NEW TECHNOLOGY USED IN GAS TURBINE BLADE MATERIALS.

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ABSTRACT:

After the world word II, gas turbines became an important technology for its applications in aeronautics and industrial processes. At the beginning materials used for the engine's construction and more precisely; materials used in compressor and turbine blade-materials, could not survive more than a few hundred hours at then relatively modest temperatures and low power settings; on the other hand, reliability and thermodynamic efficiency were relatively low, producing some accidents causing damage to equipment and injures to people.

In this paper, new technologies for increasing the performance, reliability and emissions in gas turbines due improvements materials, are discussed and presented.

Keywords: Gas turbine engine, Compressor, Turbine, blade, Oxidation, Corrosion, Coatings, Ceramics.

1. INTRODUCCIÓN.

The gas turbine engine is a machine delivering mechanical power using a gaseous working fluid. It is an internal combustion engine like the reciprocating Otto and Diesel piston engines with the major difference that the working fluid flows through de gas turbine continuously and not intermittently. The continuous flow of the working fluid requires the compression, heat input, and expansion to take place in separate components. For that reason a gas turbine consists of several components working together and synchronized in order to achieve production of mechanical power in case of industrial applications, or thrust, when those machines are used for aeronautical purposes. [4],[5]

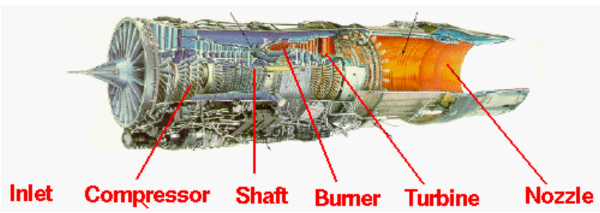

Fig 1. Components location of a typical gas turbine

During gas turbine operation, air is taken from the atmosphere and is sucked by the first row of compressor blades. From there, the working fluid receives mechanical power from the compressor causing that pressure and temperature increase rapidly. In that particular moment, air has the proper conditions to be send to the combustion chamber; component responsible for mixing the incoming air with fuel, creating combustion and producing high-temperature-flue-gases with temperatures up to 1400^{O}C – 1500^{O}C. The achievement of that high window temperature means that materials and design of those components requires special attention; Due, the region located between combustion chamber outlet and the turbine's inlet, is considered as the most sensible and challenging design point for gas turbines technology. [4],[5]

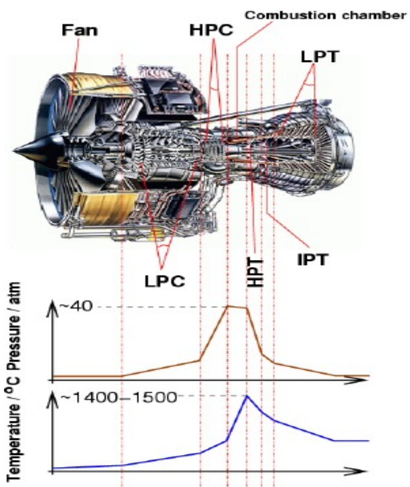

Fig 2. Temperature and pressure profile in gas turbine.

When flue gases have been released from the combustion chamber, they are driven to the turbine rows; components responsible for extracting energy from the gases in form of mechanical-rotational-power, which is used to drive the compressor and producing extra power to drive machinery or generating thrust. Later on, flue gases are liberated to the atmosphere through the exit nozzle having temperatures around 550^{O}C. [5].

2. OPERATING CONDITIONS FOR TURBINE BLADES.

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In gas turbine industry, the blade of the high pressure turbine has received the highest attention of the researchers because the challenge it provides. The ability to run at increasingly high gas temperatures has resulted from a combination of material improvements and the development of more sophisticated arrangements for internal and external cooling; for instance, nowadays, high pressure turbine blades receive compressed air bled from the compressor and it is injected to the turbine blades though small holes drilled on them, with the purpose to establish a protection layer on the edge of the blades and guaranty that hot flue gases could not affect directly them. [4]

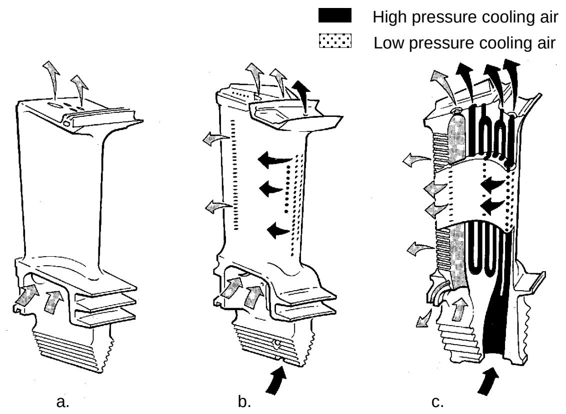

Fig 3. High pressure turbine blades with internal cooling

3. MATERIALS USED IN GAS TURBINE BLADES.

Modern gas turbines have the most advanced and sophisticated technology in all aspects; construction materials are not the exception due their extreme operating conditions. As it has been mentioned before, the most difficult and challenging point is the one located at the turbine inlet, because, there are several difficulties associated to it; like, extreme temperature (1400^{O}C – 1500^{O}C), high pressure, high rotational speed, vibration, small circulation area, and so on. The aforementioned rush characteristics produces effects on the blades that are shown on the table 1. [2]

	Oxidation	Hot corrosion	Interdiffusion	Thermal Fatigue
Aircraft	Severe	Moderate	Severe	Severe
Land-based Power Generator	Moderate	Severe	Moderate	Light
Marine Engines	Moderate	Severe	Light	Moderate

Table 1. Severity of the different surface-related problems for gas turbine applications

In order to overcome those barriers, gas turbine blades are made using advanced materials and modern alloys (superalloys) that contains up to ten significant alloying elements, but its microstructure is very simple; consisted of rectangular blocks of stone stacked in a regular array with narrow bands of cement to hold them together. This material (cement) has been changed because in the past, intermetallic form of titanium was used in it, but nowadays, it has been replaced by tantalum. [3]

This change gave improved high temperature strength, and also improved oxidation resistance. However, the biggest change has occurred in the nickel, where high levels of tungsten and rhenium are present. These elements are very effective in solution strengthening. [3]

Since the 1950's, the evolution from wrought to conventionally cast to directionally solidified to single crystal turbine blades has yielded a 250°C increase in allowable metal temperatures. On the other hand, cooling developments have nearly doubled this value in terms of turbine entry gas temperature. An important recent contribution has come from the alignment of the alloy grain in the single crystal blade, which has allowed the elastic properties of the material to be controlled more closely. These properties in turn control the natural vibration frequencies of the blade.[2]

If metallurgical development can be exploited by reducing the cooling air quantity this is a potentially important performance enhancer, as for example, the Rolls-Royce engine uses about 5% of compressor air to cool its row of high pressure turbine blades. On the other hand, single crystal alloy, is able to run about 35°C hotter than its predecessor. This may seem a small increase, but it has allowed the trend intermediate pressure turbine blade to remain uncooled. [2]

4. CONTINUING DEVELOPMENTS.

In the last several decades, thermally deposited ceramic coatings on metallic turbine blades have enabled turbine engines to operate at higher temperatures, and, according to the laws of thermodynamics, higher efficiencies. [6] Ceramic thermal barrier coating have also provided improved performance in turbine engines for propulsion and power generation. Applying a coating of a refractory insulation ceramic to metal turbine blades and vanes allows the engine to run at higher temperatures while minimizing deleterious effects on the metal blades. [1]

Ongoing advances in high-tech materials are providing even more opportunities in these areas. By combining these new materials with a good understanding of coating engineering principles and application technologies, coating manufacturers will be able to offer additional performance improvements in the future.

To improve coating performance, several important engineering principles must be considered regarding the quality of the ceramic coating. First, the coating material should be selected so that it is refractory enough to resist the high temperatures at the surface and have a low bulk thermal conductivity to minimize heat transfer to the metallic blade underneath. In addition, the thermal expansion of the selected material should closely match that of the metallic substrate to minimize potential stresses. Yttria stabilized zirconia (YSZ) is the industry standard "first generation" coating material in use today [1]. Second, the coating must have a grain and pore structure that will minimize thermal conduction to the metal-ceramic interace. A low-density coating is commonly formed using state-of-the-art deposition processes and is excellent of providing an insulating barrier. The coating should have enough porosity, so, it reduces the thermal conductivity while simultaneously adhering to the metal turbine bond-coat layer. A significant amount of microstructural engineering in thermal barrier coatings is ongoing, example of this reality, is the availability of double and triple-layered microstructures for special applications.[1],[2],[3]

Finally, the coating should stick to the turbine blade during operation. Failure of the adhesion (spalling) would suddenly expose the metallic blade to high temperatures, causing severe corrosion, located creep or melting. Generally, a metallic bond coat that shows good adhesion to both the metallic turbine and the ceramic coating is applied.[4]

5. CREATION OF THEMAL BARRIER COATINGS.

It is also important that the ceramic coating be homogenously applied to de surface of the turbine blade. This is achieved by either **ELECTRON BEAM PHYSICAL VAPOR DEPOSITION (EB-PVD)** or the **ARC PLASMA SPRAYABLE (APS)** powder method.[1]

EB-PVD is the process currently recommended for high-quality coatings. In this technique, a cylindrical ingot of the coating material is vaporized with an electron beam, and the vapor uniformly condenses on the surface on the turbine blade. One of the most important advantages of the EB-PVD process is the strain-tolerant coating that is produced.

This columnar strain-elastic structure is said to reduce the elastic modulus in the plane of the coating to values approaching to zero, thereby enhancing the lifetime in terms of flight hours or cycles of the coating. Other advantages of EB-PVD ceramic coatings, include excellent adherence to both rough and smooth surfaces. The final coating is also smooth, requiring no surface finishing. Additionally, the vapor deposition process does not plug small air-cooling holes in turbine blades during deposition. [1],[2],[3]

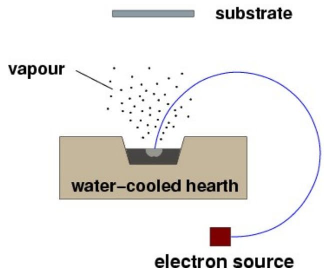

Fig 4. Schematic EBPVD process, the whole assembly would be under vacuum. Rotation of the electron beam is obtained by a magnetic field perpendicular to the drawing

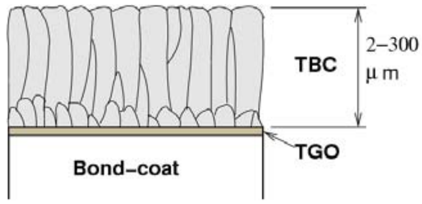

Fig 5. Schematic microstructure of a thermal barrier coating (TBC) obtained by electron beam physical vapor deposition (EBPVD). The columnar microstructure considerably enhances the strain resistance and therefore thermal cycling life

In the APS powder application method, the ceramic material is in the form of a flowable powder that is fed into a plasma torch and sprayed molten onto the surface of the metallic substrate. Droplets of molten material form "splats" on the metallic substrate. Sprayed coatings have half the thermal conductivity of the EB-PVD coatings and are therefore better isolators. .[1],[2],[3]

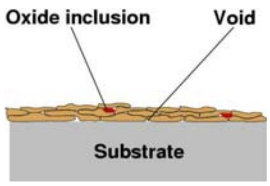

Fig 6. Schematic microstructure of thermal spray coating, showing only a few layers of particles

The "splats" form a lamellar structure consisting of fissures with a non-uniform density and pore size.

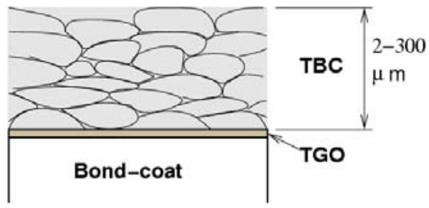

Fig 7. Schematic microstructure of a thermal barrier coating (TBC) obtained by air plasma spray (APS).

In contrast to EB-PVD coatings, APS coatings require a rough deposition surface for good adhesion. In addition, thermal sprayed coatings are more prone to spalling, reducing the performance lifetime of the coating relative to EB-PVD coatings. Thermal-sprayed parts are also not as recyclable as parts coated by EB-PVD because the extensive spalling and extrinsic cracking cause the APS-coated parts to be damaged beyond repair. However, the equipment, portability and lower production cost of a APS, often makes the process more commercially attractive than EB-PVD. .[1],[2],[3]

6. IMPORTANCE OF THE COATING SOURCE.

In thermal barrier coatings business, is really important to consider the material source (ingot) relates to the quality of the final coating. For instance, ingots for EB-PVD must have a high purity (above 99.5%) and a consistent and uniform density and pore structure. If the ingots are too dense, they will undergo severe thermal shock when they encounter the electron beam.[4]

In an ingot of non-uniform density of porosity, closed porosity may exist. In this case, the release of trapped gas may also cause spitting of eruptions. Molten spits, when trapped in the coating, will cause defects and potential failure sites. The optimum density for an EB-PVD barrier coating ingot is usually in the range of 60-70% of theoretical density. If the density is lower than the aforementioned values, the efficiency of the process is reduced.[4]

Arc-plasma sprayable powder must have a particle size large enough to flow through the plasma torch but not so large that the entire particle is not melted coming out of the plasma gun. In addition to the composition, the particle size, particle size distribution and flowability are important considerations for APS thermal spray powder. [4]

Although YSZ has been the industry standard fist generation coating material, it has a number of drawbacks that hinder the improvement of thermal barrier coatings. One problem is its lack of phase stability at high temperatures. Three commonly formed phases exits in the zirconia-rich section of the zirconia-yttria binary system: cubic, tetragonal and monolithic. Under operation or forming conditions, phase transformations can occur that cause mechanical stress and promote sapling or bond coat failure. In addition, while YSZ has a low thermal conductivity (2.4 W/m K), a refractory ceramic material with a lower thermal conductivity than YSZ would be desirable. If the coating progresibly sinters and densifies while in service, the thermal conductivity will increase along with the thermal shock sensitivity. Therefore, materials at least as refractory as YSZ are required. It can also be difficult to match the thermal expansion of YSZ-containing coatings to the bond coat layer and the metal substrate. A great deal of research is currently under way of find improved materials for thermal barrier coatings.

In order to response to that requirement, a class of lanthanide zirconate pyrochlores ($Ln_2Zr_2O_7$) [1],[4] might provide one solution.

These materials have lower thermal conductivity than YSZ (1.5-1.8 W/m K), as well as improved phase stability over a wide range of compositions and temperatures. In addition, they are less susceptible than YSZ to sintering during operation, while showing a.

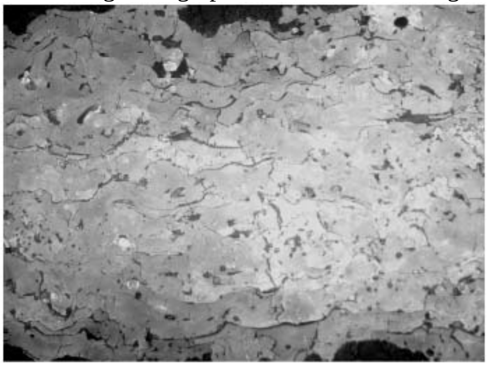

Fig 8. Micrographs of $La_2Zr_2O_7$ and YSZ coating

thermal expansion match to the bond-coat layer as good as of better than YSZ. The decreased thermal conductivity of the coating made with these materials would allow the turbine to run at higher temperature and therefore increase the efficiency. It could also allow the turbine blade to remain cooler, retarding those thermal processes that lead to coating failure and increasing the useful lifetime of the turbine.

7. CERAMIC MATRIX COMPOSITES (CMCs).

Further increases in temperature are likely to require the development of ceramic matrix composites. A number of simply shaped static components for military and civil applications are in the engine development phase and guide vanes for axial compressors have been manufactured to demonstrate process capability, such techniques involve advanced textile handling and chemical vapor infiltration that provide the ultimate challenge. It will eventually appear because the rewards are so high, but it will take much longer to bring it to a satisfactory standard than was anticipated a couple of decades back. [1],[4]

Ceramic matrix composites are at the forefront of advanced materials technology because of their light weight, high strength and toughness, high temperature capabilities, and graceful failure under loading. Research work has concentrated for some years on fiber reinforced ceramics for this application, as opposed to monolithic materials which possess adequate strength at high temperatures but the handicap of poor impact resistance.

Today's commercially available ceramic composites employ silicon carbide fibers in a ceramic matrix such as silicon carbide or alumina. These materials are capable of uncooled operation at temperatures up to 1200°C, barely beyond the capability of the current best coated nickel alloy systems. Uncooled turbine applications will require an all oxide ceramic material system, to ensure the long term stability at the very highest temperatures in an oxidizing atmosphere. An early example of such a system is alumina fibers in an alumina matrix. To realize the ultimate load carrying capabilities at high temperatures, single crystal oxide fibers may be used, giving the possibility to operate under temperatures of 1400°C.

Higher operating temperatures for gas turbine engines are continuously sought in order to increase their efficiency. However, as operating temperatures increase, the high temperature durability of the components of the engine must correspondingly increase. Significant advances in high temperature capabilities have been achieved through formulation of iron, nickel and cobalt-base superalloys.

While superalloys have found wide use for components throughout gas turbine engines, alternative materials have been proposed. Materials containing silicon, particularly those with silicon carbide (SiC) as a matrix material and/or as a reinforcing material, are currently being considered for high temperature applications, such as combustor and other hot section components of gas turbine engines; like, combustion chambers, transition ducting (which takes the combustion products and directs them towards the turbine section), the nozzle guide vanes, the surrounding shroud section, and others.

8. CONCLUSIONS.

Gas turbines constitute a wide and good option for power generation used for both, industrial and aeronautical applications. This technology is requesting for better and more reliable materials to use mostly in those areas in which temperatures are extremely high; like, fist row of turbines and combustion chamber.

Blades materials for turbine area in gas turbines have advanced rapidly in the last 2 decades. Nowadays, those blades are constructed using special alloys and are covered by special coats. Those modifications are intended to increase the allowed temperature up to 1500^{O}C without cooling. In this sense, the overall efficiency increases.

Ceramic coating is applied to de surface of the turbine blade using several methods. The most important ones are: ELECTRON BEAM PHYSICAL VAPOR DEPOSITION (EB-PVD) and ARC PLASMA SPRAYABLE (APS) powder method.

Besides the technology aimed to produce better coats, materials science is currently working extensible in CERAMIC MATRIX COMPOSITES, formed basically by silicon carbide fibers and special fabrics in order to increase the temperature gap in locations specially sensible for gas turbine operation. .[1],[2],[3]

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