www.amlett.com, www.vbripress.com/aml, DOI: 10.5185/amlett.2014.588 Published online by the VBRI press in 2014

Thermal spraying, optimization and characterization of abradable seal coating for gas turbine for service temperature up to 750° C

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Received: 12 February 2014, Revised: 21 June 2014 and Accepted: 28 June 2014

ABSTRACT

In thermal power plants, significant improvements in overall efficiencies can be achieved by reducing the leakage flows in compressor and turbine sections. One way to minimize these leakages is by the use of thermally sprayed abradable sealing coatings. This paper discusses the development of abradable coating for gas turbine shroud segments for service temperatures up to 750 ºC. The abradable coating is developed using plasma coating technique. Effects of coating properties on changing the coating parameters are also discussed. Porosity, bond strength, micro hardness, erosion and abradability tests were performed over the plasma coated samples. Porosity, bond strength, micro hardness and erosion tests results were coming within the bracket suggested by the previous researchers; however abradability tests were not upto the mark. An in house abradability test rig was developed and abradable testing at room temperature was performed using this rig. The results obtained with the abradable test rig were not upto the mark and more testing and analysis is currently being performed to achieve more satisfactory results with the test rig. Copyright © 2014 VBRI press.

Keywords: Abradable coatings; erosion number; abradability; gas turbine.

Shadab Siddiqui is Sr. Engineer at BHEL Gurgaon. His current area of research is in surface engineering and thin film plasma sputter coatings. His previous research interest lies in the area of thick film design and fabrication, metal/ceramic joining, and characterization. He has presented his work in several international conferences including MS&T, ASME and ASM International. He has served as the secretary and vice president of student chapter of Materials advantage at FIU, Miami, USA. He was also the president of student chapter of IMAPS at FIU, Miami, USA. He is also a member of Golden key honor society.

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Introduction

An increase in efficiency by 1 percent on the current installed 2500 GW electricity base worldwide will lead to a reduction of carbon dioxide emissions by 300 million tonnes per year, with savings of roughly 100 million tonnes of fossil fuel **[1]**. This will effectively reduce the emission of greenhouse gases which in turn will reduce the cause of global warming. A 1 percent increase in the gas turbine efficiency can be achieved by reducing the tip clearances in the high pressure turbine section. The cross section of high pressure section of a gas turbine engine is shown in **Fig. 1 [1]**. Several models have been quantified by different authors that correlate the efficiency of a turbine engine with the tip clearances. A model was presented by Bringhenti and Barbosa **[2]** that correlate well with the performance of an existing engine. In this model the efficiency is calculated by Eqn. 1.

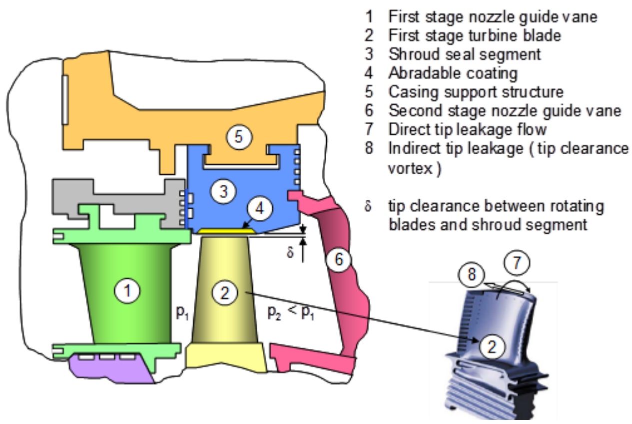

Fig. 1. Cross section of high pressure stage of a gas turbine engine **[1]**.

$$\eta = \eta_{ref}\left[1 - k.\left(\frac{\delta}{h}\right).\left(\frac{rt}{rm}\right)\right] \quad (1)$$

where k = 1+ 0.586 ($\psi_{ztip}^{3.63}$)
η is the rotor efficiency with tip clearance effects included
δ is the tip clearance height
h is the blade span
ψ_{ztip} is the tip Zweifel loading coefficient

It is estimated that an increase in efficiency by 0.5% for a 1000MW plant would save 1 Million dollars per year, along with the reduction in the emission of CO_2 **[3]**.

For the last several years abradable coatings have been successfully used in gas turbines as clearance control coatings **[4]**. There are several classes and categories of abradable coatings and these coatings have been used successfully in the land and air based gas turbines **[5-6]**. These coatings act as sacrificial coatings as they get abraded upon contact of rotating turbine blades with the coated stationary component, thereby reducing the leakage of gas in between the blade tip and the stationary component. **Fig. 2** below shows how these coatings works and a comparison in the clearances between an abradable coated and a non-coated case **[7]**.

Case I represents a situation without any abradable coating and in the event of rub there is wear of the blade leading to increase in the gas path clearance. Case II represents a shroud with abradable coating and in the event of rub blade cuts the abradable coating cleanly without or minimal wear of the blade itself and gas path clearance remains same as designed.

In the present work thermal spraying, optimization and characterization of abradable coatings for gas turbine for service temperatures up to 750 ºC have been discussed.

A lot of work has already been done to increase the efficiency of gas turbine by reducing the clearance between the rotating turbine blade and stationary component using different techniques like honeycomb braze seal, Ni-Graphite abradable seal, FELTMETAL™ seal etc. Different researchers give advantage of one over another **[8]**. However one clear advantage of plasma spray coating is, it is an insitu process and can be performed over the component without dissembling it from the rest of the turbine.

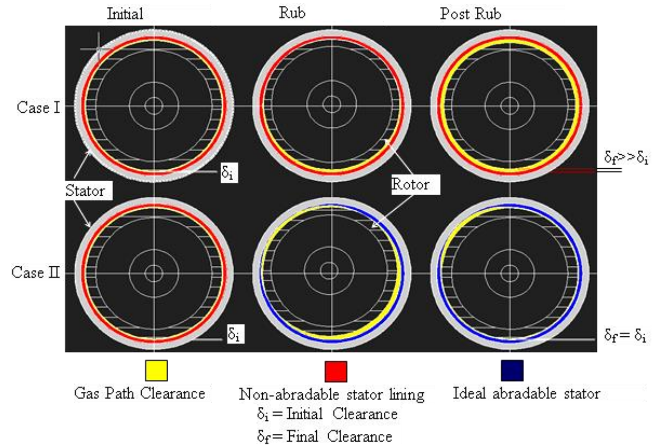

Fig. 2. Comparison in the initial and final clearances for uncoated and abradable coated cases.

In the present method a novel room temperature abradability experiment was performed along with the other standard tests like Porosity, bond strength, micro hardness, and erosion. An in house abradability test rig was developed which is discussed in the later sections.

Experimental

Materials

The samples over which coating is done are magnetic SS 410 grade of 5 mm thickness. The powders used for bond coat and top coat are mentioned below:

Bond coat powder: AMDRY 962, Ni-Cr-Al-Y alloy powder for plasma thermal spray application manufactured by Metallization Ltd., USA. The particle size of the powder is -106 +53 microns. The composition of the powder is as follows: Ni 22Cr 10Al 1.0Y.

Top coat powder: Metco 2043, CoNiCrAlY with polyester and BN, manufactured by Sulzer Metco, USA now Oerlikon Metco. The particle size of the powder used is - 176 + 11 microns. The composition of the Metco 2043 is as follows: Co 25Ni 16Cr 6Al 0.3Y 4BN 15 Polyester.

Boron nitride provides solid lubrication for an improved abradability and polyester component is introduced to achieve the high porosity level desired for abradable purpose.

Thermal spraying of abradable plasma coating

In the present work the abradable coating is done by thermal spraying technique using a 80 KW plasma spray system with a Sulzer Metco 9 MB gun. The spray parameters are given below. Thickness measurement during coating process was done using electromagnetic induction based gauge Elcometer 456.

Plasma coating trials were carried out after grit blasting using 20 grit virgin aluminum oxide. The roughness of the grit blasted surface as measured by Mahr portable surface roughness gauge was roughly 9.2 microns R_a value.

Process parameters that were kept constant during the trials are as follows:

Plasma Gun: 9 MB
Primary gas as Ar: 100 FMR
Secondary Gas H_2: 10 FMR
Arc Current: 450 Amps

Process parameters which were iterated during the trials were:

Spray distance in mm
Gun traverse rate in mm /second
Spray rate in gm/minute
Carrier gas flow rate.

First the thermal spraying of bond coat layer was done on the grit blasted sample over which a top coat layer was plasma sprayed. The thickness of the bond coat layer was kept constant in each experiment at around 150 microns. After plasma spraying of the top coat, the coated sample was heated at 455 ºC for 6 hours to burn the polymer content of the coating. Heating rate was kept at 10 ºC/minute. All the testing and analysis of coating properties are done after this step.

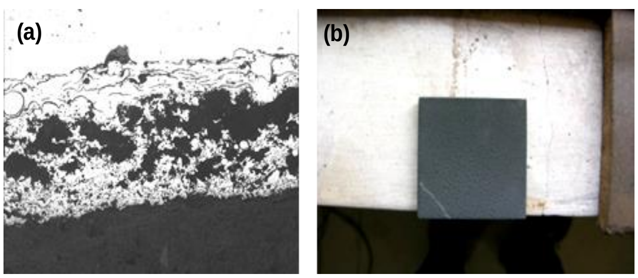

Fig. 3. (**a**). Optical image at 100X showing non-uniform porosity and (**b**) top shot showing lumpy coating.

Results and discussion

Porosity and microstructure

Initial trial was done at a spray distance of 75 mm, gun traverse speed between 200-300 mm/second, and at spray rate of between 16-20 gms./minute (powder feeder disk speed of 4 rpm) from the substrate.

The metallographic examination of the coated sample was done after cross sectioning on a Struers Minitom low speed cutting machine using diamond cutting wheel and subsequently hot mounting using Bakelite. The sample was diamond ground and polished to 0.5 micron. Metallographic examination revealed that the sample contained non uniform porosity as well as chunk of porosity was present in the central region as shown in **Fig. 3** (**a**). Leica DM 4000M microscope was used for optical microscopic imaging and measuring the porosity of the coated sample. It was noticed that during the initial trials as the thickness of the coating was increased to beyond 600 microns a lumpy structure started to appear in the coating as shown in **Fig. 3** (**b**).

Both of these problems of chunk of porosity and lumpy structure were overcome in the subsequent trials by controlling the carrier gas flow rate and changing the spray distance of the top coat powder. **Fig. 4** (**a**) shows below a microstructure of coating after reducing the carrier gas flow rate. **Fig. 4** (**b**) shows the porosity measurement using Leica QWin software. The porosity of the coating after heat treatment was in the range of 45-52%.

Bond strength

The bond strength was measured as per ASTM D 4541 using Positest pull-off adhesion tester and a dolly of 20 mm diameter. The dolly was glued to the sample using HTK Ultra Bond 100 adhesive, cured in the oven at 120 ^{o}C for 120 minutes and air cooled for at least 6 hours.

During the initials trials the porosity was non uniform and the bond strength values for these samples were less than 1400 psi. For the later samples with homogenous porosity the bond strength values obtained were in between 2400 Psi to 2600 Psi.

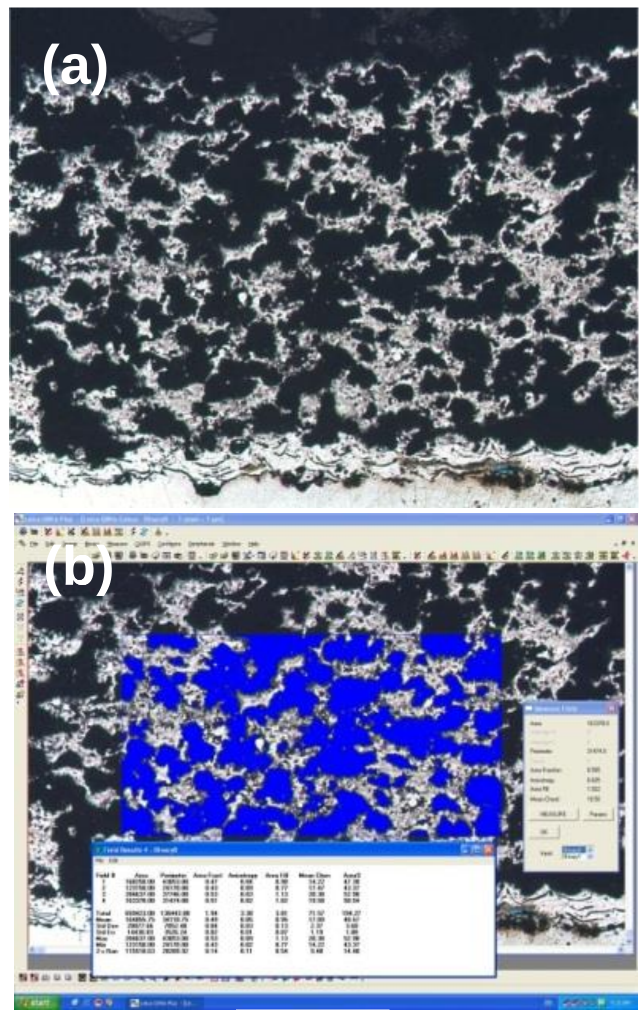

Fig. 4. (**a**) Optical image at 50X showing uniform porosity and (**b**) porosity measurement using Leica QWin software.

Fig. 5 (**a**) and (**b**) above shows the bond strength tested samples. Failure was observed to occur between the layers of the different plasma coated powder rather than at the interface of the substrate and the coating. This signifies that the values obtained from this test were a measure of cohesive strength rather than bond strength for this coating.

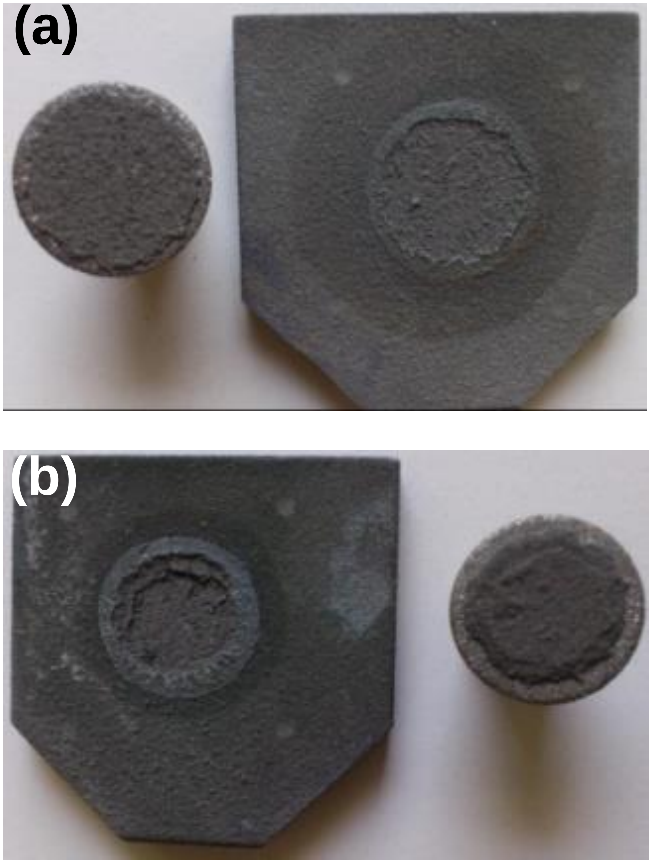

Fig. 5. (**a**) Bond tested 400 µm thick abradable coating and (**b**) bond tested 1 mm thick abradable coating.

Hardness measurements as per HR15Y

Abradable coatings are comparatively softer and the hardness of abradable coatings is measured using Rockwell superficial hardness on HR15Y scale, which uses a 12.7 mm carbide ball as indenter and hence the hardness measurements are not taken on the cross sectioned samples; rather hardness is done directly on top of the coated base metal sample. For this purpose the coating thickness is kept around 2 mm.

Table 1 below shows the results ofHR15Y hardness measurements done on three abradable coating samples after heat treatment of coating. The hardness testing was done at DMRL, Hyderabad.

Table 1. Hardness values on the top coat post heat treatment.

Sample no. 1	Sample no. 2	Sample no. 3
70	67	71
66	70	68
78	68	74
66	72	71
Average = 70	Average = 69.3	Average = 71

The overall average hardness measured was in the range of 65 to 72 on HR15Y scale.

Erosion testing

Erosion testing was performed as per ASTM G 76 standard using a DUCOM air jet dry sand erosion tester. 50 microns alumina was used as erosive media. Lexan standard samples were used to standardize the erosion testing parameters. The experiment was done at 30 º angle. The dimensions of the samples required are 22 mm by 24 mm by 6 mm. **Fig. 6** (**a**) below shows the erosion tested Lexan standards and the abradable coated samples.

Test parameters used to standardize the parameters on the lexan samples are as follows:

Time = 3 minutes
Pressure = 6 kg/cm^2

Erosion number = (time for a certain amount of sand to flow)/ (depth of erosion indentation mark in mils).

The depth of erosion indentation mark was measured by a dial gauge fitted with a fine pin as shown in **Fig. 6** (**b**).

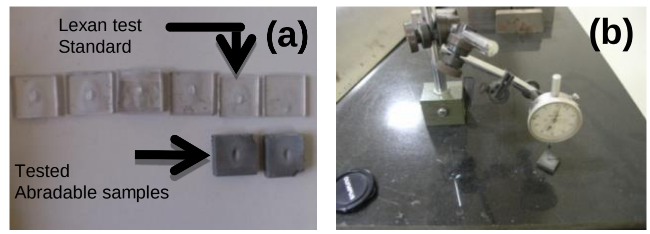

Fig. 6. (**a**). Erosion tested Lexan standards and abradable samples. after erosion testing and (**b**) indentation depth measurement technique using dial gauge fitted with a sharp needle.

Under the above mentioned parameters the erosion number of lexan sample was coming roughly around 5.64 (seconds/mil).The erosion number of abradable coated sample is in the range of 4.3 (seconds/mil) to 4.7 (seconds/mil) with an average of 4.47 (seconds/mil).

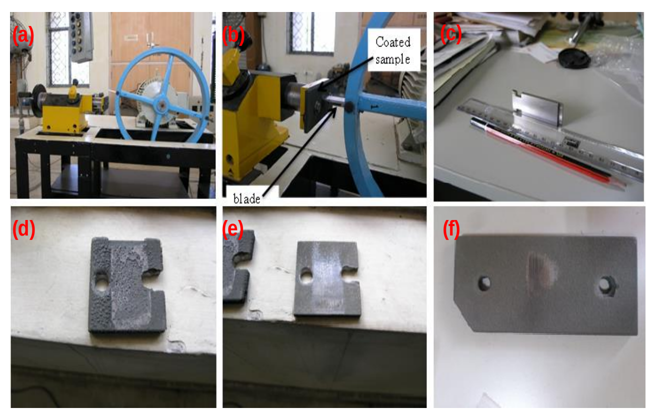

Fig. 7. (**a**) Abradability test rig, (**b**) blade and coated sample, (**c**) blade and (**d-f**) abradability tested samples in the rig shown in (a).

Abradability test

An in house Abradability test rig was fabricated in BHEL R&D, Hyderabad **[9]**. Test rig is shown in **Fig. 7** (**a**) and the mounted sample and how the sample is rubbed against a rotating blade is shown in **Fig. 7** (**b**). A 10 H.P motor having a maximum rpm of 1500 is connected to a wheel of diameter 500 mm. **Fig. 7** (**c**) shows an image of blade used to study the abradability behavior. The blade is machined from the super alloy blade materials of gas turbine.

Fig. 7 (**d-f**) shows results of abradability test performed through the above rig on the abradable coated samples. **Fig. 7** (**d**) below shows an image of a slightly better groove formed on the coating. Rest of the samples did not formed a perfect groove rather there is a wear mark over them. More testing is required for this test to get a conclusive idea of the abradability and wear behavior of the coating. There was not any significant difference in the hardness values obtained for the samples shown in **Fig. 7** (**d-f**). They were all in the range of 68-72 HR15Y.

Conclusion

Initial trials yielded non uniform porosity when the spray distance was kept at 75 mm while on increasing the spray distance to 125 mm the results obtained showed uniformity in the porosity of the coating. The porosity of abradable coating for all the trials is coming in between 45 to 52%. Bond strength testing yield a value of average cohesive strength of 2500 Psi. The hardness values are coming in a narrow band of 65 to 72 on HR15Y scale. Erosion number of abradable coated sample is in between 4.3 (seconds/mil) to 4.7 (seconds/mil) with an average of 4.47 (seconds/mil). Abradable testing did not yield results up to the level of satisfaction and more testing/ analysis is required to achieve a fine cut groove with the abradability test rig. The team at Surface Coatings and Treatment (SCT) department at BHEL R&D Hyderabad is involved in performing more experiments to get a perfect cut groove with the abradable test rig.

Acknowledgements

The author would like to acknowledge BHEL Management for providing the opportunity to work on this project. The author would also like to acknowledge Mr. Vivek Arya, Mr. B. K. Pant for robot programming, Mr. E. Dass and Mr. S. Yadgiri for metallographic preparation of samples, Ms. Ramandeep and Mr. R. K. Parkala for erosion testing and Dr. B. Venkatraman of DMRL for his support during testing. The author would also like to acknowledge Mr. Kamaldeep Gupta of BHEL Rcpm. for technical discussions.

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