Solid State Science and Technology, Vol. 19, No 1 (2011) 32-39
ISSN 0128-7389

ATMOSPHERIC PLASMA SPRAY OF NiCrAlY BOND COAT WITH DIFFERENT FEED RATES

S. Istikamah*, M. F. Fazira and R. J. Talib

Advanced Material Research Center (AMREC) SIRIM Berhad,
Lot 34, Jalan Hi-Tech 2/3, Kulim Hi-Tech Park,
09000 Kulim Kedah, Malaysia

**Corresponding Author: istikama@sirim.my*

ABSTRACT

Thermal barrier coating (TBC) is used to reduce the temperature imposed on hot section of the component, which are subjected to high temperature such as gas turbine and diesel engine. TBC consist of a metal bond coat (MNiCrAlY, M=Ni Co) and a ceramic top layer (ZrO_2/Y_2O_3). The bond coat is used to mediate the contact between the top coat and the metal alloy substrates, while the top coat of zirconia coating offer an excellent thermal shock resistance as a thermal barrier coating. In this study, the bond coat of Ni22Cr10Al1.0Y powders were deposited on M2 steel substrates by atmospheric plasma spray technique repeated at three different feed rate i.e., 0.5, 1.0, 1.5 rpm while other parameters were kept constant. The surface morphology demonstrates overlapping splat and other appears to be poorly consolidated by fine particles, with no definite splat structure. Results show that an increase in feed rate resulted in increase of thickness of bond coat and surface roughness but decrease in hardness of the coatings. The studies also show that deposition of ZrO_2-$8Y_2O_3$ has higher resistance towards hot corrosion when compared to the application of bond coat only.

Keywords: NiCr; corrosion; bond coat;

INTRODUCTION

Thermal barrier coatings (TBCs) have been employed to protect the metallic components (e.g. combustion cans, blades and vanes) from oxidation and corrosion at high temperature by air plasma spraying (APS) process or the electron beam physical vapor deposition (AB-PVD). The current TBC system is formed of metallic bond coat (e.g., NiCrAlY), of 100 to 150 μm thickness, that provides an oxidation resistances and yttria stabilized zirconia (YSZ) top coat, of 250 to 350 μm thickness, that provides thermal stability to the base metal cause by insulation from the heat [1].

A bond coat is usually employed in TBCs to protect the substrate from oxidation to improve their structural effectiveness and the adhesion between the zirconia-based top coat and the superalloy substrate. The bond coat is usually deposited on the substrate using the APS process because of economic consideration even though a high number of defects such as pores and microcracks can occur. However, an increase in the working temperature of a turbine can lead to service limits of the TBCs having a bond coat prepared using the APS process. Therefore, mechanical properties and oxidation resistance of a bond coat in the TBC system should be enhanced and improved to elongate their lifetime [3].

In this work, the Ni22Cr10Al1.0Y bond coat was deposited on M2 steel substrate via APS process. The effect of feed rate parameters was evaluated on the splat structure, thickness, surface roughness and hardness. The top coat of ZrO_2-8Y_2O_3 was deposited on the high mechanical properties of bond coat with required thickness.

MATERIALS AND METHOD

The bond coat powder being used is a conventional Ni22Cr10Al1.0Y, AMDRY 962 by Sulzer Metco, USA exhibits overall particle size distribution varying from ~50 to 140 μm while the top coat is nanostructured ZrO_2-8Y_2O_3, Nanox S4007 by Inframat, USA with the particle size between 15 to 150 μm. Prior to the spraying, the M2 steel substrate, 14.7 x 19.8 mm was blasted and cleaned ultrasonically in acetone. The system used for the plasma spray was a Praxair 100-kW with a standard SG-100 torch. The deposition conditions are listed in Table 1.

Table 1: Spraying parameter

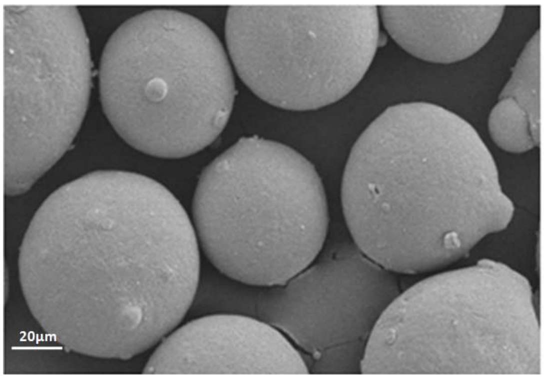
Process Parameter	unit	*B1*	*B2*	*B3*	*T1**
Feed rate	rpm	0.5	1	1.5	4
Argon sec gas	psi	35	35	35	40
He primary gas	psi	50	50	50	120
Argon carrier gas	psi	30	30	30	30
Preheat passes		1	1	1	0
No of passes		2	2	2	4
Robot speed	%	40	40	40	40
Current	A	700	700	700	700
Spraying distance	mm	100	100	100	80

*The parameter of B2 was choosen to deposit the top coat, ZrO_2-8Y_2O_3 powder, with the parameter of T1

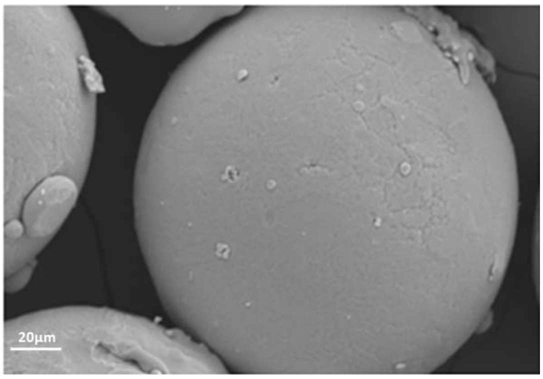
The morphology of the feedstock, the as-sprayed coatings and the thickness of cross-section (ground and polished to remove any residual stress induced) were observed with field emission scanning electron microscope (FESEM, Model Leo 1525, USA). The phase compositions of the coating were examined by X-ray diffractometer (XRD, Model D8, Bruker, Germany). Coating surface roughness was measured for each sample using a surface roughness tester (Mitutoyo). The Vickers microhardness measurement was performed at 100g load for 10s (Zwizk/Roell, Model ZHV10) on the cross-section of coatings. Both roughness and microhradness values are quoted at an average of 10 measurements for each coating.

RESULTS AND DISCUSSION

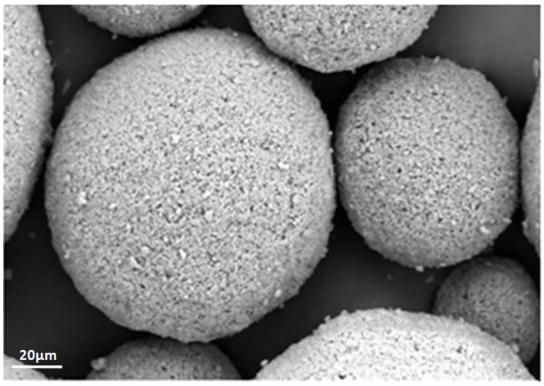
Figure 1 shows the morphology of conventional Ni22Cr10Al1.0Y (spherical in shape) and nanostructured ZrO_2-$8Y_2O_3$ (agglomerated and sintered particle) powder. It can be seen clearly in Figure 1(d) that the nanosized grains of ZrO_2-$8Y_2O_3$ are agglomerated into a microsized powder.



(a) NiCrAlY (500x)



(b) NiCrAlY (1KX)



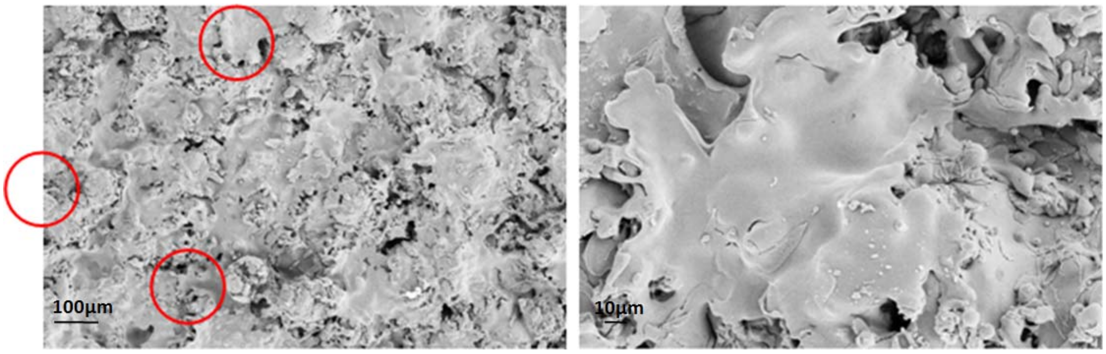
(c) YSZ (1KX)

(d) YSZ (2KX)

Figure 1: Morphology of the NiCrAlY and YSZ feedstock

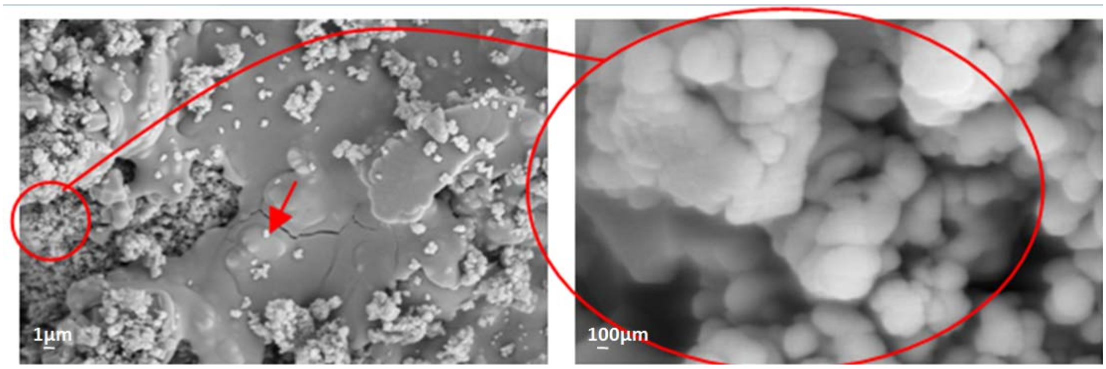
Figure 2 presents the splat morphology of as-sprayed NiCrAlY bond coat. It shows that it possess two kinds of structure. One is densely packed, overlapping (pancake-like) splat as clearly shown on Figure 2(b). The other appears to be poorly consolidated by particles with no definite splat structure as highlighted in Figure 2(a). Figure 3 presents the splat morphology of nanostructured zirconia coating on the bond coat of NiCrAlY. It can be seen that the surface in mainly formed by melted powder with microcracks network (arrow). The microcracks may originate due to the release of the residual stress as molten splats solidify and cool down rapidly. The microcracks are fine and evenly distributed in the coating. It relates to increase of the toughness of the nanostructured zirconia coating (Zhou et al., 2007). It also shows that an irregular shaped granule are formed (circled) and connected with each other, surrounded with many micropores

(Figure 3(b)) with particle size ranging from 50 to 120 nm. The underlying parts of the powder still retain the nanostructure of the powder.



(a) (b)

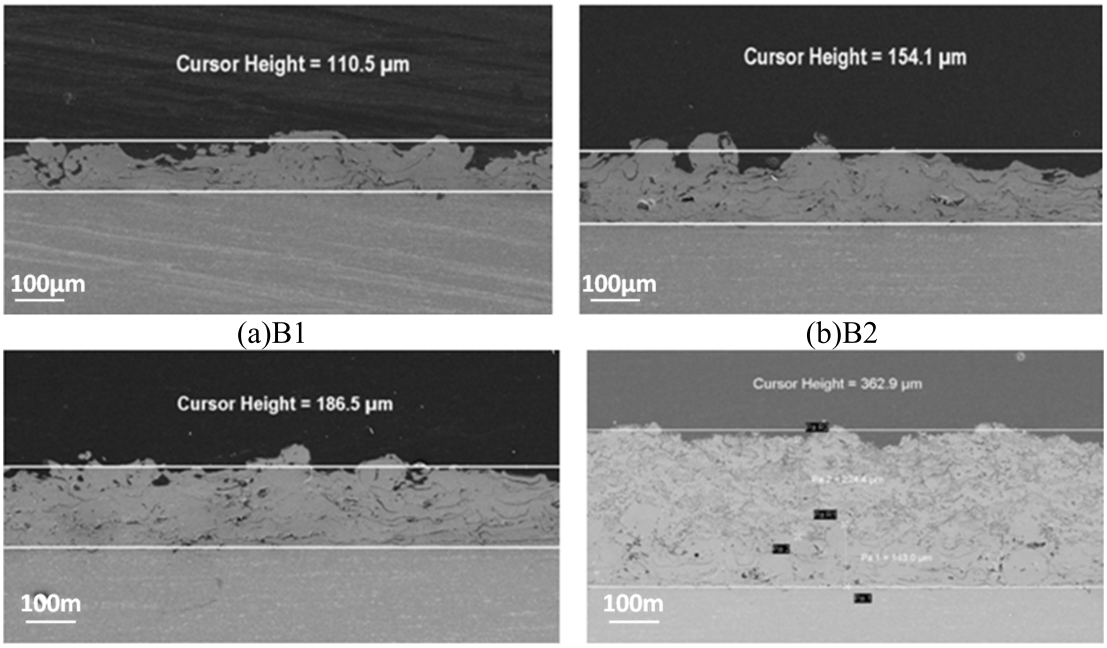
Figure 2: Splat morphology of as-sprayed coating (a) low and (b) high magnification



(a) (b)

Figure 3: As-sprayed zirconia coating deposited on bond coated of NiCrAlY (a) low and (b) high magnification

The SEM images of polished cross-section of the sprayed coatings are shown in Figure 4. Increase in feed rate shows increase in thickness of coatings. Taylor et. al (1992) claimed that the thickness of bond coat is in the range of 100 to 150 µm to protect the substrate from oxidation. As the coating of B2 shows 154 µm thickness, this parameter was selected to deposit the top coat of YSZ as shown in Figure 4 (d).



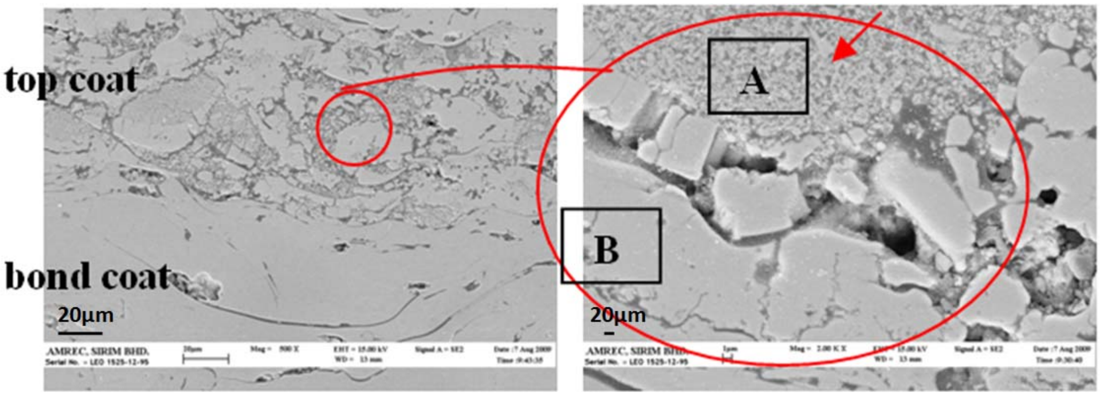
(a)B1 (b)B2

(c)B3 (d)T1

Figure 4: SEM micrographs shows the thickness of coatings (a)B1, (b)B2, (c)B3 and (d)T1

Recently, thicker TBCs, with the thickness of more than 100 µm, have been developed to improve the efficiency of gas engines by allowing an improvement in turbine inlet temperature, and by reducing the amount of cooling air required by the hot section component. A major problem concerning the thick TBCs is an observed reduction in the performance of the coatings when subjected to the thermal shock loads. As shown in the Figure 4(d), the thickness of 363 µm was achieved as the YSZ deposited on NiCrAlY bond coat. However, Steffens et al., (1999) claimed that the necessity thickness of TBCs is up to 500 µm to achieve better heat insulation serves different purposes for diesel engines and aircraft and spacecraft industries, as well as for the chemical and nuclear industries.

In plasma spraying, the microstructure of the coating is strongly dependent on processing conditions. Typical microstructure of the coating system can be observed in Figure 5. A very dense and homogeneous bond coat was obtained. It also has a lamellar structure with microcracks and pores. For the top coat, YSZ, the coating also presents a porous and lamellar structure as clearly shown in Figure 5(b). The feedstock which has been melted (splat) can be observed in regions where a large, dense and smooth structure is found (B). However, the splats are separated by interlamellar pores resulting from rapid solidification of the lamellae, very fine voids formed by incomplete intersplat contact or around unmelted particles (arrow), and cracks due to the thermal stress and tensile quenching relaxation stresses. The unmelted feedstock (A) is similar morphology to that of the feedstock particles; i.e., an agglomeration of particle loosely bound to each other.



(a) (b)

Figure 5: Fracture images of bond and top coat

The results of the as-sprayed coatings are summarized in Table 2. When the feed rate increases, the number of non-molten particles should increase. The presence of non-molten particles increase the roughness of the coating, and it lower the values of hardness due to low particle cohesion. According to the value shown in Table 2, roughness has not increased too much after increase the feed rate parameter. However, considerably lower mean roughness was found for top coat YSZ (T1).

Table 2: Thickness, roughness and microhardness measurement of the coating system

Coating system	B1	B2	B3	T1
Thickness (µm)	110.5	154.1	186.5	362.9
Roughness (µm) Ra	12.44	12.62	12.83	10.51
$HV_{0.1}$ mean (x)	357.4	336.6	323.2	205.0

The average microhardness in the as-sprayed top coat YSZ coating is $HV_{0.1}$ = 205. The noticeable decrease in microhardness is observed in the top coat as compared to the bond coat as shown in Table 2. These value is relatively lower as compared to other references [6,8]. Highest hardness is in demand to ensure the performance of the final product of plasma spayed thermal barrier coatings.

Figure 6 shows the XRD patterns of the NiCrAlY bond coat as-sprayed at different feed rate and for YSZ deposition. Increase in feed rate up to 1.5 rpm shows an intensified crystalline phase as refered to 2-Theta 43.45. For T1 specimen, the top coat of YSZ fully covers the bond coat. The nanostructured YSZ exhibit only presence of tetragonal phase of yttrium zirconia oxide. This tetragonal zirconia (non transformable phase T') exhibits a higher thermal expansion coefficient and thermal conductivity than the other phases of zirconia [9].

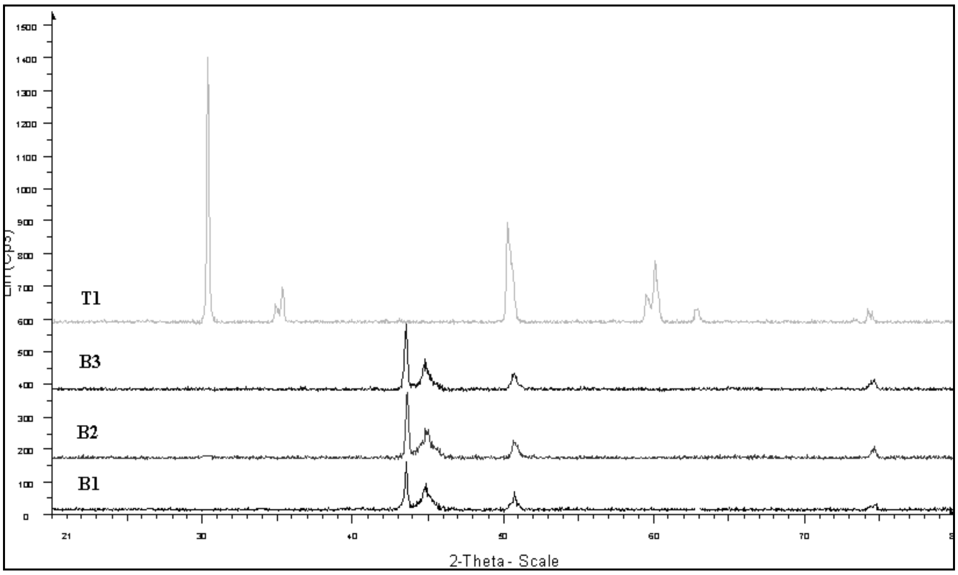


Figure 6: XRD pattern of the NiCrAlY bond coat sprayed at different feed rate parameter and top coat of YSZ

CONCLUSIONS

It is found that the different feed rate of bond coat NiCrAlY has significantly effect the morphology, thickness, roughness and hardness of the coating. As the feed rate increases, the thickness and roughness was enhanced proportionally while the values of hardness was decreased. However, for the top coat of YSZ, the hardness tends to drop as the feed rate is increased. Further research need to be done to get the best thickness of bond coat with higher hardness value of top coat.

ACKNOWLEDGEMENT

The research work was funded by Ministry of Science, Technology and Innovation of Malaysia under Science Fund with project number 03-03-02-SF0080.

REFERENCES

[1] I. Gurappa and A. Sambasiva Rao, *Surf. Coat. Tech.* **201** (2006) 3016
[2] R. Taylor, J.R. Brandon and P. Morrell, *Surf. Coat. Tech.* **50** (2) (1992). 141
[3] S. Ahmaniemi, J. Tuominen, M. Vippola, P. Vuoristo, T. Mäntylä, F. Cernuschi, C. Gualco, A. Bonadei and R. Di Maggio, *J. Therm. Spray Techn.* **13** (3) (2004) 361
[4] C. Zhou, N. Wang and H. Xu, *Mater. Sci. Eng.:A,* **452-453** (2007) 569
[5] A. Protinha, V. Teixeiraa, J. Carneiro, J. Martins, M.F. Costa, R. Vassen and D. Stoever, *Surf. Coat. Tech.* **195** (2005) 245
[6] H. Zhou, F. Li, B. He, J. Wang and B. Sun, *Trans. Nonferrous Met. Soc. China,*

17 (2007) 389
[7] H.D. Steffens, Z. Babiak and M. Gramlich, *J. Therm. Spray Techn.* **8** (4) (1999) 517
[8] R.S. Lima, A. Kucuk and C.C. Berndt, *Surf. Coat. Tech.* **135** (2001) 166
[9] B. Liang, and C. Ding, *Surf. Coat. Tech.* **191** (2005) 267