œrlikon metco

Thermally sprayed abradable coating technology for sealing in gas turbines

The use of thermal spray technology has revolutionised turbomachinery sealing technology by being able to "tailor design" abradable thermal spray powders and spray them to a designated hardness range, using thermal spray technology to high levels of microstructural control. In this way a wide range of turbomachinery sealing application design criteria can be met together with the judicious use of incursion test blade wear mapping techniques and dedicated environmental and cyclic tests which assist greatly with formulating a coating specification.

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Introduction

A rub event between dynamic and stationary components in most turbomachinery initiates a number of dynamic effects which disturb the turbine steady-state running condition and initiate an overall reduction in performance, either momentarily or permanently. These effects have been elegantly summarised by Muszynska et al (1989) (Fig.1), of which the "friction effect", resultant wear and clearance opening is a permanent, non- reversible side effect. In order to provide for a safety margin to prevent rub events and subsequent damage it is therefore necessary to leave clearances beyond the free ends of the blades and vanes. Changes in rotor vs. stator clearance arise from a number of causes of which the most common are from differential thermal expansion effects between rotor and stator components, rapid changes in engine condition or loading such as a hard aircraft landing or surge, "over temperature" running conditions, or rapid shutdowns arising from a sudden fuel starve for example in a power gas turbine. Other distortion related factors are normal casing out-of- roundness, clearances in bearings and rotor vibrations arising from changes in gas flow dynamics and instabilities.

There are distinct economic advantages associated with having very tight sealing clearances in turbomachines as documented by numerous studies over the past few decades. Lattime & Steinetz (2004) cite a 25µm reduction in tip clearance in a high pressure turbine (HPT) that can lead to a 0.1% reduction in Specific Fuel Consumption rate (SFC) which translates to some 0.02 billion gallons of fuel saving annually for US airlines. In another cited example (Chupp et al 2002), huge fuel savings associated can be achieved with 0.3 - 1% improvements in fuel consumption by refurbishing large land based gas turbine compressor sealing systems. In an industrial application example concerning gas compressors used in an ethylene production plant (Whalen, Alvarez & Palliser, 2004), gas leakage across labyrinth, shaft and balance piston seals were estimated as approx. 4% of total efficiency losses. Assuming a linear relationship between leakage efficiency and clearance, a 50% reduction in seal clearances would lead to a 2% increase in efficiency. This would translate into some $700 000 annual savings for a 200 billion lb / annum ethylene facility.

Maintaining tight seals in aero engine compressors can pay large dividends in terms of reducing the number of compressor stages and hence engine weight, required to maintain a desired pressure ratio. By keeping the stage efficiencies as high as possible by maintaining low tip clearances and the design pressure ratio, undesired weight additions to the engine are avoided.

There are also added hidden costs from loss of design clearances that results in a loss in engine power or thrust. This usually means requiring an increased engine fuel burn rate or throttle setting in an aero
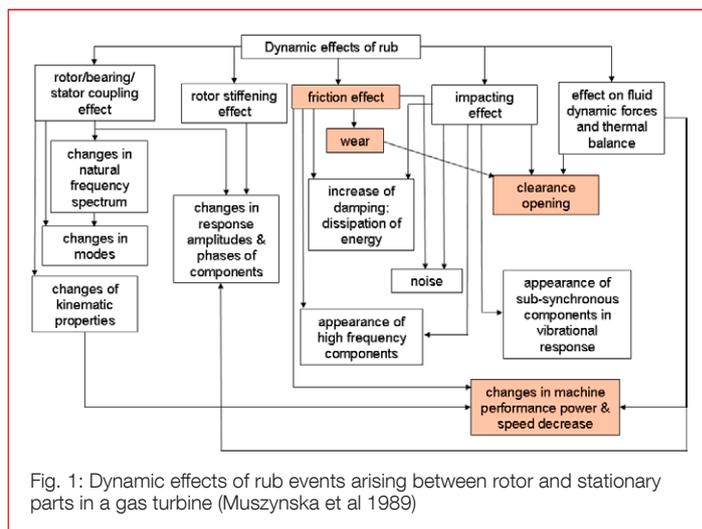

Fig. 1: Dynamic effects of rub events arising between rotor and stationary parts in a gas turbine (Muszynska et al 1989)

engine to achieve the same engine performance. The increased heat generation also increases the exhaust gas temperature (EGT) of the engine and thus reduces the life of the hot turbine components. In the case of aero engines, when the EGT exceeds a Federal Aviation Administration (FAA) certified limit, a full engine overhaul is required, costing typically over $1 million (Steinetz & Hendricks, 1998).

Other unforeseen major costs can arise when extreme operating conditions produce damage to the rotor arising from severe rubs. One example was a root cause failure investigation of a 3700kW 8 stage compressor based on a North sea gas platform (Nissler 1988), rotor severe rubs were observed during start up after routine shutdowns. The start up produced a high momentary vibration arising from liquid slugs entering the compressor and hitting the impellers. The resulting vibrations induced severe rubs at the labyrinth fin seals with the main shaft and generation of extensive friction heat on the shaft. The friction heating in turn induced a slight bow of the shaft producing yet further vibration and severe rubbing resulting in complete destruction of the seals. The problem was solved by retrofitting the compressor with abradable coating seals into which the labyrinth fins could cut efficiently without producing unwanted friction heating. The resultant retro-fit with abradable coatings produced an overall reduction in power loss by 60kW.

There are major economic benefits associated with reducing turbine tip clearances, however to realise these benefits, there need to be realistic sealing solutions in place to reduce risks associated with wear and catastrophic damage of sealing components. As the latter example illustrated, the use of "softer" abradable sealing materials and coatings can play a major role in achieving these aims.

Efforts to improve sealing in turbo-machines have existed since the early 1900's. These evolved into active clearance control using mechanical actuators, labyrinth sealing techniques and use of fluid cooling to control expansion and contraction in the seal region. Of these the use of labyrinth fin seals have become, and are still today, the workhorse sealing system of most turbomachinery (Scharrer & Pelletti (1995), Dobek (1973). Shaft labyrinth seals are commonly used in the following locations: shaft end seals, interstage seals and

balance drum (or piston) seals used for example in steam turbines. These seals are typically exposed to temperature cycles to a maximum of approximately 500°C. (Fig. 2a).

In addition to shaft labyrinth seals, another major type of sealing system are shrouded blade labyrinth seals where the blade is designed with a T-shaped tip (Fig. 2b). These tips touch each other to form a ring around the whole stage to support the blades. On the outer face of each shrouded tip are one or more knife fins that cut into the outer seal on rub contact. Shrouded blade labyrinth seals are common in high and low pressure turbine applications.

The third main type of sealing system are un-shrouded (or open tip) blade seals (Fig. 2c) where a blade tip cuts directly into a softer abradable material counterpart that is attached to a fan, compressor or turbine casing. Un-shrouded blades have less weight and are subjected to lower centrifugal stresses as a result so there are significant savings in terms of engine efficiency and maintenance.
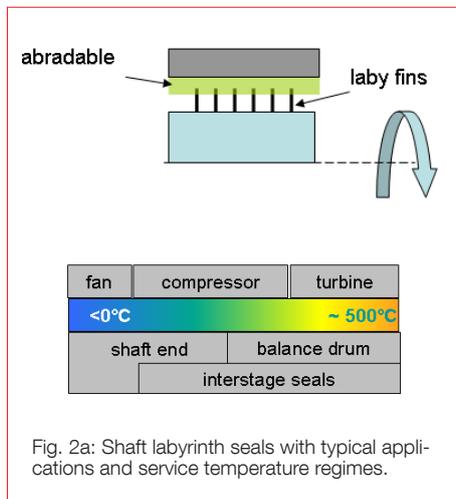

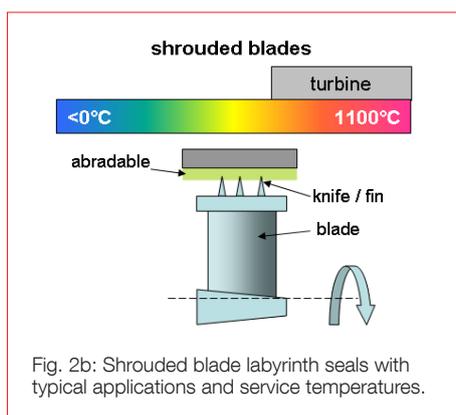Fig. 2a: Shaft labyrinth seals with typical applications and service temperature regimes.

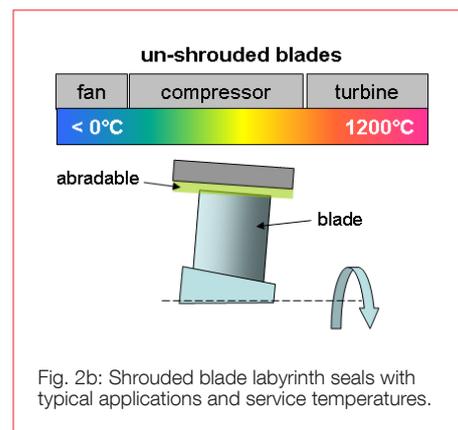Fig. 2b: Shrouded blade labyrinth seals with typical applications and service temperatures.

Fig. 2b: Shrouded blade labyrinth seals with typical applications and service temperatures.

Abradable coating design criteria

Key performance design criteria for abradable seal coating systems used in turbomachinery sealing are the following:

Rub compatibility against either blades, knife fins or labyrinth seals under various incursion conditions.

- Coating cohesive strength.
- Oxidation resistance at elevated temperatures.
- Corrosion resistance in aqueous or chemical fluids and gases.
- High temperature corrosive attack e.g., silicates
- (CMAS), chlorides, sulphides.
- Sintering resistance at elevated temperatures.
- Thermal shock / cycle resistance
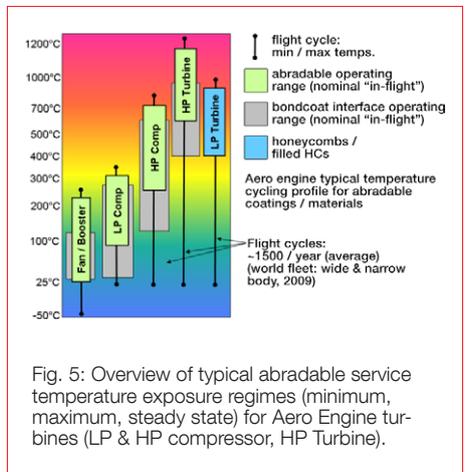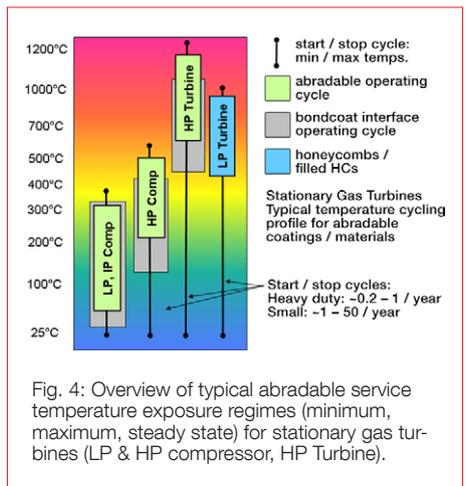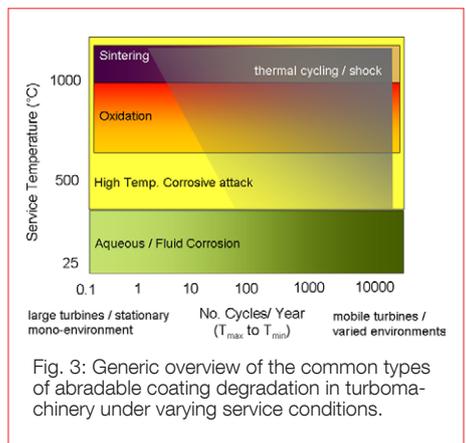- Resistance to solid particle erosion.

The relevance of one or more of these design criteria is dependent on the type of application, the level of temperature and chemical exposure to which the abradable coating is exposed and the number of engine start-stop cycles i.e. cyclic start-stop frequency.

A generic overview of the common types of degradation (Fig. 3) shows the dominance of these according to the typical number of temperature cycles experienced by the turbomachinery device per annum. In very large stationary gas turbines where start/stop cycles typically average one every 3-5 years (Fig. 4), the dominant degradation mechanisms are predominantly long term corrosion (aqueous or other fluid medium), oxidation and sintering, all of which depend on the level of heat exposure. In smaller stationary gas turbines (e.g., marine, small power plant, chemical processing), start/stop cycle frequencies may range from daily to less than once or twice a year, subjecting the abradable coating system to increasing levels of thermo-mechanical cyclic stress in

addition to corrosion, oxidation and sintering. Aero engines experience even higher start/stop cycle frequencies averaging 1500 cycles/year for both narrow and wide body commercial aircraft (Markou et al 2011). Here the coatings are subjected to significant levels of thermo-mechanical cyclic fatigue in-service (Fig. 5) and during start and stop cycles i.e. take-off and landing. In addition, aero engines tend to use more cooling on shroud segments, particularly in the high pressure turbine (HPT) with resultant higher temperature gradients between the exposed abradable surface and the bondcoat used to adhere it to the shroud segment (Fig. 5). Even higher temperature cycle frequencies are experienced for example military aero applications, helicopter engines, and turbochargers e.g., automotive.

Because of their increased mobility, Aero and other transport related turbomachinery are exposed to a wider variation of environments compared to stationary gas turbines in their service lives. These are typically salt laden sea air, erosive sand, dust, volcanic ash, and wide variations in humidity and atmospheric pollution. While stationary gas turbines also experience such varied environmental conditions, they are specific to the turbine location and this tends to make coating selection more predictable.

Meeting design criteria for specific sealing applications using abradable coatings needs to be systematic and based on as detailed overview of the designated service conditions as possible. A wide variety of abradable coating solutions is available and which have evolved over the last few decades to accommodate specific needs in the aero and industrial turbomachinery sectors. An overview of the key abradable coating systems is given below based on dominant function and key design criteria.

Fig. 4: Overview of typical abradable service temperature exposure regimes (minimum, maximum, steady state) for stationary gas turbines (LP & HP compressor, HP Turbine).

Fig. 5: Overview of typical abradable service temperature exposure regimes (minimum, maximum, steady state) for Aero Engine turbines (LP & HP compressor, HP Turbine).

Rub compatibility of abradable materials

The main function of abradable coatings are their rub compatibility against either unshrouded turbine, compressor or fan blades, the shrouded versions thereof, or labyrinth seals.
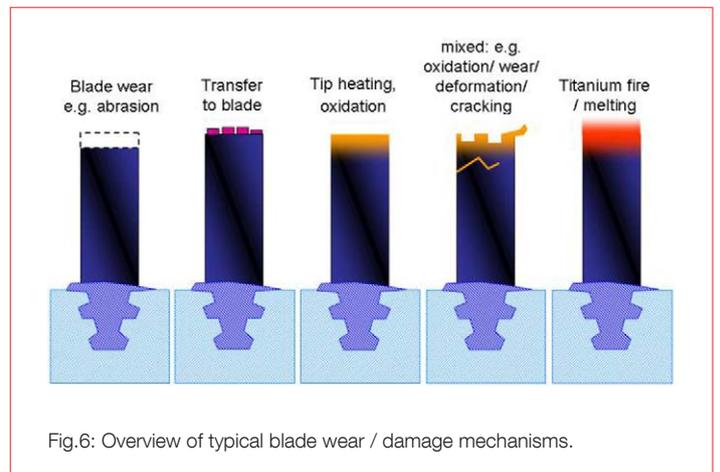
A general rule in this respect is that the abradable counterpart coating should be softer than the dynamic rubbing component material to prevent abrasive wear (Fig. 6) and/or friction induced overheating of the dynamic component as much as possible. A wide variety of materials are available that are softer than the traditional steel, titanium alloy or nickel alloy blades or knife/fin seal materials used in turbomachinery.

Polymeric materials such as resins, elastomers, polyesters and PTFEs are typical examples (Whalen 1994). In addition, low shear strength metals such as aluminium, silver, cadmium, indium, zinc, bronze and copper alloys fulfill the softness criteria to some degree (Burhans (1956), Curtis & Nixon (1962)). Temperature limitations keep the use of these materials usually below 200-250°C or less so they really only find application in the fan inlet or low pressure compressor applications of turbomachinery (Figs. 4 & 5). Low shear strength metals and alloys have a tendency to adhere to harder counterpart surfaces e.g., steel blades, producing a phenomenon known as adhesive transfer or "galling". Here material transfers to the blade or knife/fin surface (Fig. 6), increasing its height and can, when excessive, produce pronounced grooving on the shroud surface and friction heating.

Innovative approaches that combine desired properties of polymeric materials such as soft shearable and heat resistant polyesters with higher strength lightweight or dedicated corrosion resistant alloys have produced well established robust abradable sealing coatings such as Al-Si + 40 wt.% polyester coatings (e.g., Metco 601NS™) or Al-bronze + polyester (Metco 610NS™) (Oerlikon Metco 2012). The polyester phase is supported in a stronger more temperature resistant matrix and acts to reduce the overall hardness of the coating and to effectively inhibit the adhesive transfer of the supporting shearable matrix alloy to the dynamic rubbing surface.

Key to the development of these composite coating systems was the advent of thermal spray technology and thermal spray powder manufacturing techniques.

To achieve higher temperature compatibility, abradable coating materials need to be

Fig. 3: Generic overview of the common types of abradable coating degradation in turbomachinery under varying service conditions.

Fig.6: Overview of typical blade wear / damage mechanisms.

manufactured using stronger and more oxidation resistant materials. The added alloying increases the hardness of the coating overall which can only be mitigated by having secondary softer phases or macro-porosity in the coating. Two families of coating type have evolved for use at higher temperature, these being,

Flame (combustion) sprayed abradables:

Here the abradable feed powder is heated and deposited using an oxygen-acetylene mixture using flame spray gun technology (e.g., current Metco 6P-II gun hardware) that evolved from early designs in the pre-second world war period (Davis 2004). The temperatures reached are sufficient to melt or partially melt nickel and some of the lower alloy content nickel alloys. The addition of materials that combust exothermically to provide extra energy during deposition is fairly common for this family of powders. Typical examples here are graphite or the use of reactive flame spray powders such as aluminium clad together with nickel alloys which produce an exothermic reaction on heating (Dittrich & Shepard 1967). The deposition velocities and temperatures for flame spray are lower than those seen for high energy plasma deposition (Fig. 7) and are adjusted using the oxygen-fuel ratios and pressures so to produce porous coatings. Here powder size ranges are kept typically coarse resulting in less heat transfer to the particles. The resultant effect is partial melting, reduced contact areas between particles with deposition of relatively spherical particles instead of typical lamellar microstructures. This helps to maintain a controllable coarse macro-porous coating architecture. Three classic examples of flame spray abradables are:

Nickel - graphite (Ni-Gr) powders:

These are composite powders, manufactured using a hydrometallurgy autoclave process that encapsulates the graphite core inside a nickel shell to form a continuous cladding. A wide range of coating hardnesses can be obtained by different nickel to graphite ratios and by adjusting spray parameters. These coatings are suited for rub incursions against steel and nickel alloy blades, knives or labyrinth seal strips. They are also suited for incursion against titanium blades provided they have been sprayed to the correct hardness designation.

NiCrAl - bentonite powders

Similar in morphology to the Ni-Gr powders, these too are hydrometallurgical clad composite powders (e.g., Durabrade™ 2313 and Durabrade™ 2311) comprised of a core of Bentonite clay with a thin layer of alloyed NiCrAl. The powder has been specified for over 30 years in the aerospace industry (Fig. 8) and can be sprayed to different hardness levels by spray parameter adjustment (Dorfman et al 2007). These coatings are suited for rub incursions against steel and nickel alloy blades, knives or labyrinth seal strips such as those used in steam turbine balance piston applications (Sporer et al 2010). They are considered too abrasive for titanium blade applications.

NiCrFeAl - boron nitride powders

These are cermet composites, comprised of a nickel- chrome alloy with boron nitride, and aluminium, and are manufactured using mechanical cladding techniques. The aluminium undergoes an exothermic reaction with the nickel alloy component on spraying and assists the melting process. The boron nitride component boosts oxidation resistance and is also a solid lubricant that assists cutting processes during blade incursion. Powders can also be sprayed to different hardness levels for steel, nickel alloy or titanium blade compatibility, using either acetylene or hydrogen as fuel.
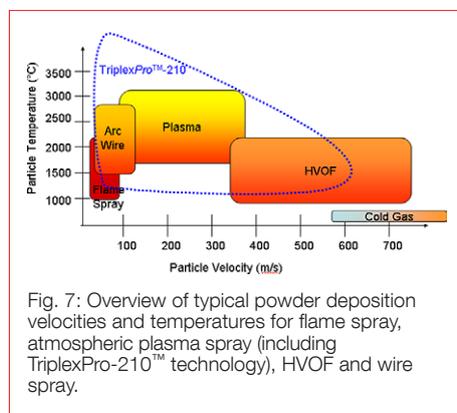

Fig. 7: Overview of typical powder deposition velocities and temperatures for flame spray, atmospheric plasma spray (including TriplexPro-210™ technology), HVOF and wire spray.

Atmospheric Plasma Sprayed (APS) abradables:

The development of plasma spray technologies arose in the mid-sixties whereupon significantly higher powder particle deposition temperatures and velocities (Fig. 7) were attainable. This led to developments in deposition of alloys and ceramics having higher melting points and associated high temperature strength and oxidation resistances. Oxidation resistant MCrAlYs e.g., NiCrAlY and CoNiCrAlY alloys and ceramics, could now be deposited through the additional energy afforded by an electrically generated plasma using primary gases such as Argon or nitrogen and secondary "fuel" gases such

Fig. 8: Typical coating microstructures for a NiCrAl - bentonite (Durabrade™ 2313) abradable flame sprayed to achieve two different levels of hardness (Top: soft, Bottom: hard).

as hydrogen or helium to adjust both the temperature and speed of the plasma. The plasma gun developments have been well documented elsewhere (Davis 2004) suffice to say, they catalysed new abradables technology by introducing two major advantages:

i) high energy heat input to powder particles — enabling melt deposition of a wide range of particle sizes and high melting point alloys and ceramics.

ii) Spraying of composite blends of different materials — to high degrees of microstructural control e.g., polyesters as fillers or porosity generators sprayed together with aluminium alloy, MCrAlY alloy or ceramic powder components.

Established examples of plasma sprayed abradables are:

Aluminium-polymer, Aluminium boron nitride and Al-bronze-polymer powders.

These coating concepts combine desired properties of polymeric materials such as soft shearable and heat resistant polyesters with higher strength shearable alloys as discussed previously e.g., Al-Si + 40wt.% polyester (e.g., Metco 601NS) or Al-bronze + polyester (Metco 610NS). (Fig. 9). Another coating concept combines Al- Si with hBN where the ceramic phase acts to boost lubricity and temperature resistance (Metco 320NS). These coatings are suited for rub incursions against either steel, nickel alloy or

titanium alloy blades, knives or labyrinth seal strips, provided they have been sprayed to the correct hardness designation.

MCrAlY - boron nitride - polymer powders.

A distinct feature of MCrAlY alloys such as CoNiCrAlY (cobalt-nickel-chromium-aluminum yttrium) matrix within coatings is their improved oxidation and corrosion resistance compared to other nickel-chromium-based abradable materials up to temperatures of 650°C and in some cases higher to approx. 750°C, depending on coating porosity levels. Unlike soft shearable aluminium alloys, coatings with stronger and harder MCrAlY alloys as abradables is controlled directly by presence of macro-porosity since they are generally harder than any of the rubbing blade or knife/fin materials. The boron nitride component provides solid lubrication, thereby improving abradability by making the microstructure cuttable by a friable mechanism. Coating porosity can vary from 35 to 60 volume percent; which is controlled through the amount of entrapped polyester in the coating. It is this controlled, web-like metallic structure that allows for excellent friability against titanium alloy, steel or superalloy blades. The coating requires a post deposition polymer removal heat treatment to create the desired porosity.
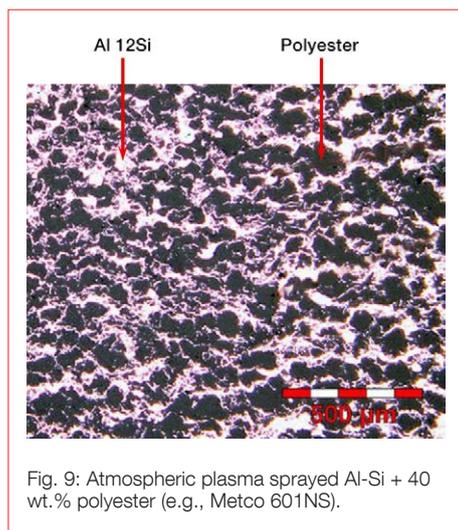

Fig. 9: Atmospheric plasma sprayed Al-Si + 40 wt.% polyester (e.g., Metco 601NS).

Ceramic Zirconia based abradables

Like the CoNiCrAlY abradables described above, modern ceramic abradable powders are nominally comprised of three phases: a ceramic matrix phase, typically Yttria or Dysprosia stabilized zirconia (YSZ, DSZ), a polymer and a solid lubricant (Dorfman, Wilson & Sporer (2008), Schmid (1997), Oerlikon Metco (2009)). The polymer entrapped in the as-deposited coating can be burned off to produce coating porosity while the added

solid lubricant, mostly hexagonal boron nitride, hBN, acts as a release agent to induce friability in the ceramic microstructure. Typical commercially available zirconia based abradable powder materials are shown summarised in Table 1. Zirconia abradable technology is essentially derived from the extensive thermal barrier coating technology base, where stabilised zirconias are well known for their excellent thermal shock resistance, toughness, and sintering resistance (Vassen & Stöver 2007). The combination of low elastic modulus of zirconias compared to other high temperature materials, their high melting and sintering resistance and ability to be sprayed relatively thick (e.g., 2.0 mm) with suitable but controllable defect and macroporosity concentrations e.g., pores and splat boundaries, all contribute to compliant (low stiffness) coating structures (Fig. 10) that greatly assist in design against thermal shock damage.

Material	Ceramic Matrix	Organics	Solid Lubricant
Metco 2460	94.0 % YSZ	3.5 % PE	---
Metco 2395	94.5 % YSZ	4.7 % PE	0.8 % hBN
Durabrade 2192	94.5 % DySZ	4.7 % PE	0.8 % hBN

Table 1: Overview of Oerlikon Metco commercial ceramic abradable powder compositions (PE = polyester, hBN= hexagonal boron nitride).
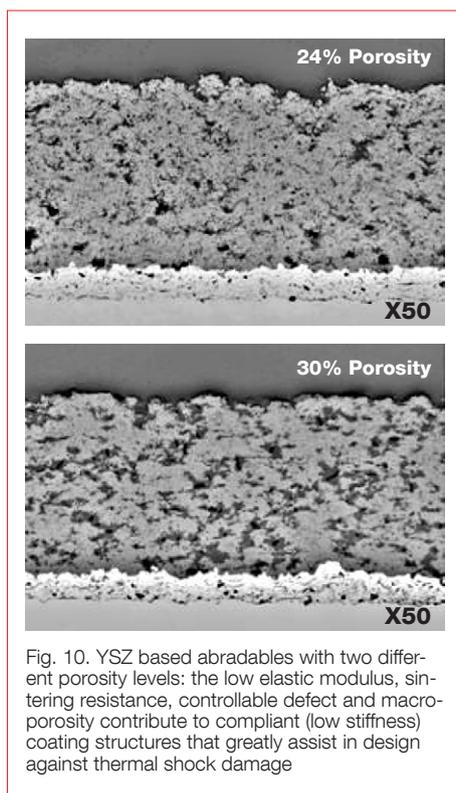

Fig. 10. YSZ based abradables with two different porosity levels: the low elastic modulus, sintering resistance, controllable defect and macroporosity contribute to compliant (low stiffness) coating structures that greatly assist in design against thermal shock damage

Because zirconia ceramics used in abradables are considerably harder than common turbomachinery blade and knife/fin materials, efficient cutting is achievable only through he use of hard tipping on the blades or knives such as cubic boron nitride (cBN). However, it has been demonstrated that ceramic abradables with porosity levels above 30-33% can cut relatively well by untipped, bare blades in applications suitable mostly for large stationary gas turbines.

Testing of Abradable coatings:

For most if not all intended abradable applications, a series of testing procedures are adopted primarily as a risk mitigation and benchmarking process and assisting towards the setting up of a coating specification and qualification process. Key testing procedures are given below:

Abradable Incursion Testing:

Of the commercially available testing faciles the Oerlikon abradable incursion test facility (Fig. 11) based in Winterthur, Switzerland, provides a vital tool for Oerlikon Metco and its OEM Aero & IGT partners in their joint abradable development programs (Wilson 2007). The facility is the largest and most sophisticated of its kind with capability for testing up to shroud temperatures of 1200°C, using a variety of blade, knife seal or labyrinth seal strip configurations. The flexibility of the rig allows for testing over a wide range of tip speeds and incursion rates, with capability for radial and axial incursion into different abradable shrouds. The rig uses a high velocity gas stream to heat the abradable specimen to the required temperature. Test blades are mounted on a turbine disc that can produce blade tip speeds of up to 500 m/s. A stepper motor allows the controlled moving of the abradable test specimen towards and into the bladed rotor. Incursion rates, the speed at which the specimen is moved into the rotor, can be adjusted from 1 to 2000 µm/s. Real turbine blades or blade dummies can be tested. While the use of original blades provides the advantage of closely simulating a specific stage design, the use of dummies with well defined geometry is the preferred set-up for systematic investigations as discussed here.

As the true incursion conditions, in particular the rub incursion rates are not readily available for all possible compressor and turbine operating conditions, an array of tip speed / incursion rate settings is typically used to qualify an abradable coating. Typical incursion test outcomes for flame sprayed NiCrAl-bentonite, and an APS sprayed

YSZ-polyester abradable coatings sprayed to optimum hardness levels are given in Figs. 12 & 13. The results are shown in the form of "wear maps" showing shroud incursion wear mechanisms and percentage blade wear (blade height loss (or gain) as % fraction of total incursion depth into shroud) as a function of blade tip incursion velocity and incursion rate. Such a standard wear map with blade tip speeds varies from 250 to 410 m/s and incursion rates ranging from 5 to 500 µm/s.

An overview of typical incursion test blade wear measurements at different incursion conditions, blade material compatibility, and coating hardness ranges is given in Fig.14 for the major abradable coating systems as a function of their maximum service temperatures.

Ageing, Corrosion, Thermal Cycle and Thermal Shock testing:

Apart from good abradability, coating resistance to thermal shock and thermal cycle durability is another major requirement for compressor and turbine seal coatings (Dorfman et al 2008, Groh 1969, Kennedy & Bill 1979). For compressor abradables, coatings can be subjected to a severe thermal cycle test where the coatings are water quench tested from elevated temperatures matching the application temperature e.g., 470°C. Coating thermal stability under these conditions is generally determined by using the change in coating strength (ASTM C 633 bond strength test for thermal spray coatings) as the yardstick.

For ceramic turbine abradables typically the coating system is cycled using a dedicated furnace cycle test facility on a one hour cycle frequency e.g., 1150°C with forced air cooling to 50°C. As the test has a high temperature dwell time at the test set temperature, this thermal shock test does also serve as a sintering test and a bondcoat endurance test. Test temperatures and cycle dwell period can be varied according to the desired end application conditions e.g., stationary large gas turbine vs. aero turbine application. Coating thermal stability can also be determined by the change in coating strength using ASTM C633 test, but the most common approach is visual characterisation of failure mechanisms i.e. cracking or debonding of the coating from the substrate. In order to investigate their long term durability and thermal stability, coatings are also subjected to elevated temperature ageing treatments in air and salt spray tests in accordance with ASTM B117. Here again,
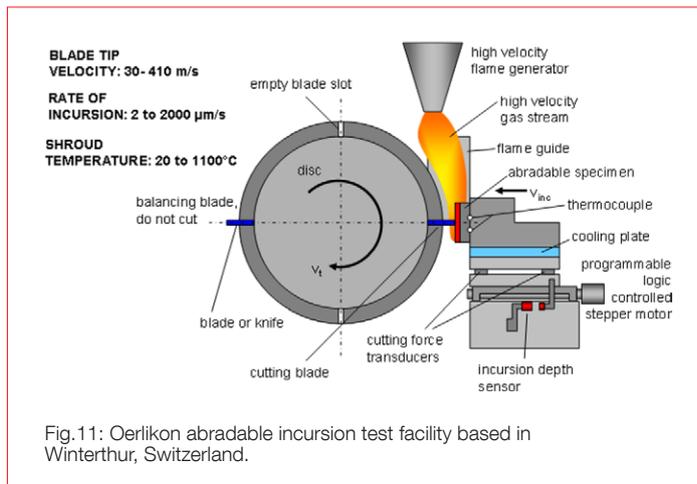

Fig.11: Oerlikon abradable incursion test facility based in Winterthur, Switzerland.

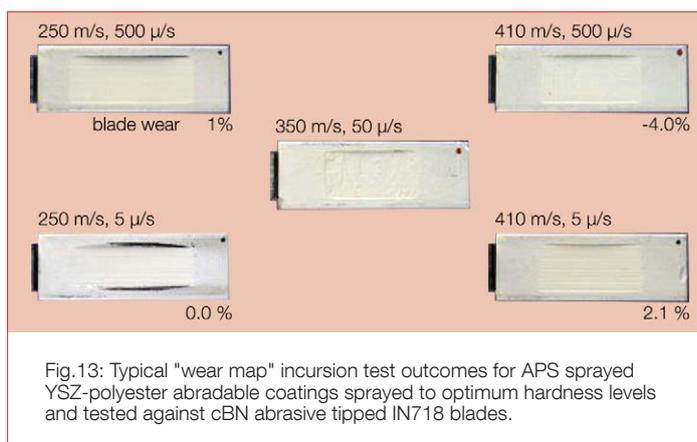Fig.12: Typical "wear map" incursion test outcomes for flame sprayed NiCrAl-bentonite against IN718 blades.

Fig.13: Typical "wear map" incursion test outcomes for APS sprayed YSZ-polyester abradable coatings sprayed to optimum hardness levels and tested against cBN abrasive tipped IN718 blades.

coating stability by ASTM C 633 change in strength is recommended. As the coating strength correlates well with hardness and erosion resistance, the determined change in UTS is also indicative of changes in other coating mechanical properties.

Erosion Resistance

The erosion resistance of abradable coatings is commonly determined according to GE E50TF121CL-A specification. The GE number is expressed in s/mil and represents the time in seconds necessary to erode 25.4 µm of the coating thickness. A higher GE erosion number means better erosion resistance. The need for solid particle erosion resistance is highly dependent on the service environment in which the turbomachinery is used. An abradable coating can last years in an industrial gas turbine for a chemical process plant where there is virtually no erosive particle contamination, or a few days in a sandy desert environment e.g., military helicopter. Here judicious coating selection is needed to optimise according to the end-use. In this respect, coating hardness (or tensile strength) is a useful general indicator of erosion resistance as shown in Fig. 15 for the major compressor abradable systems. In very aggressive erosive environments, often the best solution is to spray the coating to a high hardness while having to protect blade tips from excessive wear using abrasive tipping such as cubic boron nitride or a hard coating.

Summary

By being able to tailor design abradable thermal spray powders and spray them using APS or flame spray technology to high degrees of microstructural control, a wide range of turbomachinery sealing application design criteria can be met. Use of incursion test blade wear mapping techniques together with dedicated environmental and cyclic tests are judicious risk mitigation tools and assist greatly with setting up of a coating specification.
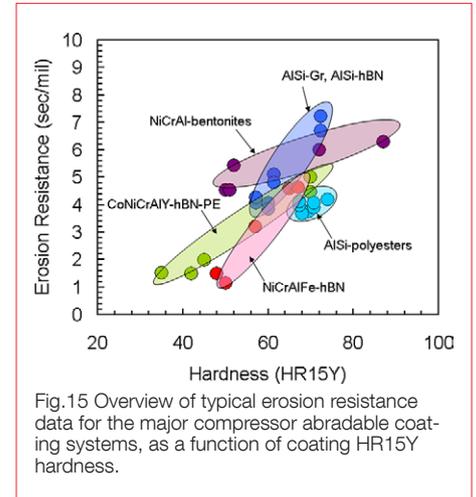
Fig.15 Overview of typical erosion resistance data for the major compressor abradable coating systems, as a function of coating HR15Y hardness.
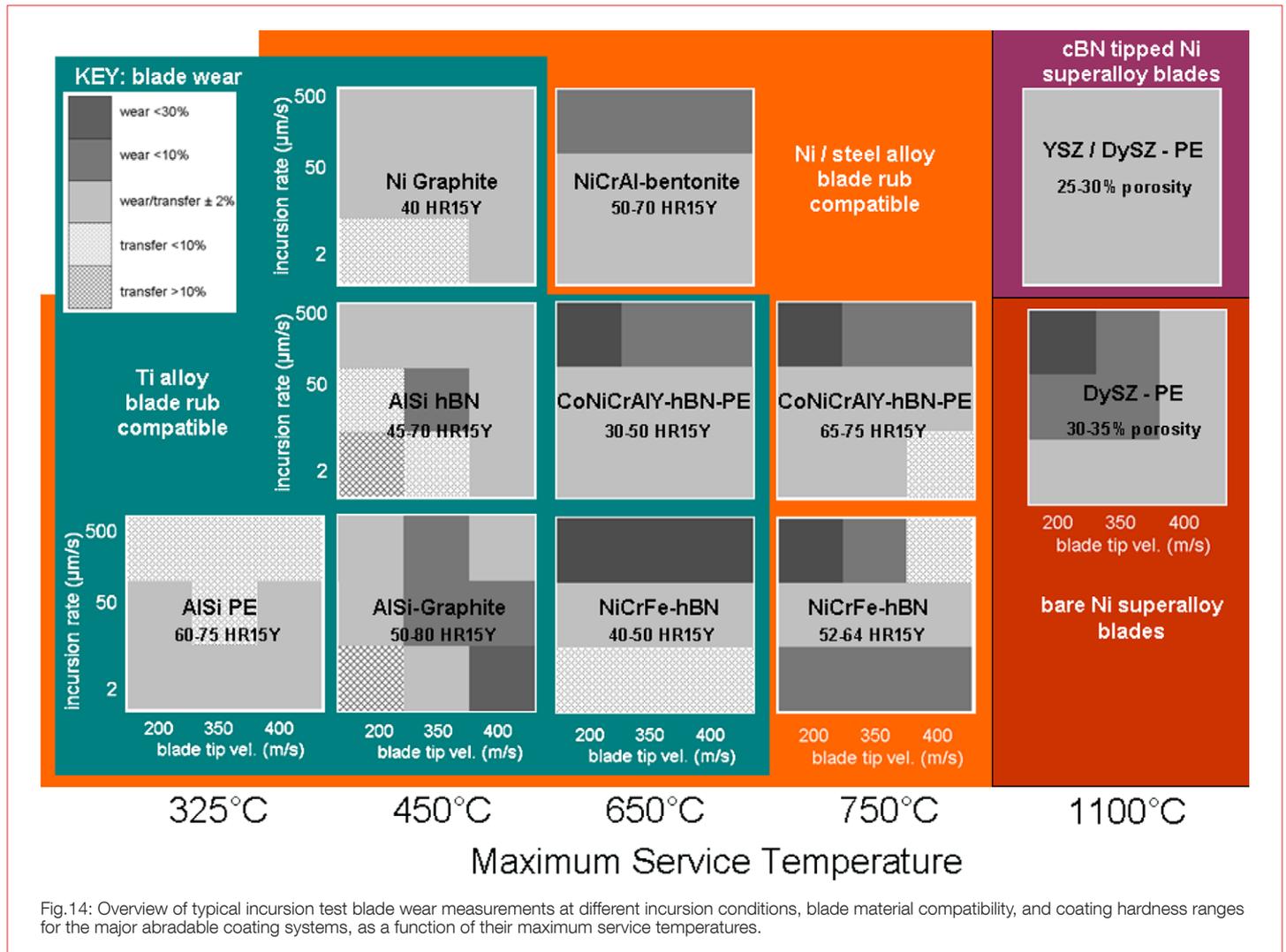

Fig.14: Overview of typical incursion test blade wear measurements at different incursion conditions, blade material compatibility, and coating hardness ranges for the major abradable coating systems, as a function of their maximum service temperatures.

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Oerlikon Metco enhances surfaces that bring benefits to customers through a uniquely broad range of surface technologies, equipment, materials, services, specialized machining services and components. The surface technologies such as Thermal Spray, Thin Film, Plasma Heat Treatment and Laser Cladding improve the performance and increase efficiency and reliability. Oerlikon Metco serves industries such as aviation, power generation, automotive, oil & gas, industrial and other specialized markets and operates a dynamically growing network of more than 50 sites in EMEA, Americas and Asia Pacific. Oerlikon Metco, together with Oerlikon Balzers, belongs to the Surface Solutions Segment of the Switzerland-based Oerlikon Group.

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