Journal of Thermal Spray and Engineering, 4: 115-119
ISSN (Online): 2582-1474; DOI: https://doi.org/10.52687/2582-1474/406

The Indian Thermal Spray Association
ITSA ASSOCIATION FOR THERMAL SPRAY TECHNOLOGY AND RESEARCH

Peer-Reviewed NTSC2023 Special Issue

The Effect of Fuel Gas Pressure on The Properties of Nickel-Chromium-Iron-Aluminum-Boron Nitride Abradable Coating

Hariharan Venkataraman · Vishal Uttamrao Bagade

Gas Turbine Research Establishment, Defence Research & Development Organisation, Ministry of Defence, Govt. Of India, Bangalore , India.

ABSTRACT

Abradable coating of Nickel Chromium Iron Aluminium Boron Nitride Cermet Powder sprayed by flame spray process is used as clearance control coating on the aero engine components. Nimonic alloy Su-263 is used as substrate material for this coating. Ni5%Al composite powder sprayed through atmospheric plasma spray is used as bond coat. Different trials on test samples were carried out with varying pressures of fuel gas acetylene in the flame spray process. Coated samples from all the trials were analysed for hardness measurement and microstructure evaluation. It was observed that pressure of fuel gas acetylene in the flame spray process has direct influence on the hardness as well as microstructure of the coating. Appreciable change in rate of deposition of coating was also noticed due to variation in fuel gas pressure.

ARTICLE HISTORY
Received 16-01-2023
Revised 20-11-2023
Accepted 20-12-2023
Published 06-04-2024

KEYWORDS
APS, Flame Spray
Fuel Gas Pressure
Hardness, Rate of Deposition, Bond Coat
Topcoat, Nimonic alloy Su-263

Introduction

Core airflow in the gas turbine engine determines the high performance of the engine. The specific fuel consumption of the engine is influenced by the core airflow. Core airflow is improved by reducing the leakage in the blade tip. Abradable coatings are carried out on aero engine components for clearance control between the rotating blades and the stationary casings. Abradable coating would wear in preference to the blades. Low pressure compressor and High-pressure compressor casings are coated with abradable coating to protect the rotating blades from getting damaged and also to maintain minimum tip clearance [1-8]. Minimum tip clearance is governed by abradable coatings to ensure that maximum air flow is transferred to the compressor to provide more thrust to the engine while reducing the fuel consumption. Aero gas turbine engine blades rotate at 3000 to 10000 rpm when the engine operates. Thermal expansion, misalignment or rotation induced strain may result in the blade rubbing the casing [7]. Abradable coatings would also experience hot gases and thereby the coatings shall be resistant against oxidation, corrosion, and thermal shock. Abradable coatings are usually the composite mixtures of three phases viz., metal matrix, second phase a solid lubricant also called dislocator phase and porosity to meet the requirements of better abradability, and the resistance against corrosion and erosion [12-16]. These abradable coatings are carried out through the thermal spray coating processes viz., Atmospheric Plasma Spray (APS) and Powder Flame Spray. There are different types of abradable coatings carried out on the gas turbine engine part to get better abradability and the resistance against erosion and corrosion. Selection of abradable coatings is mainly based on the service temperature of the gas turbine engine part. The details of different types of abradable coating powder of Oerlikon Metco with their service temperature are furnished in Table 1.

Table 1: Different types of abradable coating powder of Oerlikon Metco with their service temperature [16, 21-24]

Sl. No:	Name of the coating powder	Typical Composition	Typical size range	Service Temperature (ºC)
1.	Metco 601 NS	Silicon 7% Polyester 40% Aluminium (Balance)	-125 +11 µm	325
2.	Metco 320 NS	Silicon 8% Boron Nitride 20% Organic Solid 8% Aluminium (Balance)	-212 µm +22 µm	480
3.	Metco 301 NS	Boron Nitride 5.5% Aluminium3.5% Iron 8% Chromium 14% Nickel Balance	-120 + 45 µm	815
4.	Metco 307 NS	Nickel 75% Graphite 25%	-90 +30µm	480
5.	Metco 308 NS	Nickel 85% Graphite 15%	-90 +30µm	480

This paper studies the effect of the pressure of fuel gas acetylene on the hardness as well as microstructure of abradable coating of NiCrFeAlBN cermet composite powder sprayed through flame spray process. The solid lubricant boron nitride allows coating to be abraded with low friction with minimal mating component wear. It also controls porosity in the coatings in addition to its role of

Corresponding Author: Hariharan Venkataraman:, Tel: +919902265934
Email: nithari2007@gmail.com

Contents lists available at http://www.inscience.in/JTSE.html

solid lubricant [21]. Chipping and erosion of coatings are controlled by metal matrix in the coatings. The dislocator phase ensures that the abradable debris created by the blade rub with the coating is sufficiently small not to block the tip gap. Abradable coating needs to be soft enough to be abraded by the blades in the same time to be sufficiently hard to withstand the erosion caused by the hot gases with high velocity [9-11]. The hardness of the abradable coatings plays a very crucial role in determining abradability and erosion resistance behaviour of the coatings. Softer coating would be better abradable but less resistant against erosion while harder coating would perform well against erosion but less abradable in nature.

Experimental

The abradable coating of Metco 301 NS consists of boron nitride, aluminium, Iron and nickel chromium alloy cermet composite powder. This coating is sprayed on aero engine components for clearance control applications in the service temperature range of 760°-815°C [11] using powder flame spray process. SEM Photomicrograph of Metco 301NS [21] powder has been furnished in Fig. 1.

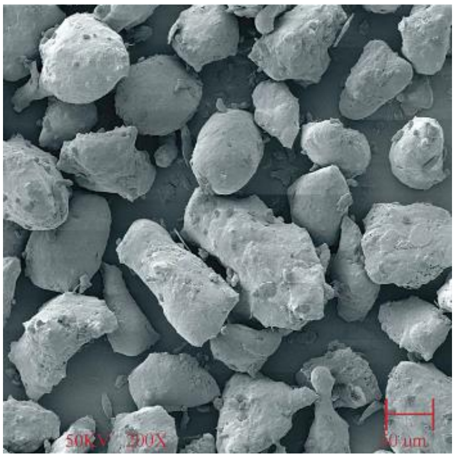

Figure 1: SEM image of Metco 301 NS powder (Source: Technical Bulletin of Oerlikon Metco)

The following steps were followed in the coating process of test samples. The process was divided into the following two major sub processes.

Surface Preparation of Test samples

Test samples were first decreased with Acetone. Then the samples were subjected to grit blasting using 20 mesh size fused alumina grit. A pressure type grit blasting machine was used. The air pressure of 2.0 bar was set during blasting. Nozzle of 10 mm diameter was used. Standoff distance of 150mm was maintained while blasting. Angle of 90 degree was almost maintained between the test sample and the blasting gun throughout the blasting process. Ultrasonic cleaning with acetone for 5 minutes was also carried out after grit blasting to remove the grit inclusion on the blasted surface. Inspection of grit blasted test samples was also carried out using 20X magnifying glass to check the quality of grit blasting.

APS and Powder Flame Spray Coatings on Test samples

Bond coat of Metco 450 NS was sprayed through Atmospheric Plasma Spray (APS) process using 9MB spray torch of Sulzer Metco. Multicoat APS Process Controller, Twin 120-A powder feeder unit of Sulzer Metco and IRB4600 robot with IRC5 robotic controller of ABB were used in this process. The abradable topcoat of Metco 301 NS was sprayed using 6PII Spray torch of Sulzer Metco. 6CE controller and 5 MPE powder feeder unit of sulzer metco were used for flame spray process. Coating of Metco 450 NS was carried out to the thickness of 200 µm. Test samples grit blasted as explained above were first fixed in the fixture which in turn was mounted on the 2-axis turn table in the spray booth. Micrometers in the range of 0-25 mm were used for coating thickness measurement on the samples. Process parameters for the Metco 450 NS coating are furnished in Table 2. Pre-heating cycle with APS flame temperature of 120°C was carried out on the test sample prior to bond coating. A pyrometer integrated with the coating facility was used to measure the temperature. Online particle diagnosis system Accuraspray G3C of TECNAR installed in the Integrated Robotic Thermal Spray Coating Facility was employed to measure the particle velocity of coatings. Particle velocities of metco 450 NS and Metco 301NS were measured in the range of 145-178 mm/sec and 82-117 mm/sec respectively. 6-axis ABB robot was used for spraying both bond coat as well as topcoat. In the powder flame spray process of Metco 301 NS coating, acetylene is used as fuel gas along with oxygen for producing the flame. Nitrogen is employed as carrier gas to feed the powder into the flame. Since Metco 301 NS is not self-bonded coating to the substrate, Metco 450 NS composite powder of Nickel Aluminium was used as bond coat for Metco 301 NS coating. Bond coat of Metco 450 was sprayed using Atmospheric Plasma Spray (APS) Process. As per the design criteria, Metco 301NS abradable coating to the thickness of 1500 µm with the bond coat of Metco 450 NS to the thickness of 200 µm is required to be sprayed on the aero engine components Standoff distance of 230mm was fixed for all the trials of topcoat. Coating powder details of Metco 450 NS and Metco 301 NS are furnished in Table 3. Both the powders were thoroughly tumbled in the container before transferring into the feeder to avoid the lump formation which is likely to interfere the free flow of the powder and thereby smooth & continuous injection of the powder into the flame was ensured. The test samples of 25 mm Dia x 6 mm thick made up of Nimonic Su-263 material were used for the coating trials. After completion of bond coat, the samples were subjected to the topcoat of Metco 301 to the thickness of 1500 µm. For each trial two test samples were coated for metallographic evaluation. One test sample was used for measuring coating hardness and another for microstructure evaluation for each trial. Turn table speed of 80 RPM and spray torch speed of 5.3 mm/ sec were optimised keeping the surface speed of the test sample as 75 m/min for bond coat. The speed of turning table and that of the spray torch tend to vary with diameter of the part. In this case the sample is mounted on the rotary fixture of 300 mm diameter. Speeds were calculated as follows keeping the surface speed of the test sample constant. A standoff distance of 140 mm was set for all the trials while powder feed rate was maintained at 60 g/min.

Surface speed of the test sample (m/min) = [π x Diameter of the part (in mm) x N(RPM of turn table)] / 1000

75 = [3.14 x 300 x N] / 1000

N = 75000/942 RPM

N = 80 RPM (rounded off)

Speed of spray torch (mm / sec) = *[RPM x 4mm (Step of coating)]/ 60*
= *[80 x 4] / 60*
= *5.3 mm / sec*

Table 2: Parameters for Metco 450 Coating

Parameters for Metco 450 Coating	Values
Primary Gas Argon flow (NLPM)	40
Secondary Gas Hydrogen flow (NLPM)	8
Carrier Gas Argon Flow (NLPM)	6
Standoff distance (mm)	140
Feed Rate (g/min)	60
Turn Table speed (RPM)	80
Spray Torch Speed (mm/sec)	5.3
Surface Speed (m/min)	75

Table 3: Powder specifications

Name of the coating powder	Typical Composition	Typical size range
Metco 450 NS	Aluminum 4.5%Nickel Balance	-170 +325 mesh -88 +45 microns
Metco 301 NS	Boron Nitride 5.5% Aluminum 3.5% Iron 8% Chromium 14% Nickel Balance	-120 + 325 mesh -120 + 45 microns

Due to the fact that particle velocity of flame spray coatings which is in the range of 75-150 mm/sec is comparatively less than that of APS coatings which stands to be in the range up to 400 mm/sec, the speed of turn table on which the part is mounted, and the translational speed of spray torch would also be less for flame spray coating. In this present study too, surface speed of the test sample was kept 35 m/min for the topcoat. Subsequently the speed of the turn table and that of spray torch were also maintained respectively as 37 RPM and 3.1 mm/sec. With the reduced surface speed of the test sample, an appropriate rate of deposition was achieved in the topcoat trials.

Characterisation of coated test samples

The coating hardness of one test sample for every trial was measured by Rockwell Hardness Testing System. Another test sample from each trial was prepared as per the standard metallographic procedure. The prepared sample was subjected to microstructural analysis using Nikon upright microscope with Clemex image analysis software.

Results and Discussion

Hardness evaluation and Microstructure analysis

The test coupon was extracted from the test sample from each trial. Mounting of the extracted coupon and the grinding & polishing operations were carried out as per the standard metallographic procedure. The coupon prepared was then subjected to microscopic studies. Microstructure of the Metco 301 NS coating captured using Nikon upright microscope with Clemex image analysis software has been furnished hereunder. Substrate and two layers of coating are inferred from Fig. 2a and 2b. Bond coat and topcoat layers are marked in Fig. 2a. Further in Fig. 2b, varied phases in the topcoat viz., metal matrix, dislocator phase, porosity were indicated.

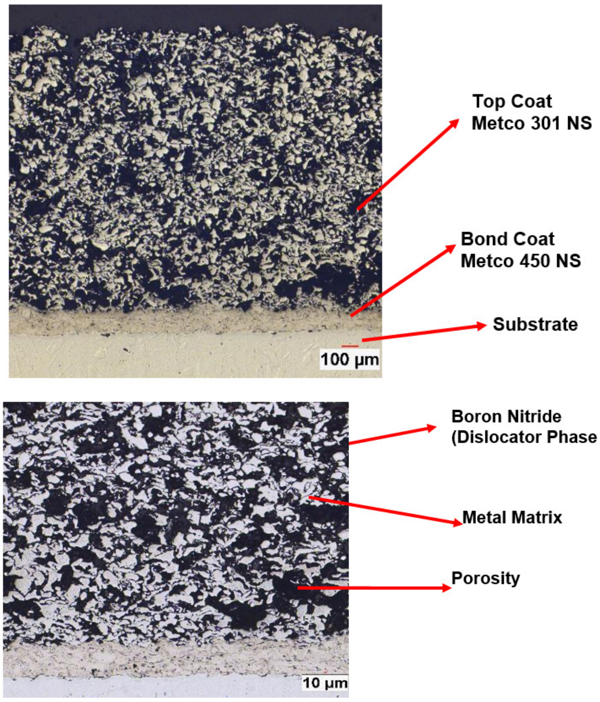

Figure 2: (a) Microstructure of Metco 301 NS, (b) Microstructure of Metco 301 NS

In all the 7 experimental coating trials microstructure met the quality requirements specified in the specification. But the hardness of the coating was very low in the first 5 trials. Required hardness of metco 301 NS coating shall be in the range of 45-58 HR 15Y. But it was intriguing to find that hardness value was so low notwithstanding the change in flow rate of fuel gas acetylene as shown in Table 4. The hardness value was measured using the Rockwell Hardness Testing System. As per the recommendation of Oerlikon Metco coating trial was carried out by increasing the fuel flow to achieve more hardness [21]. As the coating was soft in the first trial, the fuel gas flow varied in the range of 51 (FMR) to 65 (FMR) in the subsequent four coating trials. The coated test samples were subjected to the destructive testing for microstructure analysis to meet the desired quality requirements. But the attempts made to achieve more hardness did not yield a convincing result. Of late it had been decided to reduce the pressure of the fuel gas acetylene to the minimum value of 15 PSI. Further Metco 301 NS coating was sprayed on test samples using the parameters as shown in sl.no. 6 of Table 4 keeping the pressure of fuel gas acetylene at 16-18 PSI. Coated test samples were subjected to hardness evaluation and microstructure analysis as well. The hardness was measured as 47 ± 1 HR 15Y. Further another trial was also carried out with the change in parameters as shown in S. No. 7 of Table 4 with the fuel pressure of 15-17 PSI. In this trial the hardness was also 48 ± 2 HR 15Y which is also in acceptable range of 45 – 58 HR 15Y. During first five coating trials the rate of deposition was very poor in the range of 15-45 µm/ pass as against the recommended rate of 150 µm/ pass recommended by Oerlikon Metco. But in the last two trials, rate of deposition of coating was increased appreciably to the value of 120-140 µm/ pass.

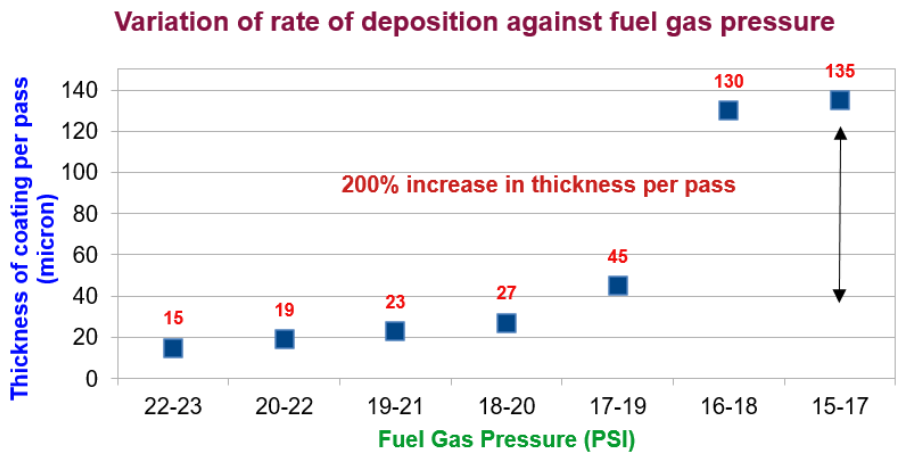

Figure 3: Variation of rate of deposition against fuel gas pressure

Table 4: The parameters used in the seven trials of coating of Metco 301 NS on test samples

Trial No.	Parameters used							
	Acetylene		Oxygen		Powder Feed Rate (g/min)	Standoff Distance (mm)	Hardness achieved (HR 15Y)	Porosity (%)
	Flow (FMR)	Pressure (PSI)	Flow (FMR)	Pressure (PSI)				
1.	51	21-23	40	35	100	230	19 ± 7	15 ± 3
2.	55	20-22	40	35	100	230	29 ± 1	17 ± 4
3.	59	19-21	40	35	100	230	33 ± 1	19 ± 1
4.	63	18-20	40	35	100	230	36 ± 4	20 ± 1
5.	65	17-19	40	35	100	230	38± 2	20 ± 1
6.	65	16-18	40	35	100	230	47 ± 1	22 ± 1
7.	65	15-17	40	35	100	230	48 ± 2	22 ± 3

By keeping the pressure of fuel gas acetylene at 15-17 PSI dual benefits of higher hardness as well as increased rate of deposition were achieved. A significant 200% increase in rate of deposition against the reduced fuel gas pressure was achieved which is shown in Fig. 3. The parameters shown in Table 4 were used in the seven trials of coating of Metco 301 NS on test samples.

Impact of higher fuel gas pressure on the properties of Nickel Chromium Iron Aluminium Boron Nitride coating

Acetylene gas is dissolved in acetone at the pressure of 10-16 Kg/cm^2 in cylinders. When the acetylene is drawn at high pressure from the cylinder, acetone is likely to come with acetylene and the desired combustion would not take place and the melting of coating powder especially metal part in the powder would be incomplete due to the insufficient heat energy in the absence of sufficient fuel gas acetylene in the flame [25]. This is attributed to the poor deposition rate of coating powder resulting in softer coating. In order to get a harder abradable coating of Metco 301 NS, the fuel gas acetylene pressure shall be maintained at 15-17 PSI during the coating process. The microstructure of the coating as shown in Fig. 2b comprises of NiCrFeAl metal matrix along with the solid lubricant boron nitride. Metal matrix was found to be less densed while the dislocator phase was more densed surrounding the metal matrix in the first five trials which led to softer coating. With the increase in melting of metal part of the powder due to the rise in temperature of the flame, metal matrix has increased in the last two trials and thereby attributed to the appreciable increase in the coating hardness. It was also observed that rate of deposition had also increased when the operating pressure is maintained at 15-17 PSI during the coating process. As the coating powder consumption becomes less, the cost of the coating will be reduced drastically.

Conclusions

Abradable coating trials of Nickel Chromium Iron Aluminum Boron Nitride Cermet Powder were conducted on test samples using APS process for bond coat and Powder Flame Spray process for topcoat in Integrated Robotic Thermal Spray Coating Facility. It has been observed that when the pressure of fuel gas acetylene is maintained in the range of 15-17 PSI there is significant improvement in the hardness as well as microstructure of the coating and appreciable increase in the rate of deposition of the coating. Hence it is inferred from the above coating trial that if pressure of fuel gas acetylene is set at 15-17 PSI, hardness of the abradable coating of NiCrFeAlBN falls in the specified range of 45-58 HR 15Y due to the appreciable improvement in the metal matrix of the coating. The cost of the coating can also be reduced when the coating process is carried out with the fuel gas pressure of 15-17 PSI. Based on this study it is concluded that the pressure of fuel gas acetylene has direct influence on the hardness as well as microstructure of abradable coating in the flame spray process and subsequently on the rate of deposition of coating.

Acknowledgement
The authors express their gratitude to Director, GTRE for permitting to publish this work. The support and guidance extended by the Technical Director and Associate Director of Manufacturing Group are also acknowledged. Authors are grateful to the Surface Science Engineering Laboratory of GTRE for their contribution towards measuring hardness and microstructural analysis.

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