Study of Coatings used in Gas Turbine Engine

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***Abstract* :- The components of a gas turbine operate in an aggressive environment where the temperature of service varies from ambient to near melting point of materials which introduce a variety of degradation on the components. Some components that lose their dimensional tolerance during use require repair and refurbishment when high cost replacement is avoidable. Erosion of fly ash and sand particles damages compressor blades which cause engine failure at an early stage. Dovetail roots of the compressor blades are subjected to fretting fatigue due to the oscillatory motion caused by vibration. Casing of the compressor comes in contact with rotating blades due to shaft misalignment, ovality of the casing and or inadequate clearance which cause blade and casing damage. Close clearance control that has bearing on the efficiency of the engine is therefore required in addition to preventing fire where titanium to titanium rubbing might occur. Wear out of the several contact surfaces which undergo rotating and reciprocating motion occur during the running of the engine need protection. Hot gases that are produced by burning the contaminated fuel in the combustion chamber will cause oxidation and corrosion on their passage. In the hot section rotating and stationary components need thermal insulation from higher operating temperature leading to enhanced thermodynamic efficiency of the engine. This wide range of functional requirements of the engine is met by applying an array of coatings that protect the components from failures. This paper focuses on various coatings used in gas turbine engine and its methods of application, characterization, degradation mechanisms and indicative future directions to a practicing industrial engineer.**

Keywords – Erosion resistant coating, Anti-fretting coating, Abradable coating, Wear resistant coating, Oxidation and corrosion resistant coatings, Thermal barrier coating(TBCs), Air Plasma Spraying (APS, Thermally Grown Oxide (TGO), yttria stabilized zirconia (YSZ), Electron Beam Physical Vapour Deposition (EB PVD).

INTRODUCTION

The gas turbine is an internal combustion rotary engine, the most widely known example of jet aircraft engine. Basically, the engine burns a lean mixture of fuel with compressed air. The hot, pressurized combustion gases expand through a series of rotating turbine wheel and blade assemblies resulting in shaft power output, propulsive thrust, or a combination of the two. The engine produces the thrust through a combination of these two portions working in concert, engines that use more jet thrust relative to fan thrust are known as low bypass turbofans, conversely those that have considerably more fan thrust than jet thrust are known as high bypass turbojets. Most commercial aviation jet engines in use today are of high bypass

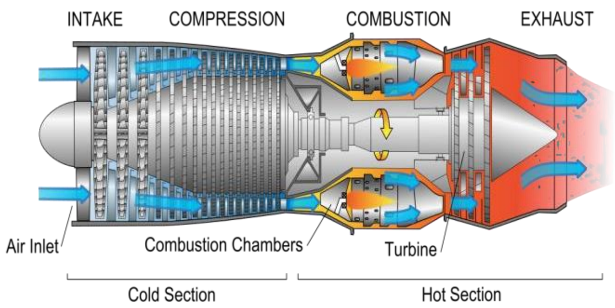


FIG.1.1-SCHEMATIC DIAGRAM OF A GAS TURBINE ENGINE

The working fluid in a gas turbine is a permanent gas, in contrast with a condensable vapour in the steam turbine, produced in a gas generator at high pressure by continuous combustion in a combustion chamber.

MATERIALS USED IN GAS TURBINE ENGINE

In 1903, the Wright brothers built an aluminum block engine because of its light weight compared to cast iron. Its melting point of 660 °C was well above the engine's operating temperature, so for them it was a good choice. However, aluminum could not be used in the hotter parts of a turbine engine where temperatures reach of 1800 °C or more because it would melt.

FAN

This typically does not get very hot (<150 °C) so aluminum, titanium, or stainless steel are all suitable for the fan blades. Most engines use titanium because it has a high strength-to- weight ratio, is corrosion and fatigue resistant, and would be able to withstand the impact of a bird strike.

COMPRESSOR SECTION

The pressure of the air can be raised up to 30 times and the temperature, depending on the number of stages in the compressor, can rise up to 1000 °C. Aluminium and/or titanium are added for strength, and chromium, as well as rare earth elements like yttrium are added to improve corrosion resistance.

COMBUSTION CHAMBER

Temperatures can exceed 1800 °C and super alloys are used without the titanium or aluminium for strength because there are no moving parts. Instead, refractory metals are often added to a super alloy. Ceramics and ceramic-metal mixes are also used here because of their high heat resistance.

TURBINE

The first set of turbine blades are in the highest pressure, hottest part of the gas flow and are generally made of nickel- based super alloy or ceramic blades. Unheated outside air is circulated through channels inside of the turbine blades to keep them from melting in this extreme environment. The turbine blades can be made of iron-based super alloy or even stainless steel**.**

EXHAUST

The Inconel [nickel-chromium-iron] alloys are frequently used in Exhaust section of the Gas turbine engines because of their ability to maintain their strength and corrosion resistance under extremely high temperature conditions.

CASING

Although it need not withstand high temperatures like the core of the turbine, the materials here need to be strong enough that if a blade were to break off it would be contained inside the casing and not enter the wing or cabin of the aircraft and cause further damage. Aluminum or some polymer matrix materials are used as engine casing.

COATINGS USED IN GAS TURBINE ENGINE

When a substrate material has to be chosen for its bulk design properties that are in contradiction with the requirements for its surface design properties, coating is applied to the mechanical strength for the component. Coating protects the component effectively from a variety of environmental degradation factors such as abrasion, erosion, wear, fretting oxidation and corrosion.

EROSION RESISTANCE COATINGS

Erosion resistant coatings Erosion is an incremental material loss from a solid surface due to mechanical interaction between that surface and a fluid or solid particles. It is caused by impinging solid particles or water droplets. The compressor of gas turbine engine are prone to performance losses due to erosion of the compressor blades when being operated in regions with dusty and sandy atmosphere and when sand, fly ash, salt and ice crystals or volcanic ashes are ingested Erosion resistant coatings prevent compressor blades from premature loss of material. Erosion resistant coatings are built over a bond coat. The multi-layered top TiN–Ti coating has a typical layer thickness of 3 µm The overall thickness of alternate layer of ceramic and materials is 25 µm. During impact of a solid particle the brittle ceramic layer cracks but its propagation is arrested by the soft metallic layer. Typical Vicker's hardness of the coating is 2800–3200 and the operating temperature range is −60 °C to 600 °C.

ANTI-FRETTING COATINGS

Fretting is an accelerated surface damage that occurs at the interface of contacting materials subjected to small radial oscillatory motions combined with centrifugal load. The amplitude of the oscillatory motion is of the order of tens of microns Compressor blades of gas turbine undergo centrifugal forces during running. These centrifugal forces in combination with vibratory load cause fretting motion between the dovetail joint of the compressor blade and the disc. Shot peening, which is the process of the material surface with special steel shot, glass or ceramic beads, has been used for the purpose of producing plastic yielding and residual stress at the surface which improves fretting fatigue resistance. A typical compressor blade root has copper nickel indium (Cu 38Ni or Cu 36Ni 5 In) anti-fretting coating on its contact surfaces of the dovetail root that had undergone shot peening. Over and above that, a polymer bonded molybdenum disulphide (commercially known as Molydag) thin film of near about 15 µm thickness having a co-efficient of friction
0.07 is provided for additional lubrication. The thickness of anti-fretting copper nickel indium coating varies from 13 to 100 µm. Typical bond strength of the coating is 20 MPa with a hardness of 48Rb. The manufacturing routes for the anti- fretting coating are atmospheric plasma spray, combustion powder spray and arc spray. Attainable porosity level is 0.5% and surface roughness for as sprayed coating is 5–10 µm Ra and after grinding/lapping is 2–3 µm.

ABRADABLE COATINGS

Abradable coatings are applied to the rubbing surface of the casing of the rotating components of the gas turbine to minimize the clearance between casing and the rotating part to have enhanced gas turbine efficiency. At rotating speeds of the order of 10,000 rpm, rotating blade tip may rub against the stationary casing, due to either thermal expansion, misalignment or rotation induces strains. Abradable seals act as sacrificial layers between the blades and the casing and are soft enough to avoid significant wear to blade tips, thus allowing much smaller clearances. In case of compressor bearings, the inner race is coated with abradables for reducing friction High temperature abradable seals are used in high pressure gas turbine of jet engine. As the stored elastic energy of the abradable coating is more than its adhesion strength, it rebounds and debonds. The ejected debris, that is higher in volume because of the newly created free surface is typically of the size less than 100 μm and has to escape through the rough blade tips. Abradable coating will therefore have small matrix particles, a polymer or a fugitive phase to generate porosity and solid lubricants or release agents to act as dislocators within the coating.

WEAR RESISTANT COATINGS

Wear and corrosion resistant coatings are most frequently based on transition meta carbides (WC, TiC, Mo_2C, TaC, NbC, Cr_3C_2) and their alloys (NiCoCrAlY) and some hard oxides (Al_2O_3, TiO_2, Cr_2O_3) .They are usually applied by APS, detonation process and HVOF. Pure carbide powders cannot be melted at high temperatures and deposited even at high enthalpy plasma jets. This is due to the reason that at such high temperatures, oxidation, decarburization and thermal decomposition generally occur. Therefore carbide particles are embedded into easily melted binder materials with high ductility such as Ni, Co, Cr and their mixtures and alloys respectively.. Tungsten carbides are used at temperatures below 540 °C and chromium carbides are applied up to 815 °C. Al_2O_3–TiO_2 coatings are composed of TiO_2 as reinforcement in the Al_2O_3 matrix. The Al_2O_3 matrix distributes the stresses in the composite material homogeneously where as O_2 mechanically reinforces the material. This type of coating is prepared by matrix with the reinforcement during powder production and by plasma spraying and can take temperatures up to 1100 °C.

OXIDATION AND CORROSION RESISTANT COATINGS

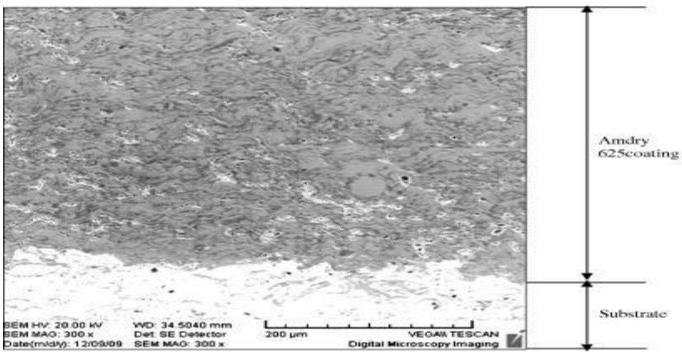
High temperature components of gas turbine are exposed to a wide range of thermal land mechanical loads in addition to an oxidizing and corrosive environment that may contain contaminant such as chlorides, sulphates and erosive particles. Aluminium and chromium contents are kept at a reduced level (5–12% and 3.4–5% respectively in super alloys in order to obtain their desired high temperature strength and micro structural stability. This situation leads to a fall in oxidation and corrosion resistance of the material. Therefore appropriate coatings are applied to protect the surface of the component from oxidation and corrosion.

THERMAL BARRIER COATINGS

Thermal barrier coatings (TBCs) are two layer (duplex) coating systems which comprise of an oxidation and corrosion resistant inner layer called 'bond coat' and an insulating ceramic outer layer called 'top coat'. The bond coat serves two purposes: (1) it protects the metallic substrate from the ingression of hot gases and their attack on the substrate; (2) it serves as an intermittent layer that gives better between the substrate and the top coat. As a detailed discussion was made on the oxidation and corrosion resistant coating in the preceding section, focus in this section is made only on the insulating ceramic coat with barest minimum reference to the bond coat. The TBC system will have a Thermally Grown Oxide (TGO) that forms between the bond coat and the top coat. This TGO is the α-Al_2O_3 that forms a protective layer on the bond coat to prevent the inner surface of it from further oxidation. The TGO is grown to 2–3 μm on the bond coat before the application of the ceramic top coat by a suitable heat treatment process to enhance the adhesion of the latter on the former. The TGO in some cases is grown during the ceramic coat deposition. TBC systems typically consist of yttria stablized zirconia (YSZ) top layer, which has low thermal conductivity that is almost constant with increasing temperature, is chemically inert in combustion atmospheres and has a co-efficient of thermal expansion which is reasonably compatible with nickel based super alloys. Seven percent partially YSZ is used as the TBC material because it retains its meta stable tetragonal phase up to 1200 °C without any phase transformation. TBCs are sprayed either by APS or by Electron Beam Physical Vapour Deposition (EB PVD). At 25 °C, the thermal conductivity of APS coatings varies from 0.8 to 1.0 W/mK where as EB PVD coatings vary from to 1.9 W/m K. Therefore APS coatings provide superior thermal insulation. But the spallation resistance of EB PVD coatings is 8–10 times more than that of APS coatings due to the superior in plane compliance of EB PVD coating. $La_2Zr_2O_7$ has a co-efficient of thermal conductivity that is close to APS 7% YSZ.

RESULTS

FIG.4.1.-MICROSTRUCTURE OF EROSION RESISTANT COATING



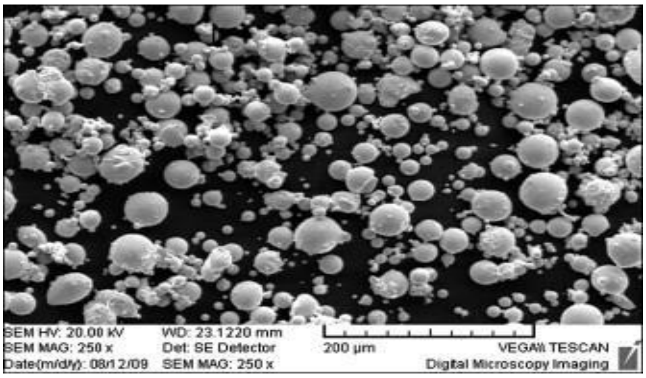


FIG.4.2.-MICROSTRUCTURE OF AMDRY 625 ANTI-FRETTING COATING

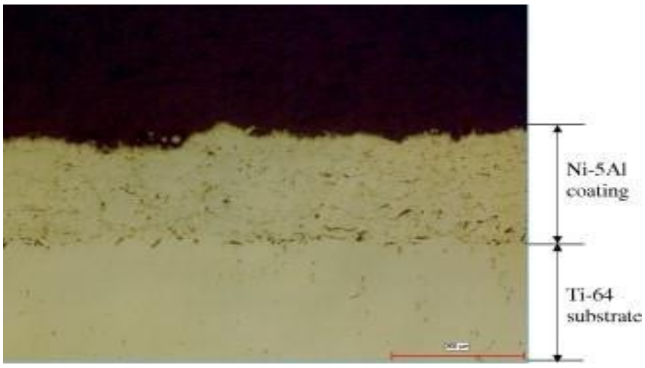


FIG. 4.3.-MICROSTRUCTURE OF ABRADABLE COATING

WEAR RESISTANT COATING

CONCLUSION

We had studied and analyzed about the details of various gas turbine engine coatings, their methods of application, characterization, degradation mechanisms and possible future directions. The results clearly shows that

1) Erosion resistant coatings protect the compressor blade from sand particles and fly ash thereby improving their performance and life. Alternate layers of soft and hard coatings are applied to the compressor blades and vanes for enhanced erosion resistance.
2) Anti-fretting coating protects the contact area of the dovetail part of the compressor blade root from fretting fatigue failure.
3) Abradable coatings offer close clearance control thereby increasing the engine efficiency. A fugitive phase with the solid lubricant and a brittle cermet form the desirable composition of the abradable coating. As abradable coatings are not self bonding a bond coating is applied as a bottom layer before the application of it.
4) Wear resistant coatings give extended life of the parts that undergo rotary and reciprocating rubbing motion. Agglomerated nano-WC–17Co coating is gaining currency with superior hardness and toughness over conventional microsized powder coating.
5) Oxidation and corrosion resistant coatings are applied through either diffusion or overlay process. While diffusion process is economical for bulk processing, there is less scope in it for altering the chemistry of the coating.
6) Thermal barrier coatings offer increased component life with a decrease in operating temperature of the metal. Solution precursor plasma spray is gaining momentum for higher thickness application and agglomerated nanopowder of yttria stabilized zirconia provides lower thermal diffusivity, improved thermo mechanical durability, higher in plane fracture toughness in comparison with conventional plasma spray powders.

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