Solutions Flash
Improved anti-fretting solution for titanium alloys outperforms conventional coatings

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Today's situation

The configuration and fit of gas turbine compressor blade roots and disc slots is critical, designed to withstand the vibrations and high dynamic forces generated in service. Lightweight titanium alloys are extensively employed in aircraft turbine engines.

Fretting wear between the mating surfaces of the disc and blade root is a major concern that must be addressed to reduce the potential of catastrophic failure. This fretting is primarily the result of high frequency vibration generated by air flow through the compressor rotating blades. The vibration from the airfoil is transmitted to the blade root, creating small, relative oscillating movement between the root and the disc, resulting in fretting wear of both components. In addition, with changes in disk speed, particularly on engine start, radial strain resulting from the outward motion of the blade results in extreme centrifugal loading that causes slip along the surface of the dovetail.

Current state-of-the-art is to thermal spray alloys of copper-aluminum (CuAl), copper-nickel (CuNi) or copper-nickel-indium (CuNiIn) to either the blade root or the disc slot. However, space restrictions prevents coating all but the largest of disc slots, and the possibility exists to cause thermally-induced fatigue in this critical area.

These traditional coating materials have temperature limitations that prevent their use in the higher intermediate and rear stages of the compressor. The ability of these coatings to resist high compressive stresses are limited, such as when large turbine blades are used. Over time and under load, these coatings have been reported to deform undesirably, further limiting their protective functionality. It has also been reported that these coatings work-harden in service, contributing to disc wear.

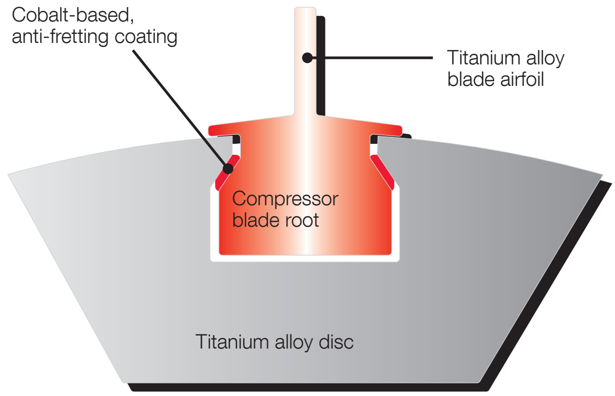
The Oerlikon Metco solution

Cobalt-based Amdry™ 958 has been designed to protect against metal-to-metal wear on frictionally engaged, titanium alloy parts resulting from fretting, adhesion and galling. Coatings of Amdry 958 are advantageous when only one surface of the friction couple can be coated because of space restrictions, such as in a dovetail attachment of a compressor blade to a disc.

The composition of Amdry 958 permits its use throughout the compressor, even in the much hotter, rear stages of the engine. Furthermore, coatings of Amdry 958 are extremely effective on blade roots, eliminating the risk associated with disc slot coatings.

Amdry 958 can be applied to titanium alloy compressor blade roots using air plasma spray or the Metco DiamondJet™ HVOF process. Only those surfaces of the blade root that are in contact with the disc slot need be coated (see schematic representation below). Typically, a thin coating of only 100 – 150 µm (0.004 – 0.006 in) provides effective protection and excellent service life.

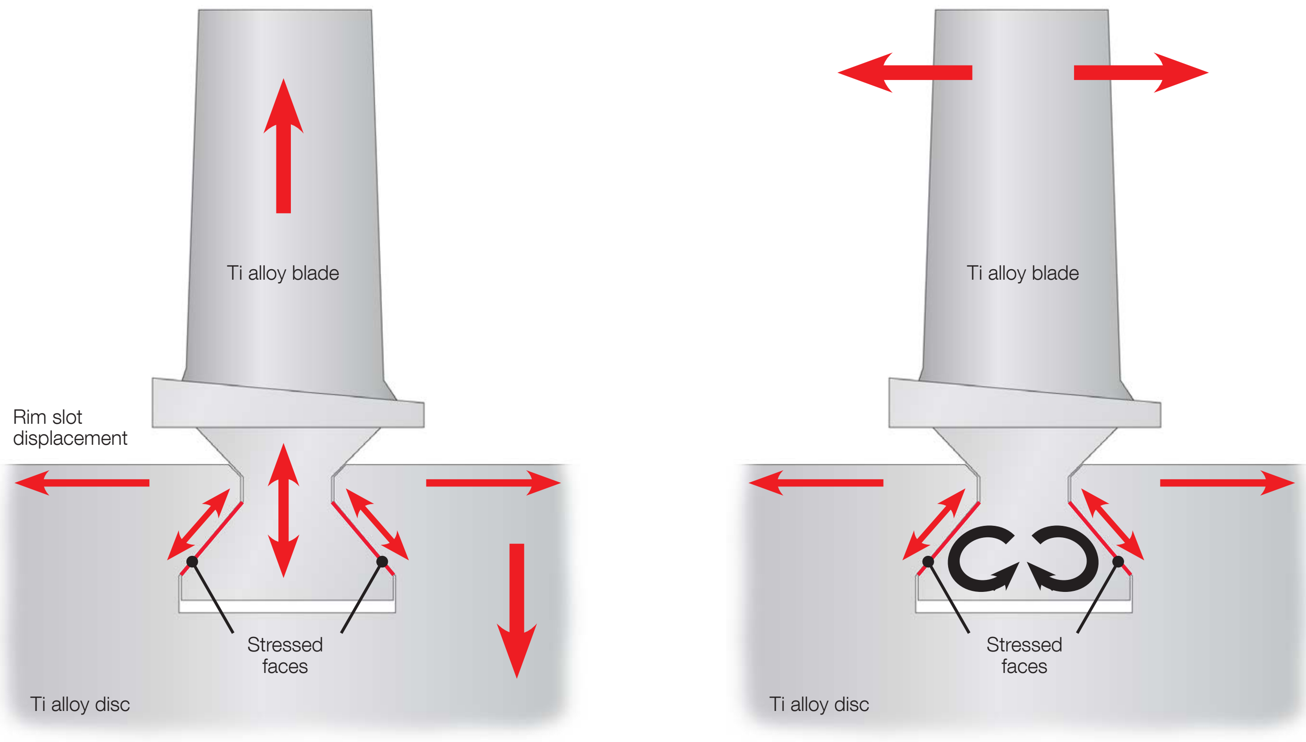
Coatings of Amdry 958 exhibit high compressive strength, and can be used on compressor blades of all sizes, including large blades in the fan and low compressor sections.



Schematic representation of a typical coating application on a compressor blade root.

Solution description and validation

Sources of fretting fatigue in a blade and disc system



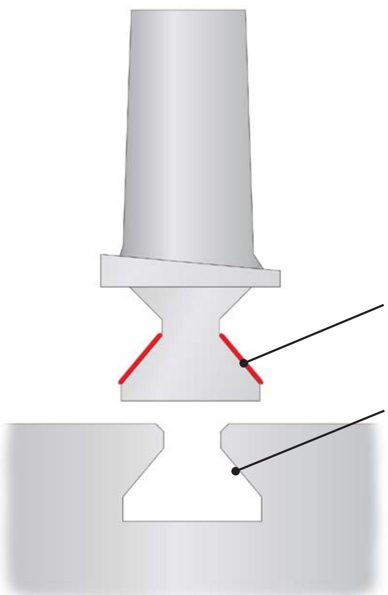
Radial strain
With changes in disc speed, the slot can open and the blade moves outward under centrifugal load. Thus, slip along the surface of the dovetail occurs.

Blade vibration
The primary source of blade vibration is from aerodynamics, which causes the blade to oscillate. Thus, slip along the surface of the dovetail occurs.

Coating application

Amdry 958 is applied as a thermal spray coating to the dovetail root of the blade. This is advantageous for several reasons:

- Surfaces that experience dynamic loading in service are the only areas that need to be coated with a typical coating thickness of 100 – 150 µm (0.004 – 0.006 in), minimizing material usage and processing time.
- Coating is applied to easily accessible surfaces of the blade root rather than the disc slot, which may be inaccessible because of its size and geometry. This also means that potential damage to the disc as a result of thermal spray processing is eliminated.



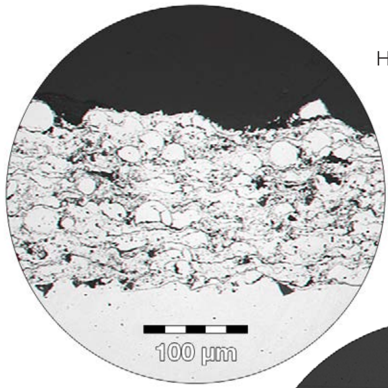
Tailored coating structure

Amdry 958 can be applied using either the DiamondJet HVOF spray process or atmospheric plasma spray, which permits engine designers to choose a coating structure best suited for the specific application requirements.

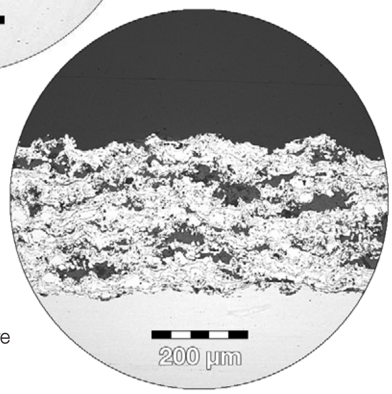
- Coatings applied using DiamondJet HVOF contain a lower percentage of retained hBN, have significantly higher hardness, and lower porosity.
- Coatings applied using atmospheric plasma spray have a higher percentage of hBN, higher porosity and are softer.

Service temperature

Amdry 958 can be used at service temperatures up to 450 °C (840 °F). Therefore, it can be used throughout the compressor section of the engine. This is an advantage over coatings such as CuNiIn, that have a maximum service temperature of only 315 °C (600 °F).



HVOF Microstructure



APS Microstructure

Typical coating properties

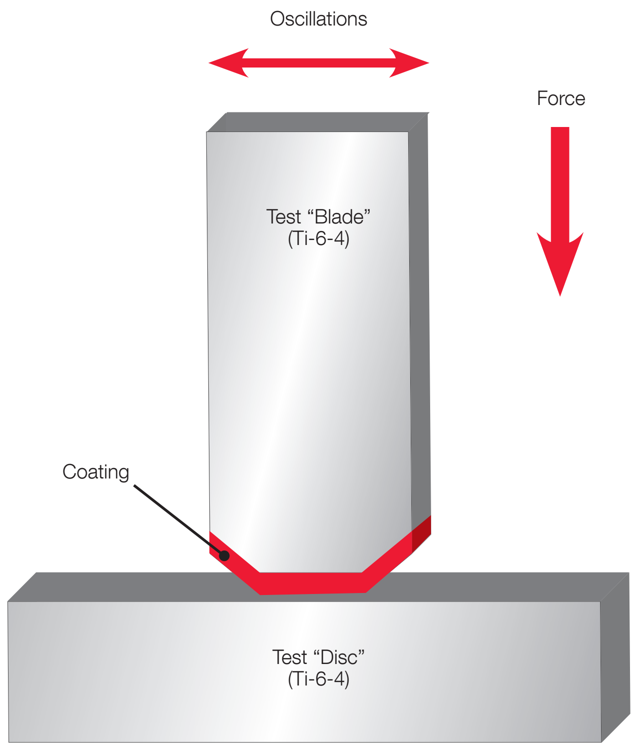
	HVOF		APS	
Substrate preparation	dry grit blast		dry grit blast	
Bond coat	not required		not required	
Coating thickness	100 – 150 µm	0.004 – 0.006 in	100 – 150 µm	0.004 – 0.006 in
Thickness per pass	3 µm	0.0001 in	10 µm	0.0004 in
Maximum thickness [a]	800 µm	0.031 in	750 µm	0.029 in
Coating color	grey with white specks of hBN		grey with white specks of hBN	
Microstructure characteristics	low retained hBN content, dense, some unmelted particles		high retained hBN content, higher porosity	
Bond strength	41 – 55 MPa	6000 – 8000 psi	24 – 35 MPa	3500 – 5100 psi
Microhardness (HV300)	300 – 330		150 – 270	
Porosity + hBN + Oxides (vol. %)	< 10		40 – 50	
Coefficient of friction (Fretting)	0.36 – 0.40		0.36 – 0.40	
Coating density	7.8 g/cm^3		6.0 g/cm^3	
Coating weight	0.78 kg/m^2/0.1 mm	0.040 lb/ft^2/0.001 in	0.60 kg/m^2/0.1 mm	0.031 lb/ft^2/0.001 in
Finishing	as-sprayed		as-sprayed	
As-sprayed surface roughness (Ra)	4.5 – 6.5 µm	175 – 250 µin	6.0 – 9.0 µm	235 – 350 µin
Maximum service temperature	450 °C	840 °F	450 °C	840 °F

[a] Thickness limits per testing performed and / or verified by Oerlikon Metco

Rig testing

Extended rig testing simulating actual turbine engine fretting wear conditions over 10,000 oscillation cycles (except as noted) on titanium alloy (Ti-6-4) components.

The results of this testing demonstrates that Amdry 958 co-balt-based anti-fretting material outperforms CuNiIn. Amdry 958 clearly had a lower coefficient of friction, and wear and pitting was significantly lower over a number of different test conditions.

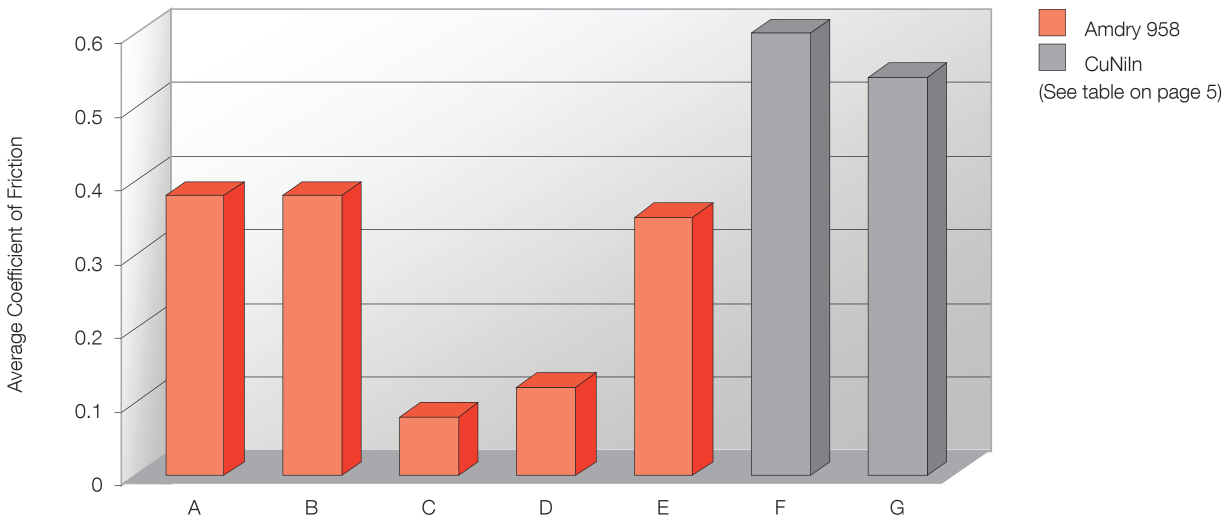


Test rig apparatus

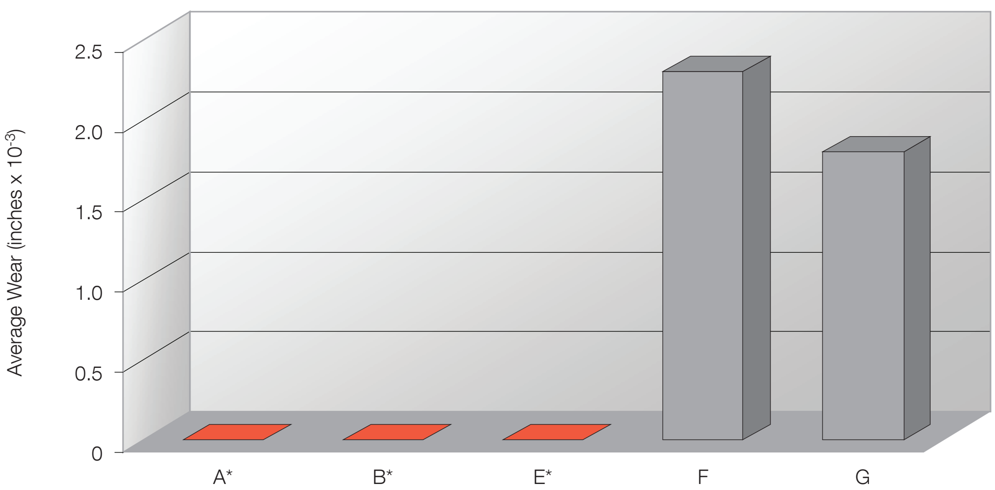
Sample	Coating material	Coating process	Lubrication	Test temperature		Test pressure [a]	
A	Amdry 958	HVOF	No	24 °C	75 °F	345 MPa	50 ksi
B	Amdry 958	APS	No	24 °C	75 °F	345 MPa	50 ksi
C	Amdry 958	HVOF	Yes	24 °C	75 °F	930 MPa	135 ksi
D [b]	Amdry 958	HVOF	Yes	24 °C	75 °F	345 MPa	50 ksi
E	Amdry 958	HVOF	No	315 °C	600 °F	310 MPa	45 ksi
F	CuNiIn	APS	No	24 °C	75 °F	345 MPa	50 ksi
G	CuNiIn	APS	No	315 °C	600 °F	310 MPa	45 ksi

[a] ksi = psi x 1000
[b] This sample tested for 30,000 cycles

Coefficient of friction results

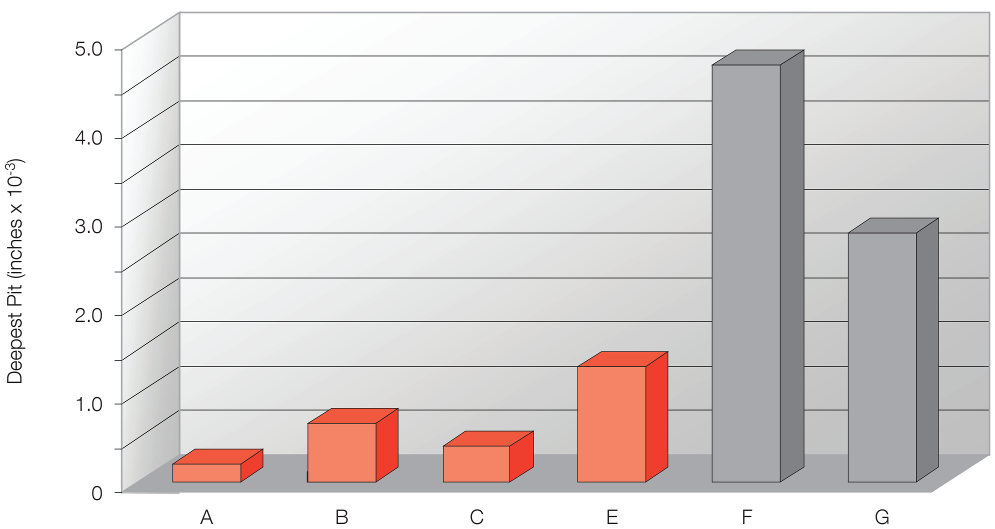


Wear results



* No disc wear; some coating transfer to the disc was evident

Pitting results



Effects of reduced work hardening

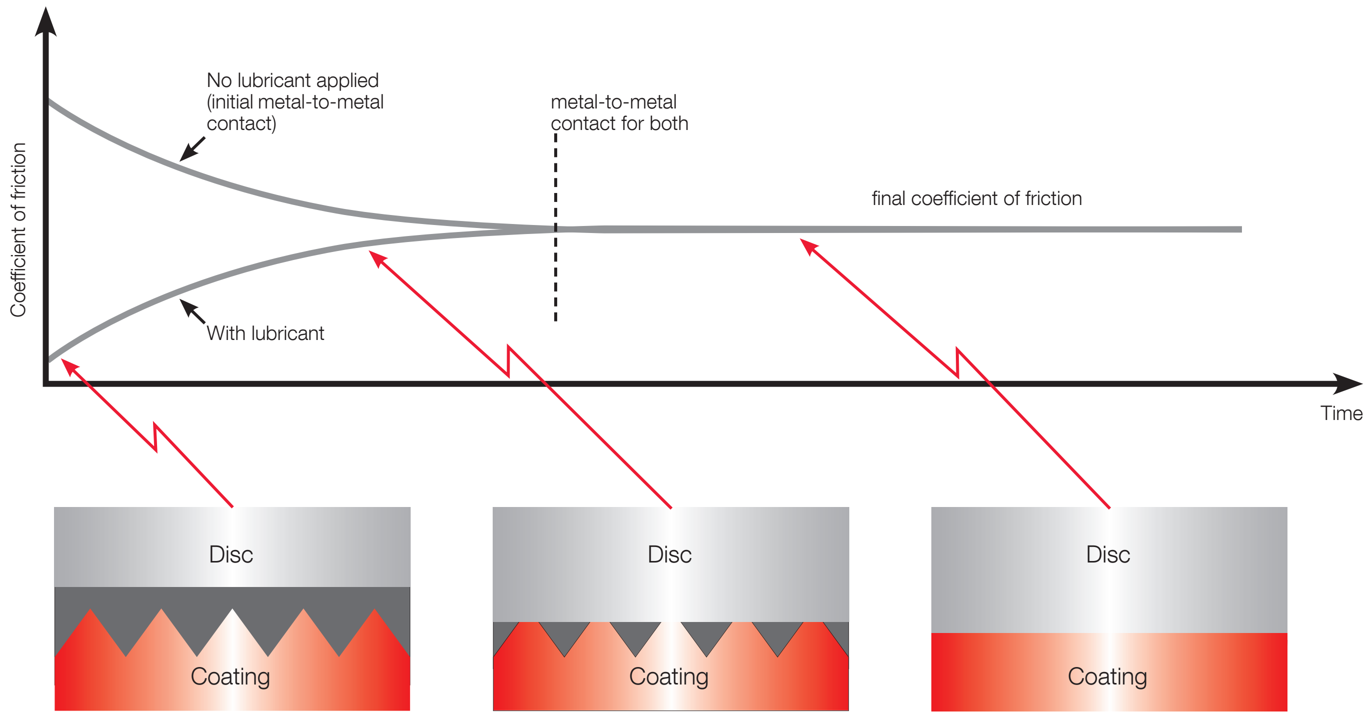
Conventional anti-fretting coatings such as CuNiIn and CuAl have been reported to work harden with repeated cycling. The hardened coatings cannot distribute the stress evenly to the disc surface that can result in impact wear to the disc. Cyclic testing of Amdry 958 coatings has shown that the tendency of these coatings to work harden is significantly lower. Therefore, Amdry 958 anti-fretting coatings are less likely to cause disc wear.

Cyclic load testing

Coated fan blades were tested at a 20 mt (44,000 lb) pull load and cycled to coating failure. In this test, coatings of Amdry 958 performed nearly twice as well as the nearest conventional anti-fretting coating, demonstrating that Amdry 958 performs well in high-load situations.

Elimination of dry film lubricants

While dry film lubricants reduce frictional loading on the blade root / disc system in the early fretting cycles, these lubricants wear (initially) and deplete over time. However, the frictional characteristics of Amdry 958 coatings, as demonstrated in the previous test results, indicate that these dry film lubricants may not be required in some applications. This adds to the cost effectiveness of the Amdry 958 solution, through the elimination of a costly and time-consuming processing step.



As applied:
Low coefficient of friction with the disc in contact with the dry film lubricant for gentler initial rubbing.

Initial wear:
Coefficient of friction increases. Disc contacts both the dry film lubricant and the coating.

Depletion:
Final coefficient of friction achieved. Metal-to-metal contact of the disc to the coating.

Customer benefits

Effective

- Significantly reduces pitting and wear as a result of fretting for longer service life of compressor components; for example, the disc may be returned to service more often than with conventional anti-fretting coatings.
- Lower coefficient of friction for better wear protection.
- Higher temperature capability permits use throughout the compressor.
- Typically, thin coatings of 100 µm (0.004 in) are effective, however, much thicker coatings are easily achieved.
- Higher compressive strength withstands extreme pressures in applications with large blades.
- CoCrAlYSi and hBN (hexagonal boron nitride) composition is corrosion and oxidation resistant.
- Can be applied using air plasma spray or HVOF spray, permitting the coating system to be tailored to application requirements.

Efficient

- Application to blade roots reduces possible damage to the disc that could lead to catastrophic fatigue failure.
- Oerlikon Metco's cobalt-based anti-fretting materials can be tailored to meet specific turbine OEM requirements.

Economical

- Better performance and long service life reduces costs for repair or replacement of compressor components.
- Effective with low coating thicknessfor reduced material costs and fast application time.
- Application to blade root simplifies coating set-up and reduces production time.
- Dry film lubrication can be eliminated for some applications, eliminating a time-consuming processing step and reducing overall application costs.

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