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Topological characterization of wear tracks in thermally sprayed abradable coatings

J.-L. Seichepine, S. Albertazzi, P. Nardin, C. Coddet, Belfort/F, and D. Sporer, Stockport/GB

Abradable coatings are located on the stationary parts of gas turbines, in front of blades, which cut a track in them. This has to be achieved with minimum wear of the blades, in order to control the over-tip leakage. These coatings are generally deposited by thermal spraying of composite powders comprising a metal base, a polymer filler generating porosities and a dislocator such as hBN. The very demanding properties are nowadays adjusted using rig tests, where samples are rubbed by the contact of a dummy, simulating actual working conditions in an aircraft engine. Several types of behaviour are usually described, but few numerical data are produced from these tests. Only the blade wear (or metal transfer) is generally measured. As the understanding of contact phenomena is fundamental for the development of predictive models allowing the design of more performing materials, a comprehensive characterization process of the rub path was developed. The study was based on a topological survey made by laser profilometry, giving three-dimensional maps. These maps were then processed by image analysis and several parameters were computed, like surface roughness and parameters giving information on the shape and orientation of the holes or grooves in the rubbed surface of the samples.

1 Introduction

Air seals in aircraft jet engines represent one of the most challenging and key technologies world-wide. Well functioning seal systems allow to keep rated pressure ratios, the best efficiency and an optimized specific fuel consumption. For instance, abradable coatings are used to control the over-tip leakage of air in the compressor between rotor blades and casings, labyrinth seals as well as drums and stators.

Increasing performances of engines induce more severe working conditions for the coating, which have to be continuously improved. That is why it is important to gain a better understanding of the complex phenomena occurring when a blade contacts an abradable coating.

Efforts are presently done in two complementary directions: modelling the thermo-mechanical behaviour of the seal and characterizing it experimentally. This paper presents a route allowing to go further in the analysis of the results given by the industrially used abradability test. It provides additional information useful for understanding and then simulating the abradability.

2 Abradable coatings

Abradable seals allow the blade to cut a track in the coating thickness but this has to be achieved with minimum wear of the blade. Furthermore, the abradable material must not erode due to the hot gas flow otherwise sealing effectiveness is lost.

Many such gap-sealing products are available for use in the compressor section of gas turbines [1].

Our study was focused on materials already used or being presently developed to gain the combination of properties required in the high pressure compressor.

These abradable coatings are deposited by combustion or plasma spraying of composite powders, comprising a metal base, a polymer filler generating porosities and a dislocator. This combination results in deposits which are very porous, easily removed by the contact of the blade, but able to resist to the severe environmental conditions.

The reference materials for this study, already industrially used were AlSi-BN (powder supplied by Sulzer Metco under the reference SM 320) and NiCrAl-Bentonite (powder supplied by Sulzer Metco under the reference SM 314). The new material being presently developed is NiCrAl-BN, with different rates of BN and sprayed with polyester, in order to increase the porosity.

3 Abradability test

The performance of the coatings are usually evaluated by abradability rig testing. Tests are conducted in a dynamic abradability rig, Fig. 1.

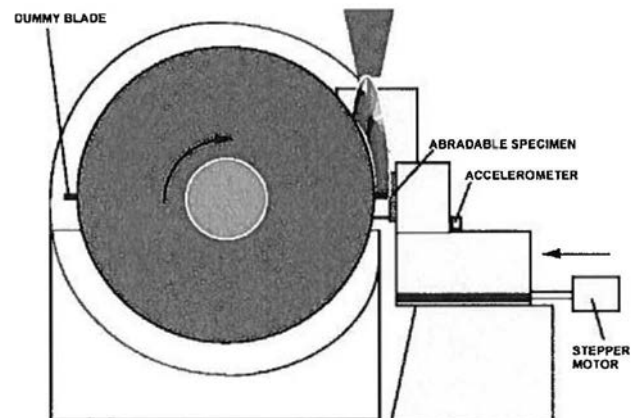


Fig. 1. Schematic of Standard Test Rig.

The contact phenomena occurring in an engine are reproduced between a dummy blade and an abradable specimen. The rig is equipped with two independent drive systems, one for the rotor and the other for moving the seal specimen radially into the rotor. The speed of the specimen radial motion, or incursion rate, and the rotor speed are adjusted to obtain a realistic simulation of different typical working conditions. Furthermore, a heating system allows to make tests at increased temperatures [2] [3] [4].

The main results of these tests are measurements of the blade wear (or metal transfer from the coating to

it), records of temperatures, and observations of the rubbed zones on both the blade and the coating. So several typical behaviours have been identified, like pure cutting, smearing, grooving or melting. This information is classically summarized in wear maps [1] [4].

Meanwhile, only few numerical data are usually produced from the analysis of the rubbed surfaces.

4 Profilometry

A comprehensive characterization process of the rub path cut by the blade in a tested coating was developed. The study was based on a topological survey made by laser profilometry. By this technique, the distance from a reference plan to the scanned surface was measured with a resolution of 50 points/mm in both directions, giving a three-dimensional map [5].

The general shape of the rubbed zone is cylindrical, because of the circular motion of the blade. This mean shape is removed numerically, giving a table of the distances of the surface points to the mean surface, which can be plotted as a map of grey levels, Fig. 2. From this data, different parameters can be computed, like the surface roughness S_a .

$$S_a = \frac{1}{n \times m} \times \sum_{x=0}^{n-1} \left[\sum_{y=0}^{m-1} d(x,y) \right]$$

Where:

- $d(x,y)$ is the distance between the (x,y) point and the mean plan,
- n is the number of points sampled in x direction,
- m is the number of points sampled in y direction.

5 Image analysis

The analysis of some wear tracks showed different topographies, with craters isotropically distributed or with grooves in the direction of the blade motion, or even with grooves perpendicular to the blade motion. To get more information, the maps obtained by laser profilometry were processed by image analysis.

In a first step, the grey-level maps were binarized, giving black-and-white pictures where the areas above the mean surface are white and the areas below the mean surface are black. Then the shapes were simplified with the "despeckel" filter, that replaces each pixel by the mean value of its 5 neighbours [6]. This filter was run several times, until the stabilization of the contours, Fig. 2.

To go further in the characterization of the peaks shape, the local dimensions of the white areas of these pictures were examined extensively. The whole pictures were scanned in both directions x and y , detecting the white sets of pixels encountered and measuring their lengths. The results are tables of lengths h_x and h_y , Fig. 3.

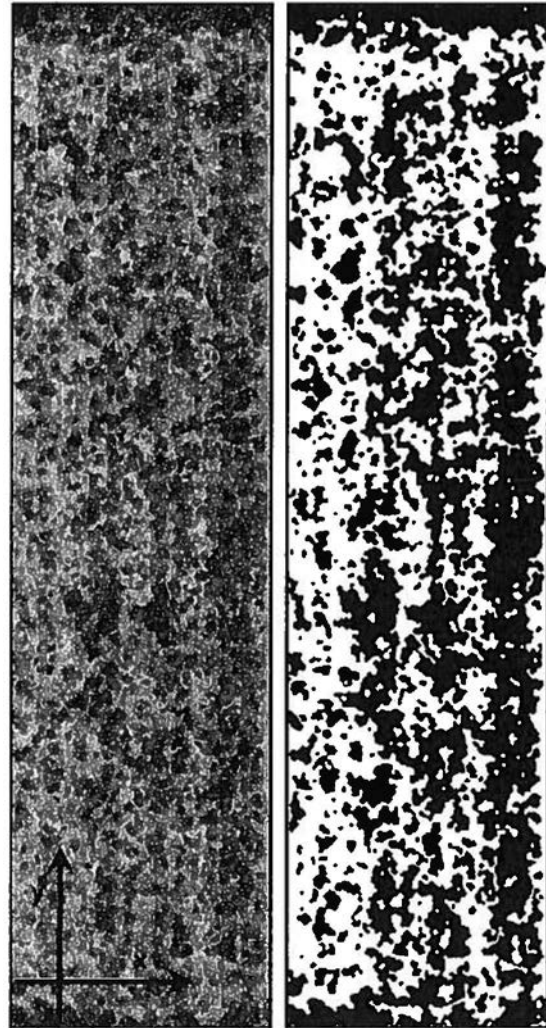


Fig. 2. Typical wear track scan.
 y is the direction of blade motion.
 - Left: grey levels.
 - Right: Binarized and filtered.

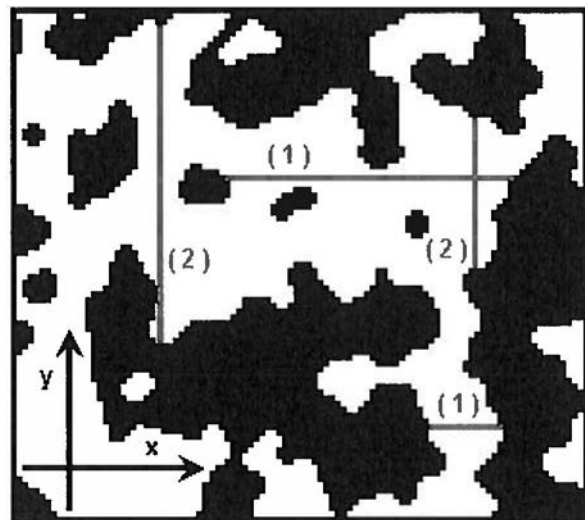


Fig. 3. Image analysis on a binarized wear track scan.
 (1) / (2): Segments of white area in x / y direction, having a length of h_x / h_y .

6 An original parameter

The tables of values h_x and h_y were used to compute a new parameter called "anisotropy coefficient", giving numerical information about the shape and orientation of the grooves or holes in the coating. The idea was to have it equal to -100 for a square picture perfectly banded in the horizontal x direction, equal to 0 for a perfectly isotropic picture and equal to +100 for a picture perfectly banded in the vertical y direction, Fig. 4.

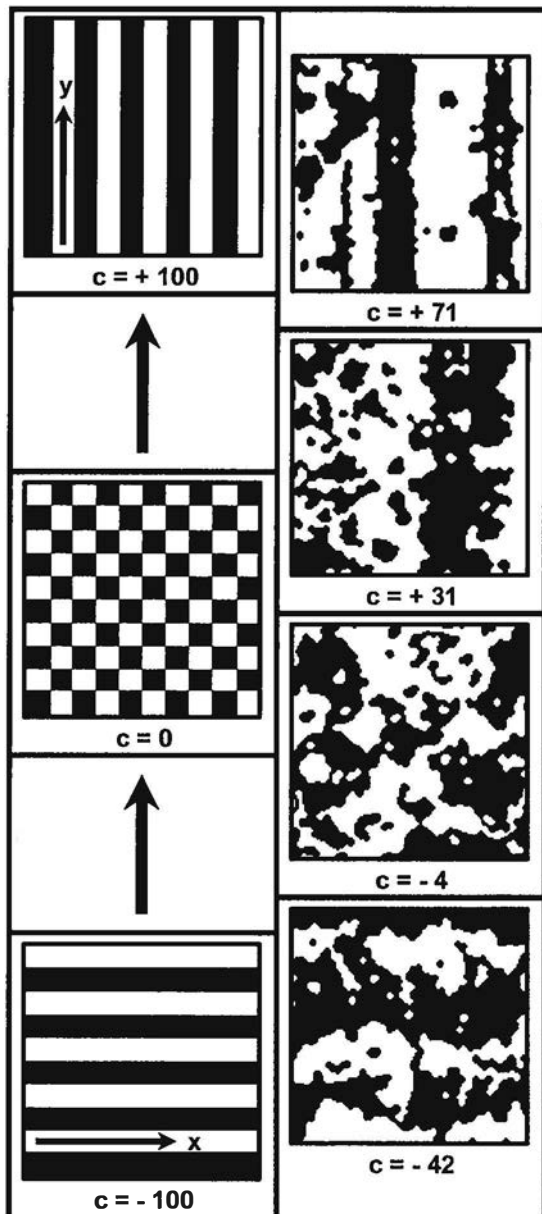


Fig. 4. Increasing values of the anisotropy coefficient c .
 - Left: Ideal cases.
 - Right: Typical real cases.

This coefficient was calculated in several steps. First the mean values $\overline{h_{x0}}$ and $\overline{h_{y0}}$ of the lengths of the whole sets of segments are determined. Then, 2 ranges of segments are arbitrarily defined. Those whose length is

lower than the mean values are arbitrarily considered as belonging to small insignificant areas. Those whose length is higher than the mean values are considered as describing the main significant white areas or main peaks and the mean values of their length are calculated.

- $\overline{h_{x1}}$ is the mean value of the lengths h_x higher than their mean value $\overline{h_{x0}}$.

- $\overline{h_{y1}}$ is the mean value of length h_y higher than their mean value $\overline{h_{y0}}$.

The anisotropy coefficient c is finally defined by the following equation:

$$c = 100 \times \cos \left[\arctan \left(\frac{\overline{h_{x1}}}{\overline{h_{y1}}} \right) \right]$$

7 Analysis of a set of wear tracks

26 wear tracks belonging to 9 abradable specimens were characterized by laser profilometry. For each of them the roughness S_a and the anisotropy coefficient were computed. Table 1 summarizes the test conditions (blade tip speed, incursion ration), the measured blade wear (as a percentage of the total incursion) and the results obtained from laser profilometry and image analysis (roughness S_a and anisotropy coefficient c).

Coating	Sample	Tip Speed	Incursion Rate	Blade Wear	Roughness S_a	Anisotropy coefficient c
		m/s	$\mu\text{m/s}$	%	μm	
NiCrAl - Bentonite		305	2,5	3	56	-2
		305	138	33	48	24
		153	760	71	62	40
AlSi - BN		305	2,5	46	93	78
		305	138	-14	25	65
		153	760	-20	16	64
90 NiCrAl - 10 BN	1	305	2,5	0	47	0
		305	138	0	44	-8
		153	760	18	60	9
	2	305	2,5	0	39	-2
		305	138	-2	49	4
		153	760	36	46	1
	3	305	2,5	0	34	2
		305	138	-2	34	-4
		153	760	3	41	73
80 NiCrAl - 20 BN	1	305	2,5	3	51	-19
		250	500	3	44	-15
		153	760	28	68	26
	2	305	2,5	3	41	0
		250	500	50	35	-1
		153	760	41	40	6
	3	397	10	5	39	1
		397	100	-5	37	-2
		397	100	0	37	5
	4	397	10	-5	21	0
		397	100	-5	18	14

Table 1. Test conditions and results for 26 wear tracks.

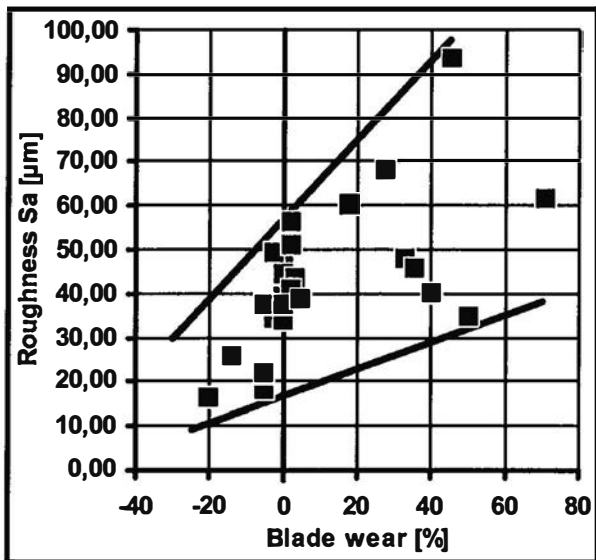


Fig. 5. Roughness versus blade wear for the 26 wear tracks analysed.

On this table as usually a negative blade wear means that metal has been transferred from the coating to the blade tip.

The given anisotropy coefficients are mean values of 5 values computed from square areas along each wear track.

The computed surface roughnesses S_a have been compared to the blade wears. Some consistency appeared: the surface roughnesses are rather high in case of severe blade wear and rather low in case of metal transfer, Fig. 5.

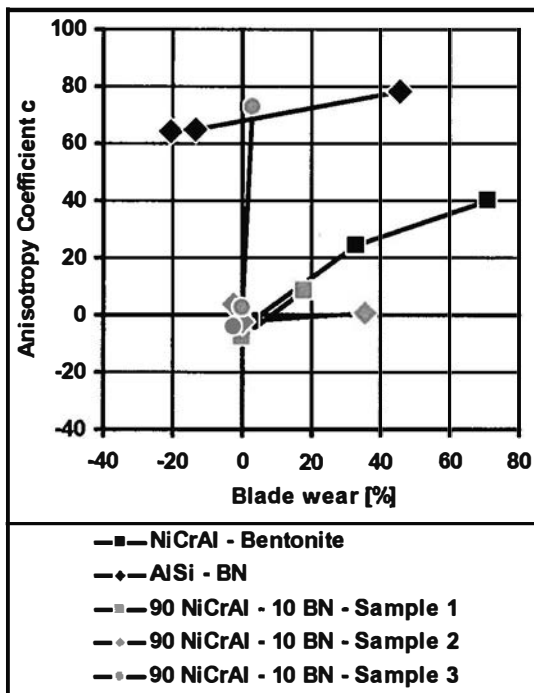


Fig. 6. Anisotropy coefficient versus blade wear for the first set of 5 samples.

In the same way the computed anisotropy coefficients have been compared to the blade wears for the 26 wear tracks. Different behaviours were characterized for the different samples, Fig. 6 and Fig. 7.

For instance, the wear tracks in the AISi - BN sample have always a high anisotropy, with $c > 0$ increasing with the blade wear, meaning that grooves always appear in the direction of the blade motion.

For other samples, the wear tracks surfaces are always quite isotropic ($-10 < c < +10$).

The wear tracks in 80 NiCrAl - 20 BN sample 1 have a particular topology with grooves perpendicular to the direction of the blade motion resulting possibly from inhomogeneous coating hardness. That is highlighted by significantly negative values of the anisotropy coefficient c obtained with low values of the blade wear.

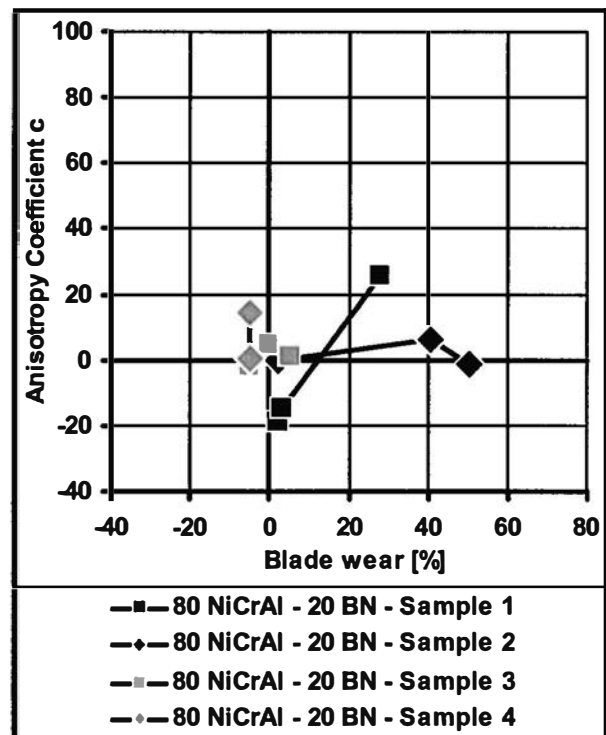


Fig. 7. Anisotropy coefficient versus blade wear for the second set of 4 samples.

8 Conclusion

A set of wear tracks in abradable coatings were submitted to laser profilometry. The measurements obtained were then processed by image analysis allowing to compute parameters characterizing the surface topologies.

An original coefficient was defined to give numerical information about the anisotropy of the wear track surfaces.

It appeared that this process gives a useful tool to go deeper into the understanding of the complex abradability phenomena.

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- RTWH - Thermal Spraying Group, Aachen/DE
- Neomet Limited, Manchester/GB
- Institute of Plasma Physics, Praha/CZ
- RALSA, Langreo/ES
- UTBM – LERMPS, Belfort/FR

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