-sprayed deposit that requires post-deposition heat treatment to crystallize. Therefore, APS YbDS coatings remain sensitive to the specific processing conditions under which they are deposited, and simultaneously optimizing phase composition and microstructure remains an open challenge for the field.

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