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Improved cold sprayed CoNiCrAlY bond coat in thermal barrier coating

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ABSTRACT – An improved CoNiCrAlY bond coat in thermal barrier coating (TBC) was developed by fabricating the bond coat under optimized condition using cold spray (CS). The smoothed particle hydrodynamics (SPH) method was used to model CoNiCrAlY deposition and estimate the optimum velocity which is normally obtained via costly and time consuming experiments. The performance of TBC with bond coat cold sprayed under optimized condition was assessed. It was found that the TBC exhibit slow growing undulated TGO with minimal mixed oxide. The improved CS bond coat can reduce the probability of spallation of the top coat and the failure of TBC.

1. INTRODUCTION

Thermal barrier coatings (TBCs) are widely used in gas turbines to increase their efficiency. A TBC consists of a metallic CoNiCrAlY bond coat and a ceramic top coat. During service, a thermally grown oxide (TGO) develops and continues to grow between the top coat and the bond coat. The formation of TGO plays a crucial role in the failure of TBC [1]. One of the commonly observed failure mechanisms is the spallation of the top coat initiated by rapid and uneven TGO growth and formation of mixed oxide. The performance of TBC with cold sprayed (CS) bond coat is significantly improved compared to a TBC with conventional thermal sprayed bond coat [2]. CS is a relatively new powder deposition technique used to deposit metal particles at temperature below the melting temperature of the metal. Under optimized condition, the impacting particles can form dense coatings with low oxide content thus minimizing thermal damage to the substrate [3]. However, there are relatively few reports on the formation of CoNiCrAlY coatings obtained by the CS process.

In this study an improved CoNiCrAlY bond coat in TBC was developed by fabricating the bond coat under optimized condition using CS. The smoothed particle hydrodynamics (SPH) method was used to model CoNiCrAlY deposition and estimate the optimum velocity which is normally obtained via costly and time consuming experiments. The performance of TBC with bond coat cold sprayed under optimized condition was assessed. It was found that the TBC exhibit slow growing undulated TGO with minimal mixed oxide. The improved CS bond coat can reduce the probability of spallation of the top coat and the failure of TBC.

2. METHODOLOGY

2.1 *Materials*

The feedstock powder used to deposit the bond coat is the gas atomized AMDRY 9951 (Sulzer Metco). It is a conventional CoNiCrAlY powder with a spherical morphology and a size distribution ranging from 5 – 37 µm or an average size of 25 µm. The substrate on which the powder is deposited is Inconel738LC. Inconel718 and high carbon steel will be used in the numerical analysis as a material substitute to Inconel738LC and CoNiCrAlY respectively.

2.2 *Numerical Model*

The SPH modeling of the CS process was performed using an in-house research program developed in FORTRAN. The impact of high carbon steel on Inconel718 is simulated using SPH. The Johnson-Cook parameters and Gruneisen equation of state are obtained from literatures [4, 5] and presented in Table 1.

Table 1 Material properties of high carbon (HC) steel and Inconel718.

Properties (Unit)	HC steel	Inconel 718
Density, ρ (g/m^3)	7870	8220
Shear Modulus (GPa)	79	77
Heat capacity (J/kg/K)	465	430
Reference temperature, T_0 (K)	298	298
Melting temperature, T_m (K)	1700	1570
JC parameter, *A, B, C, n, m* *(MPa)*	450, 1700 0.017,0.65 1.3	460, 1100, 0.0073, 0.55, 1.0
Gruneisen parameter Γ	2.2	1.07
Intercept Us-Up curve *c* (m/s)	4580	4573
Slope Us-Up curve, *S*	1.49	1.338

2.3 *Cold Spray Deposition and Oxidation Tests*

The specimens used in this study were TBCs comprising an 8wt.% Yttria-stabilized zirconia (YSZ) (Sulzer Metco NS-204) top coat and a Co-32Ni-21Cr-8Al-0.5Y (Sulzer Metco AMDRY9951) bond coat, deposited on a Ni base superalloy, Inconel738LC. The YSZ top coat was manufactured by arc plasma spray and the CoNiCrAlY bond coat was manufactured by CS. The bond coat was deposited with He, at 2 MPa and 600 °C, parameters that yield the optimum velocity. For comparison the bond coat was also deposited at 1 MPa and 600 °C. To confirm the influence of particle velocity on TBC performance, the oxidation behaviour of the bond coat is investigated. Cross-sections of the specimens were prepared for the oxidation testing. These samples were then subjected to isothermal oxidation at 900 °C for 100 h. Samples from the oxidation tests were mounted in a phenolic resin and manually polished to a mirror finish.

3. RESULTS AND DISCUSSION

Figure 1(a) shows the deformation pattern and temperature contour of a 25 µm powder particle on a flat substrate at the optimum velocity. The optimum velocity is obtained via Er/Ed graph given in Fig. 1(b). The optimum velocity was found to be 900 m/s where the Er/Ed value is the lowest, i.e, where the tendency to rebound is the lowest.

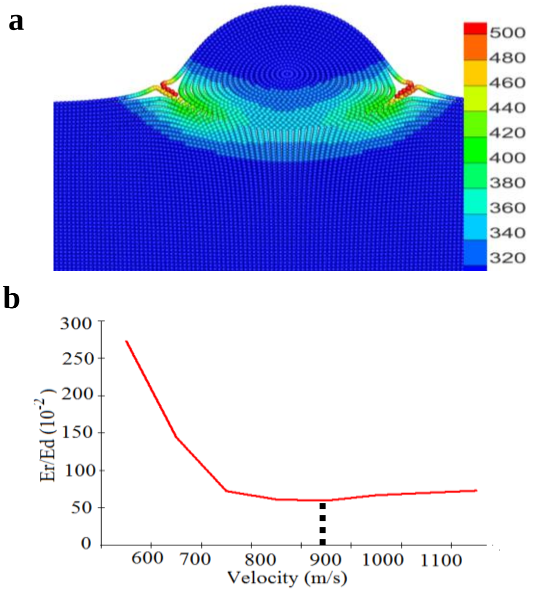

Figure 1 (a) Deformation pattern and temperature contour of a powder particle impacting on a flat substrate at (b) optimum velocity obtained using Er/Ed graph.

Microstructures of the TGO development are given in Fig. 2. An undulated TGO is formed between the top coat and the bond coat interface. After 100 h of oxidation, the bond coat cold sprayed at the optimum velocity exhibit a dense and uniform morphology. Whereas the bond coat cold sprayed at a velocity lower than the optimum velocity exhibits a porous and more undulated TGO with formation of detrimental mixed oxides. This can be attributed to the low porosity of the bond coat deposited at the optimum velocity.

4. CONCLUSION

The impact behaviors of each case are numerically analyzed using SPH. The optimum velocity was determined by evaluating the ratio of rebound and deposition energy. The bond coat was deposited at the optimum velocity and oxidized at 900°C for 100 h. The TGO exhibit a dense and uniform morphology compared to the TGO on the bond coat deposited at velocity lower than the optimum velocity. High quality bond coat that forms a stable and continuous alumina can be produced by the CS deposition technique deposited at the optimum velocity.

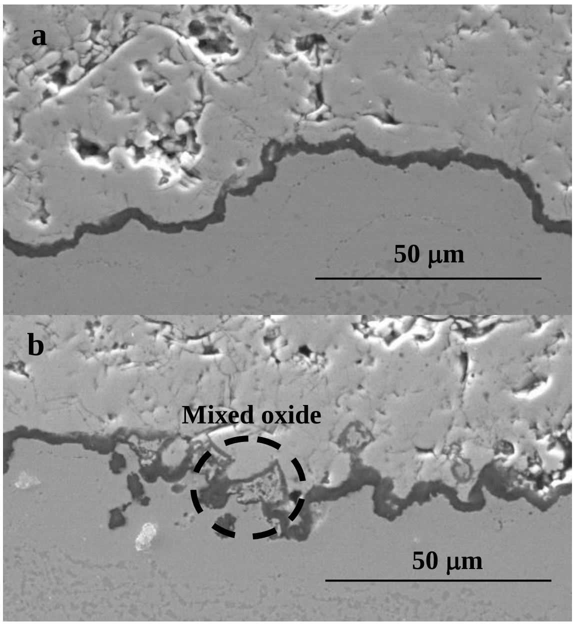

Figure 2 TGO development of bond coat cold sprayed at (a) optimum velocity and (b) velocity lower than the optimum velocity after 100 h of oxidation.

5. ACKNOWLEDGEMENT

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6. REFERENCE

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