



THERMAL BARRIER COATING ANALYSIS ON GAS TURBINE BLADES

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ABSTRACT

Thermal Barrier Coating (TBC) is a momentous element that influences the performance of gas turbine engine. This is designed to serve the purpose of protecting gas turbine components (especially combustor, stators and blades) from severe thermal environment. Turbine Entry Temperatures (TET) of gases can be higher than 1500K with TBCs providing a temperature drop of even higher than 200K across them. TBC has different layers like ceramic top coat, TGO, metallic bond coat and the metal substrate. These stacks together to form a basic TBC layer. In present research two blades with different stages has been coated for high temperature thermal analysis to check sustainability after coating. Even though combustion chambers also coated with high temperature sustainability additional advantages of coating on blades will decrease deterioration of blades and life time of blades will increase. A conceptual based linkage has been applied in research that overall performance of engine relates with turbine and compressor efficiencies.

Keywords: Thermal Barrier Coating, Turbine Entry Temperature, Coating Structure.

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INTRODUCTION

Thermal barrier coatings (TBCs) perform the important function of insulating components, such as gas turbine and aeroengine parts, operating at elevated temperature. Typical examples are turbine blades, combustor cans, ducting and nozzle guide vanes. TBCs have made possible the increase in operating temperature of gas turbines. TBCs are characterised by their very low thermal conductivity, the coating bearing a large temperature gradient when exposed to heat flow. The most commonly applied TBC material is yttria stabilized zirconia (YSZ) which exhibits resistance to thermal shock and thermal fatigue up to 1150°C. YSZ is generally deposited by plasma spraying and electron beam physical vapour deposition (EBPVD) processes. It can also be deposited by HVOF spraying for applications such as blade tip wear prevention, where the wear resistant properties of this material can also be used.

It is common practice to aluminise and pre-coat the substrate material (generally a nickel or cobalt superalloy) with an MCrAlY bond-coat.

The bond-coat is necessary to accommodate residual stresses that might otherwise develop in the coating system, caused by the metallic substrate and the ceramic TBC having different coefficients of thermal expansion.

Thermal barrier coatings

Thermal barrier coatings (TBCs) are a demonstrated and straightforward intends to ensure hot segment parts, such as blades, combustor liners, vanes, tiles...etc. present in current gas turbine engines. A TBCs system mainly consists of: substrate, top coat, and layer lying between them that is called bond coat. Because of severe work conditions where TBCs are operated, TBCs functional properties rely basically on top coats properties. Therefore, TBCs should possess phase stability, low thermal conductivity, great grip to substrate, and also a decent disintegration obstruction. Fundamental capacity of security coat is to shield substrate from any consumption and oxidation, and to enhance bond of best coat. Bond coat mainly



consists of M-CrAlY alloys, where M can stand for Cobalt, Nickel, Iron or alloys combining several atomic elements. For top coat, Yttria stabilized Zirconia is normally used and because of its excellent ability to fulfill TBCs requirements in the best way. Pure Zirconia is subject to a phase change at temperatures around 1100°C, which results in volume change and that leads to failure. Subsequently, to avoid this problem, Yttria is usually used to stabilize Zirconia; resultant material is therefore known as Yttria-stabilized Zirconia (YSZ).

Life structures of thermal Barrier covering:

An average thermal obstruction covering comprises of four layers. They are metal substrate, metallic security coat, thermally developed oxide, and fired topcoat. Metal substrate and metallic security coat are metal layers and thermally developed oxide and topcoat are ceramic layers. Metal substrate is regularly a high temperature nickel or cobalt combination that is in use in turbine engine or polycrystalline frame. Regularly 5-12 different components are included to combination depending prerequisite like weakness, creep, high temperature quality and so forth. Metallic bond coat is a compound ordinarily with organization of NiCoCrAlY. Security coat makes a security between clay coat and substrate. This layer is in charge of shaping thermally developed oxide, which is third layer, when TBC is exposed to high temperatures.

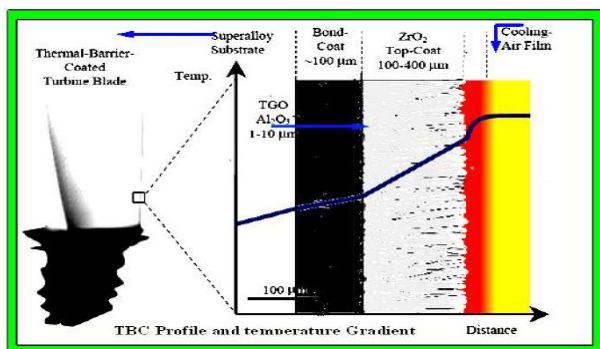


Figure: TBC profile and temperature Gradient

Figure A schematic representation of a thermal barrier coating (TBC) system. The diagram shows a cross-section of the coating layers: Superalloy Substrate, Bond Coat (~100 µm), TGO (Al₂O₃, 1-10 µm), and ZrO₂ Top-Coat (100-400 µm). A temperature gradient is shown, with the highest temperature at the top surface (Hot, High Velocity Gas) and the lowest at the bottom (Engine Cooling Air). The TBC profile and temperature gradient are plotted against distance.

alumina, and this layer shields substrate from warm oxidation and erosion by filling in as an oxygen dissemination obstruction. At long last, last coat is ceramic topcoat. It is made out of Yttria Stabilized Zirconia (YSZ) which is alluring for having low warm conductivity while staying stable at ostensible working temperatures ordinarily found in applications.

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STRUCTURE OF COATINGS

Thermal barrier coatings play a momentous role in enhancing engine performance and thermal efficiency. They consist of a ceramic top coat and metallic intermediate bond coat. Thus, they are considered as duplex systems. A typical TBC Coatings consists of three layers, top coat, bond coat and TGO.

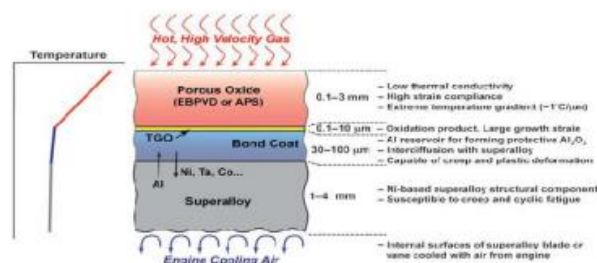


Figure: Schematic illustration of the multilayer, multifunctional nature of the thermal barrier coating system

Top Coat

The Top coat is made of ceramic materials like 6-8wt% YSZ, mullite, Al₂O₃, TiO₂, CeO₂ + YSZ, La₂Zr₂O₇, pyrochlores and perovskites. The top coat's main function is to reduce the temperature of the underlying, less heat resistant metal substrate. It is 'straintolerant' due to presence of microstructural defects (pores, cracks, splat-boundary) and also susceptible to the thermo-mechanical stresses arising during the operating conditions. Some of the properties exhibited by the topcoat are low thermal conductivity, high melting point and phase stability. The ceramic top layer is usually applied by thermal spraying, Electron beam physical vapor deposition, APS. The thickness of the top coat is usually around 500µm.

Bond Coat The main function of bond coat is to provide improved bonding strength between the top coat and metal substrate along with oxidation protection of substrate. Apart, from

this the bond coat should also provide resistance to inter-diffusion with the substrate, high creep strength, suitable ductility. Bond coat is typically a metal substrate consisting of a variety of MCrAlX alloys, where M = Ni and/or Co and X = Y, Hf and/or Si. Nickel is added to enhance oxidation resistance while cobalt for corrosion resistance. The thickness of bond coat usually varies from 75µm to 150µm. Bond coats are applied using High Velocity Oxygen Fuel (HVOF), thermal spraying and plasma sprayed. Oxidation protection is enhanced by adding Al to the bond coat. Good adherence and low thermal diffusivity make Alumina a viable option among other oxides to enhance oxidation and corrosion resistance. Yttrium is also added to provide protection from Sulphur diffusion into the coating by and promoting formation of alumina.

Thermally Grown Oxide

At temperatures exceeding 700°C, oxidation of bond coat takes place which leads to formation of thermally grown oxide or TGO at the topcoat – bond coat interface. This phenomenon is inevitable, so thermal barrier coatings are designed so that the TGO layer grows slowly and uniformly. Such a TGO will have a structure that has a low diffusivity for oxygen, so that further growth is controlled by diffusion of metal from the bond-coat rather than the diffusion of oxygen from the top-coat. The major oxide formed due to oxidation of a typically used MCrAlY bond coat is Alumina. Other oxides which are usually formed are chromia ((Cr,Al)₂O₃), spinel (Ni(Cr,Al)₂O₄), nickel oxide (NiO) and silica. The phase constituents of the TGO depends on the operating temperature, the thermal exposure time and the composition of the bond coat. As a reaction product, TGO can protect the substrate from further oxidation to some extent, while the excessive growth of TGO during thermal exposure is detrimental for TBCs' lifetime. Thus, the TGO formation and subsequent thickening, as the crucial factors controlling TBCs' durability are of significant importance in the TBCs.

TURBINE BLADE COOLING

Along with coating the blades, there is a necessity to provide sufficient cooling in order to function at higher operating temperatures. The operating temperatures are far above the permissible metal temperatures. As the turbine

inlet temperature increases, the heat transferred to the turbine blade also increases. The level and variation in the temperature within the blade material, which cause thermal stresses, must be reduced to achieve high thermal efficiency and power output. Therefore, there is a critical need to cool the blades for safe operation. The blades are cooled with extracted air from the compressor of the engine. 4633

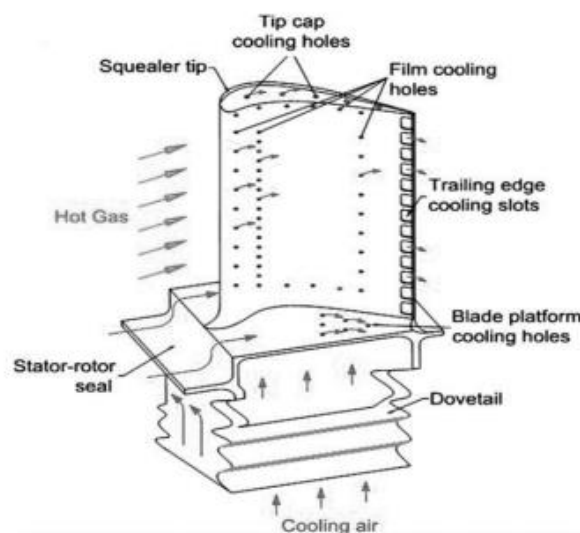


Figure: Schematic diagram of air-cooled turbine blade

The stator blades and the outer wall of the turbine flow passage use the cooling air travelling between the combustor and outer engine case where as the turbine rotor blades, disks, and inner wall of the turbine flow passage use cooling air that is routed through inner passageways. The first stage stator blades (nozzles) are exposed to the highest turbine temperatures. The first-stage rotor blades are exposed to comparatively lower temperature because of circumferential averaging, dilution of turbine gases with first stage stator cooling air, and relative velocity effects. The second-stage stator blades are exposed to an even lower temperature because of additional cooling air dilution and power extraction from the turbine gases. The turbine temperature decreases in a like manner through each blade row.

Development of coatings for protection of gas turbine blades:

Coatings are routinely used to anchor high temperature air upset sections in forefront gas turbines with ultimate objective to improve ir

insurance from oxidation, utilization and breaking down. Many covering syses and declaration procedures are curently passed on to improve surfaces of superalloys with segments, for instance, aluminum, chromium, platinum, silicon, etc which redesign ir security from high temperature debasement frames. Nevertheless, disregarding fortunate execution record of coatings, for instance, those of MCrAlY overlay type, look is continuing for less unpredictable, more affordable, elective covering strategies and for upgraded covering materials. In this paper a graph depiction is displayed of three elective covering procedures that offer noteworthy potential for keeping overlays. First relies upon use of heartbeat weight substance vapor affirmation of aluminum, etc (1) into surface of a pre-kept plasma showered layer both to infill surface-related deformations and furrmore to survey structure of outer layers. On the other hand two procedures are Sputter Ion Plating (SIP) and Occluded Plating. A wide extent of coatings structures has been spared by se techniques on cast nickel superalloy test pieces and all the more puzzling aerofoil sections.

METHODOLOGY

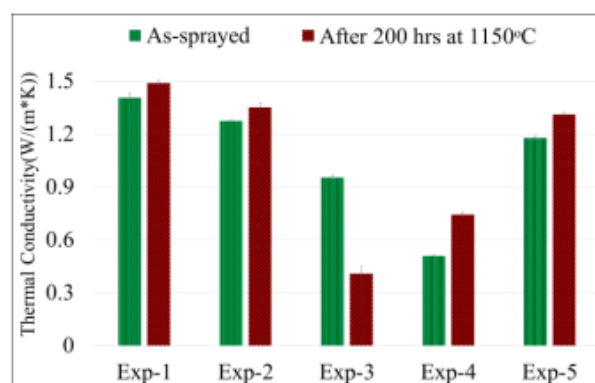
Gas turbine engines used for aircraft and power generation work at extremely high temperatures to maximize energy efficiency well beyond the melting point of the metal alloys from which they are produced. This is partly carried out through the deposition, up to around 40 000 hours prior to failure, of a multi-component heat barrier (TBC). Mechanisms for failing to understand will help to design techniques for circumvention. The findings from the quantum-mechanical computation were presented by S.M., Gupta et al. [14] for the test of impurities which damage TBCs and TM additives which make TBCs more robust. They have found a variety of positions, such as HF & Y additives, performed by Pt and early TMs to prolong TBCs' lives. In particular, Fundamental understanding of the essence of the bonding produced by such additives and its effect on TBCs' high-temperature production led to the development of principles that can be used to develop materials for even better vehicles. An atmosphere and temperature-controlled plasma pulverisation DSC/TGA and XRD studies were carried out in which Zirconia TBC (thermal barrier coatings) was Stabilized, Yttria thermal

stability was achieved. As-sprayed coats of zirconia were extremely distorted and under-stoichiometric. The thermal analysis showed that various endogenous and exothermic phenomena occur with ceramic heating. TGA demonstrated strong weight gains in the oxygen recovery process, while DSC also observed structural relief and XRD improvements. 4634

RESULTS AND DISCUSSION

Effect of Microstructural modify on thermal Conductivity

As inspect in past district, kept running with sintering can decrease general porosity and this can be joined by an augmentation in warm conductivity of covering. Such an advancement in warm conductivity be totally unwanted in gas turbine applications and, thusly, TBCs with better sintering impediment are reliably searched for. Coatings assessed in this work, after warmth treatment, demonstrated both an enhancement and decrease in warm conductivity moreover in couple of coatings it even remained unaltered.



Graph: Warm conductivity results for each of five coatings when warm treatment demonstrating a strange huge reduction

Diminishing in warm conductivity by in excess of 60% isn't all around seen in 8YSC TBCs. In any case, in this covering (i.e., Exp-3) decrease can be credited to trade off among three microstructural changes (pore coarsening, sintering and crystallite measure upgrade) as delineated in past piece. Insightfully disseminating interfaces higher phonon scattering and thusly cleave down warm conductivity. That suggests pore coarsening which influences porosity to can diminish warm conductivity, sintering on or hand lessens

porosity and from this time forward can develop warm conductivity and crystallite measure headway which reduces beyond what many would consider possible interfaces can comparably broaden warm conductivity.

As appeared in past section, covering Exp-3 have an exceptionally fundamental dimension higher change in coarse porosity (pore coarsening i.e., about 138% extension in coarse porosity), no alteration in fine porosity (tolerably hacked down sintering i.e., about 10% diminishing in fine porosity) and for most part cut down crystallite check enhancement (about 36% expansion in crystallite measure) separated from each or covering.

Surface densification of modified coatings

Optical micrographs of all as-sprinkled, phosphate settled and laser-covered covering be appeared in Figs. as-showered reference coatings show standard powerless microstructure of plasma sprinkled TBCs. In phosphate settled coatings approximately 300-400 μm thick surface layer was densified. Autonomously in laser covering a 50-150 μm thick layer be densified in view of softening of covering surface.

Phosphate settling reduced aggregate porosity of coating via 30-39 %. Demonstrate porosity estimations of as-showered and phosphate settled coatings were likely affected by draw outs that were appeared display availability. This outcome be customary for plasma showered oxide coatings. In any case, it could be recognized that extent of draw outs be bring down in phosphate settled coatings in which association of lamellae be reached out because of settling.

So deliberate aggregate porosity decrease in phosphate settled coating be decently an aftereffect of diminished porosity, yet what's more an immediate consequence of diminished extent of intensity outs. Porosity decrease in phosphate settled coating be found within like way in open porosity estimation where decay continued running from 24-48 %. It ought to in like way be seen that mercury porosimetry result tends to mean open porosity of whole covering.

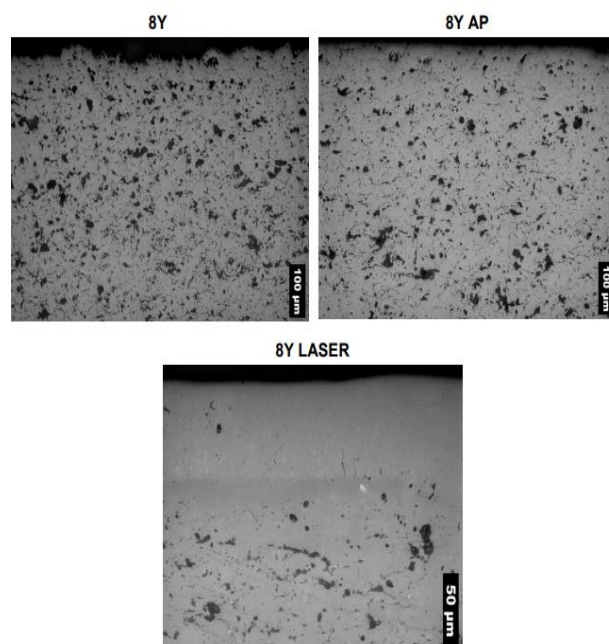


Figure: Optical micrographs of showered and adjusted 8Y based TTBCs

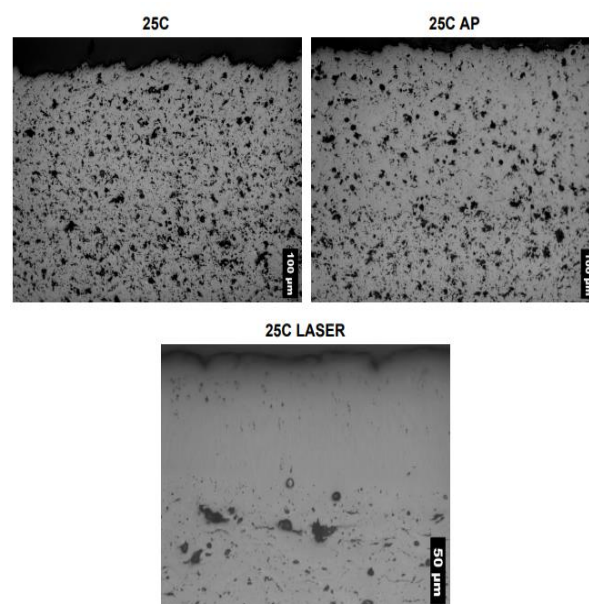


Figure: Optical micrographs of as-sprayed and modified 25C based TBCs

Top-see SEM microstructures of laser-campaigned TTBCs are showed up in Fig. 16. 8Y LASER coatings have to some degree smooth and even surface. Shade of yttria balance zirconia covering changed from light decreases to clear yellowish/white in context of laser covering framework. Optically it could be outlined as prompt and smooth. Surface geography of 25C LASER covering was furthermore rar smooth, regardless a couple of pits, 200-500 μm in

breadth, were opened to surface. Gap be likely passed on while gotten gas, from covering porosity, made tracks in an opposite bearing from condense pool in center of covering system. Light greenish/yellow shade of covering changed to dull in laser covering.

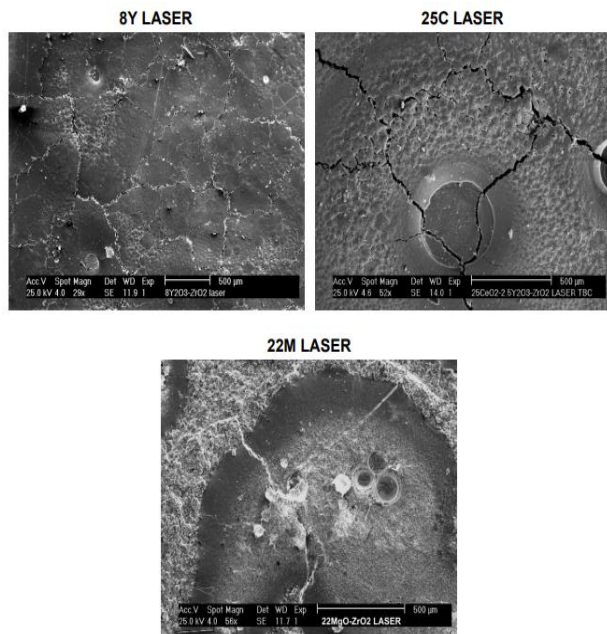


Figure: Top-see SEM micrographs of laser covered coatings

CONCLUSION

TBCs have been commonly used in gas turbines, both stationary and jet turbines, for 20 years. Combustion chambers and combustion liners and vanes are protected by parts. The heat exchangers rocket motor nozzles, exhaust collectors, jet engine parts and nuclear energy components can also be used for thermal-barrier coatings on furnace components, heat processing equipment. Impact of high temperature presentation on covering execution as far as warm properties was illustrated. Sintering was seen inside microstructure of thermally uncovered examples; prompting significantly expanded warm conductivity. Be that as it may, microstructural changes couldn't be specifically measured with microstructure methods utilized up to this point. While sintering of microstructure affected all coatings; how much warm execution corrupted was dependant on microstructural highlights. Again coatings created with a pore previous showed a littler

corruption in execution. Regarding strategies utilized for surveying effect of microstructure (change in structure) and science of coatings; laser streak strategy is most suitable for TBCs at all temperatures.

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