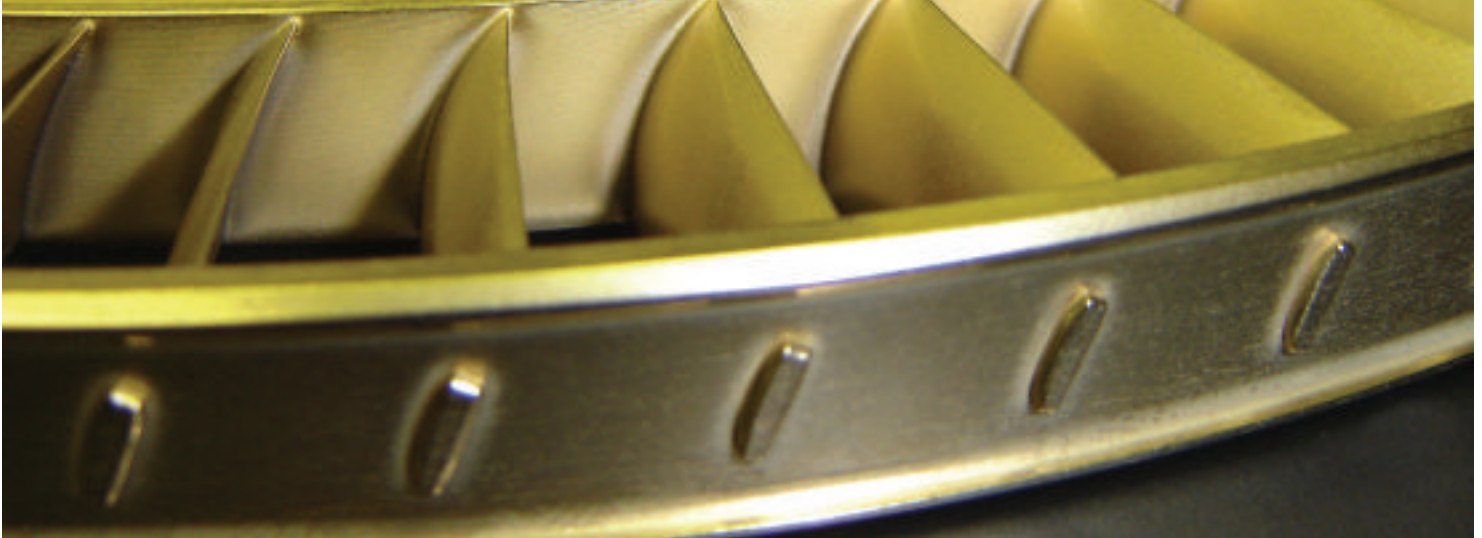


# RIC TiN coatings for improved engine efficiency and extended compressor life.



**Coatings for aerospace applications have evolved in response to the changing hurdles faced by airline operators. Corrosion resistance and erosion resistance were the primary drivers in coating development in the past but today's TiN and TiAlN coatings also address the aero-engine professional's need to realise greater fuel efficiencies both as an environmental and a cost benefit. Robert Tollett of Liburdi Turbine Services elucidates.**

The use of coatings in aerospace applications started 50 years ago with the introduction of hot section coatings to improve the performance of superalloys in hot corrosive environments. They prolonged the life of the critical blades and vanes between overhaul cycles.

In comparison, the need for 'cold section' protection was in its infancy. The 'cold section' of a turbine engine is a relative term, of course, as in turbine engines the components at the rear of the compressor section can still reach 880°F or 450°C.

During the 1960s modified 'hot section' coatings were used in the compressor sections in the form of diffused aluminides. Chromalloy's SA-12, an aluminium based heat treated coating, was used to protect compressor parts in service. This material was rough in texture and was not well liked due to the limited heat treatable nature of compressor section materials. Coating

thicknesses ranged in the 0.001" - 0.002" or (20-50 µm).

In the late sixties and early 1970s experimentation with 'galvanically' active aluminides was pioneered as a means of protecting the compressor components from corrosion. Companies such as Sermatech and Aloseal were two of the original companies that commercialised these coatings. Essentially, powder aluminium was cured at low temperatures of less than 700°F or 371.1°C. It was polished to yield a conductive (galvanic) coating over the compressor parts. While this worked relatively well on parts that operated in aqueous type corrosive environments, the materials did not function well in environments where corrosion and erosion were combined.

Cadmium and electroless nickel plating processes were also used but unfortunately all of these 'galvanically' active surface coatings were too 'soft' to last any



appreciable time in erosive environments. Even using nylon, polymer or other top coat systems did not improve performance adequately. This became one of the life limiting factors for most aero gas turbines operating in erosion environments around the world.



By the early 1990s it was evident with military and commercial operators in the Far and Middle East that corrosion protective soft coatings would not be able to address the severe erosion of parts experienced in these operations. A wide range of contaminants ranging from sub 5 micron particulate (talcum powder consistency) to large particulate sand of over 200 microns would reduce the compressor airfoils to paper thin sheets within 400-800 hours in military service, with commercial operators experiencing similar decay over a longer period of time.

Life extension techniques to challenge such difficult environments and provide a long-term solution took several avenues. Surface hardening, alloy modifications and hard coatings were all employed.

Surface hardening by 'ion' implantation has been tried with some degree of success. They are limited in life as, at under a micron, the treatment depth is too shallow and the costs prohibitive. Alloy changes and modifications have been tried with new

aerospace derivative stainless steels with higher toughness. Steels in alloy composition are limited by their inherent properties which are relatively soft in comparison to ceramics. Numerous processing techniques have been employed to apply coatings like diamond, carbides, nitrides, oxides and combinations thereof. GE and SNECMA offer hard plasma sprayed coatings on some commercial applications such as the CFM engine family.

The use of physical vapour deposition (PVD) to apply TiN coatings was first developed by Russia's military during its involvement in the Middle East. Their theatre of operations included Afghanistan and other Baltic states where sand erosion was a critical life limiting phenomenon in helicopter turbine engines. As an added challenge, a thin film coating of less than 25 microns was required to minimise changes in harmonics and fatigue properties of the rotating blades of these small turbine engines.

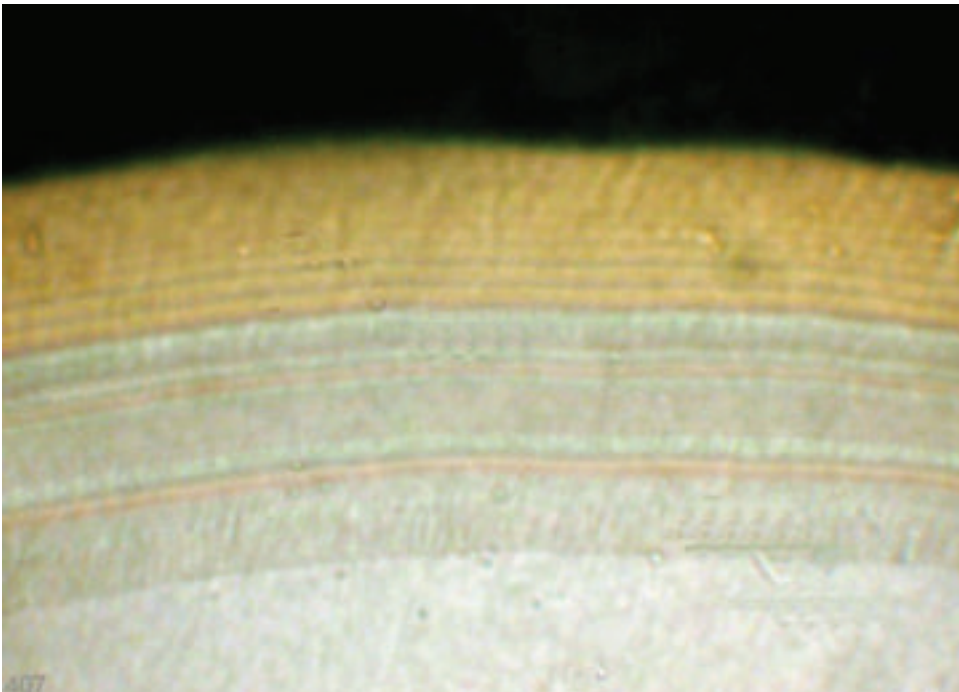
## Coatings applied through PVD processes

Today, coating materials can be applied with PVD processes using arc evaporation. Many 'flavours' of coating material exist and have proven to be effective against erosion environments. The benefit of the arc process was speed of deposition and cost. Denser films are developed by a variation of the process utilising electron beam evaporation (EB PVD). EB PVD provides a denser, more defect free, thin film for a variety of material compositions.

PVD processes are line of sight evaporation processes. In the arc evaporation technique multiple targets or cathodes are typically used to achieve uniform coverage of surfaces. In EB PVD several rod feeds can be employed to supply the various materials for evaporation and coating.

A typical depth for hard PVD applied compressor coatings is in the 5 micron to 20 micron range. Typical hardness values for coatings range from 2000 HV - 4000 HV.

Some ARC PVD processes require a roughening of the surface to clean and mechanically "lock" the coatings to the substrate material. This is emblematic of the nature of the deposition and can have detrimental effects on fatigue properties and surface smoothness. In some cases this makes the coatings undesirable for use on



highly stressed compressor rotating hardware found on new generation engines, due to reduced fatigue properties. New compressor blades tend to be highly twisted and thinner in camber, to achieve the desired “3D” performance requirements.

The electron beam (EB) process is similar to other PVD processes in that they require the evaporation of metals to a surface to be coated. The physics differ in the pressures and power sources in the EB evaporation. EB yields high purity molecule-by-molecule uniform depositions which replicates existing surface geometry.

Reactive ion coating systems enhance the throwing power of the standard PVD process by ionising the coatings being deposited. This is done by creating a negatively charged zone around the parts to be coated. The ionised plasma is then used to drive the coating to the parts electrically. This enhanced PVD process allows more uniform coating and a wrap around effect for edges and cavities.

### Engine design influences on coatings

Flow characteristics vary from one turbine engine to another. These flow variations alter the failure mechanisms and locations of wear on flow path parts. High angle attack to low angle attack of components needs to be considered when evaluating protective erosion treatments.

Typically, high angle of attack is experienced at the front of the engine compressor on the first few stages of low pressure compressor (LPC) blades and vanes. This is when airborne particulate is perpendicular (90°) to the incoming air. As the compressed air changes direction and velocity in the compressor section, the particulate attack becomes low angle (<30°).

As a result the wear characteristics on components differ from stage-to-stage of the compressor section. At the front end of the engine, leading edge erosion is likely to be a predominant failure mechanism. Further back in the compressor towards the combustion section, the low angle of attack results in predominately trailing edge erosion.

Some aircraft have specific airframe/engine design related issues that influence erosion on specific parts. The MD-88 experiences severe fan blade leading edge erosion due to water cavitation from the



wing landing gear wheels on take off and touch down. The resulting loss due to erosion of the fan blades on the JT8D-219 engine is over one per cent.

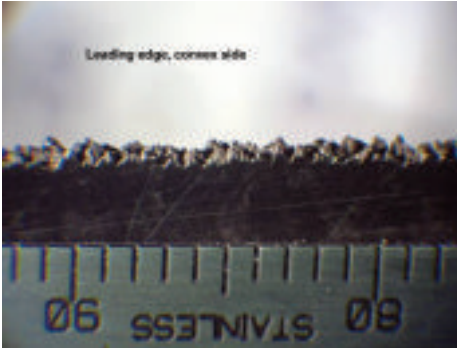
### The use of coatings to address today's challenges

With the increasing costs of fuel, one of the most critical areas for commercial operators is the loss of chord width and blade geometry. The aerodynamic work of the engine compressor is directly related to the specific fuel consumption (SFC) and overall performance margins achieved.

Over time the loss of geometry plus increased surface roughness can contribute to a loss of several per cent in overall engine performance. Deterioration in one section of the engine has a cascade effect as pilots need to increase throttle settings to compensate for poor compressor dynamics. This results in increased exhaust gas temperature (EGT) that further reduces the life expectancy of the hot section of the engine.

One of today's most interesting benefits of the use of erosion resistant coatings is not the delayed onset of component decay, or eventual part failure, but rather the maintaining of engine performance in service.

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Many engines are removed from service due to poor performance, higher than acceptable EGT temperatures, rotor speed limitations, and generally poor takeoff capabilities. The poor flight performance of engines is the first indication that parts no longer meet design criteria.

Once the aerodynamic efficiency of the compressor section has deteriorated, its ability to do work diminishes, thereby reducing the hot section's capacity to produce power. Typically, the compressor section pumps less so pilots increase throttle settings to achieve the necessary takeoff conditions. The increased throttle settings translate into higher compressor rotational speeds and more fuel consumption. The more fuel that is burned, the higher the EGT becomes to produce the same power, and the more rapidly hot section components decay. Being able to retain the original aerodynamic airfoil shape and pumping capacity ensures the takeoff capability and power regimes for safe and sustainable flight operations.

A dirty compressor can cause a three to four per cent loss on horse power. For this reason compressors are kept clean by regular on-wing washing which use surfactants or walnut shells. However, having an ultra-smooth compressor

with high surface finishes reduces the amount of airborne contamination that adheres to the compressor in the first place. It thereby reduces the need to perform on-wing washing which can be costly and environmentally unfriendly. By selecting a thin film coating with a smooth, resilient surface topography and finish, significant cost savings can be made in fuel burn, performance, and parts usage.

EB processes that use high polish and an electron cleaning of the surface as part of the process offers finishes in the 'glass' range of 8µ inch finish. This translates into a one to two per cent performance gain in power. The more slick the part surfaces are the less debris will adhere to it, and the longer time intervals between compressor washing.

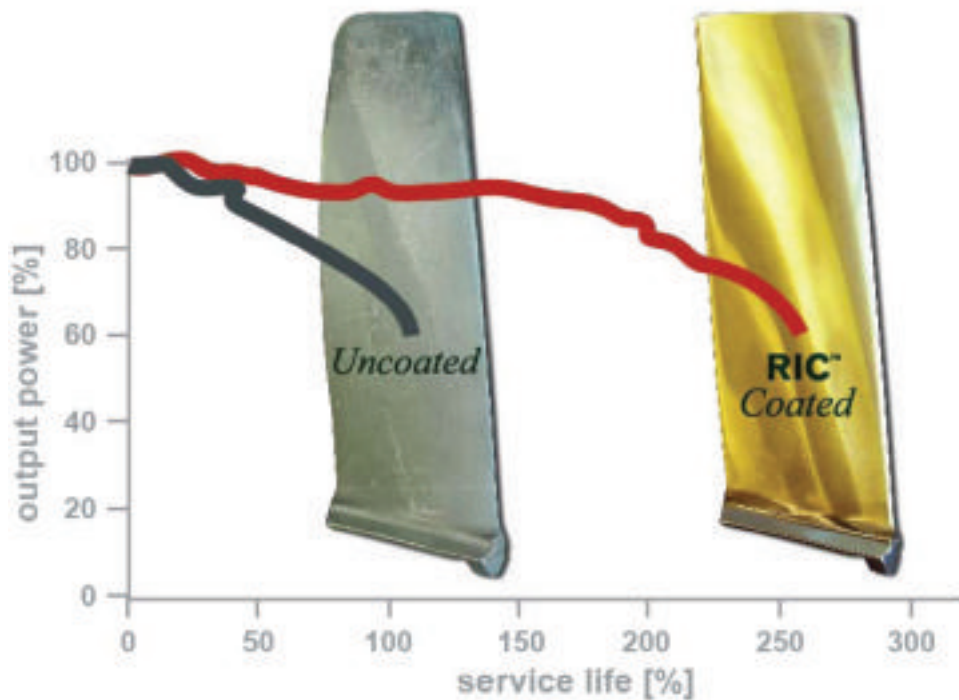
OEMs supply compressor components with typical surface finishes that range from 24µ inches to 32µ inches in roughness. Since the PVD processes deposits thin films by a plasma gas phase the molecule-by-molecule growth of the films replicates the existing surface almost exactly. Consequently, the surface finish of the uncoated component is very close to the surface finish after the coating is deposited.

EB PVD thin films that can adhere to highly polished surfaces have an advantage in the resulting surface finish and subsequent performance characteristics. Performance benefits of over one per cent are achieved in the test cell. An example is the LIBURDI RIC EB PVD process where a thin film hard coating is applied to a highly polished substrate resulting in an 8µ inch finish.

The key to compressor performance retention is achieving a superior surface finish on the air washed parts and retaining the aerodynamic geometry as it was originally designed. Thin film coatings that retain surface smoothness, leading edge profile, angle of attack, and chord width will retain performance on-wing over the life of the coating between overhauls.

**Ability to remove the coatings**

The ability to strip coatings at overhaul is of fundamental importance in achieving additional life and cost savings from components. It is important to consider the parent alloy material when utilising a coating removal methodology. Solutions that preferentially etch the coating 'titanium' work well on steel substrates. However they may not work as well on similar titanium substrates. Operators need to ensure



safe stripping practices with solutions that remove the coatings but are benign to the base alloy, thus ensuring there is no metal removal when multiple coating cycles are planned.

Temperature plays a role in many high performance engines. TiN coatings begin to oxidise at 600°C and are part of a time-temperature curve. Some compressors in modern engines can reach 1,000°C at the compressor discharge. Modified coating systems such as TiAlN offer better thermal oxidation and erosion resistance at these elevated temperatures.

Corrosion resistance is of importance to major airline operators. Nitrides are ceramic coatings which are considered barrier coatings. They are inert and neither anodic or cathodic.

The key to improving the corrosion resistance with barrier coatings is eliminating the galvanic couple and any possible breach of the coatings in non-gas washed areas. The use of multilayer coatings that lay a metal layer first and then ceramics subsequently can impede the galvanic couple. The use of layers can also reduce the likelihood of a complete breach of the ceramic. The use of other elements in the matrix can also retard the onset of corrosion on parts.

### Coatings are here to stay

Many OEMs have tried to offer new alloys to improve corrosion erosion resistance. Some are more effective than others although they are limited by the nature of the operating environment. The lightweight, cost-effective, temperature-tolerant materials of today are all steel based. Steel's erosion characteristics are well known as is its relative ductility as compared with ceramics and composite coating systems.

The application of coatings is paramount when operating in erosive environments and provides the necessary performance and survivability to achieve anticipated time between overhauls.

The performance aspects to hard coatings cannot be ignored in today's economy. Operational savings for large fleet aircraft of one to three per cent can translate into tens of millions of dollars in cost savings for commercial operators. Retaining leading-edge profile and chord-width plays a key role in long term savings for aero-engines regardless of operating environments. The aerodynamics the OEM engineers design-in can be retained longer with the right coatings programmes in place, yielding maximum fuel economy and component life. ■

