Thermal Barrier Coating: Understanding the Structure and Its Applications

Ju Golino*

Department of Material Science Engineering, Gaziantep University, Gaziantep, Turkey

Short-Communication

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***For Correspondence:**

Ju Golino, Department of Material Science Engineering, Gaziantep University, Gaziantep, Turkey

E-mail: jugolino@yahoo.com

DESCRIPTION

As a method of exhaust heat management, Thermal Barrier Coatings (TBCs) are sophisticated materials systems that are typically applied to metallic surfaces operating at high temperatures, such as gas turbine or aero-engine parts. These thermally insulating coatings, which range in thickness from 100 mm-200 mm, protect components from intense heat loads and can withstand a significant temperature difference between the load-bearing alloys and the coating surface.

Structure

In order to function well in challenging thermo-mechanical settings, a TBC must adhere to a set of standards. Appropriate porosity and proper matching of thermal expansion coefficients with the metal surface that the TBC is covering are required to handle thermal expansion loads during heating and cooling. To avoid substantial volume fluctuations, which happen during phase transitions and could cause the coating to crack or spall, phase stability is necessary. Oxidation resistance and respectable mechanical qualities for spinning, moving, or in contact parts are required in air-breathing engines.

Therefore, it may be said that the following are necessary for an effective TBC:

- A high melting point.
- There is no phase change between operational temperature and room temperature.
- Low heat conductivity.
- Inertness to chemicals.
- A metallic substrate and a corresponding thermal expansion match.
- Effective substrate adhesion.

- A porous microstructure with a low sintering rate.

The amount of materials that can be employed is highly constrained by these requirements, with ceramic materials typically being able to meet the necessary qualities.

The metal substrate, metallic bond coat, Thermally Generated Oxide (TGO), and ceramic topcoat are the usual four layers of thermal barrier coatings. Yttria-Stabilized Zirconia (YSZ), which has a very low conductivity and is stable at the nominal operating temperatures normally encountered in TBC applications, is typically used as the ceramic topcoat. The highest thermal gradient of the TBC is produced by this ceramic layer, which also keeps the lower layers cooler than the surface. The phase of YSZ, however, undergoes unfavorable phase changes beyond 1200°C, moving from t'-tetragonal to tetragonal to cubic to monoclinic. Such phase changes result in the creation of cracks within the top covering. In recent efforts to find a replacement for the YSZ ceramic topcoat, various innovative ceramics (such as rare earth zirconates) have been discovered that perform better at temperatures exceeding 1200°C but have less fracture toughness than YSZ. Additionally, these zirconates might include a lot of oxygen-ion vacancies, which could promote oxygen transport and make the TGO production worse. It is possible for the coating to spall with a thick enough TGO, which is a catastrophic mode of failure for TBCs. Such coatings would need to be used in conjunction with more oxidation-resistant coatings, like alumina or mullite.

An oxidation-resistant metallic coating known as the bond coat is immediately placed on top of the metal substrate. Although other bond coats consisting of Ni and Pt aluminides are also available, they are typically 75 m-150 m thick and formed of a NiCrAlY or NiCoCrAlY alloy. The bond coat's main function is to safeguard the metal substrate from oxidation and corrosion, especially from oxygen and other corrosive substances that can flow through the porous ceramic top coat.

Applications

Automotive: Ceramic thermal barrier coatings are being used increasingly frequently in automobile applications. They are made specifically to prevent heat loss from the exhaust manifolds, turbocharger casings, exhaust headers, downpipes, and tailpipes of engines. The term "exhaust heat management" also applies to this procedure. These work well under the hood because they lower engine bay temperatures, which in turn lower intake air temperatures.

Aviation: Research into higher combustion temperatures has been sparked by a desire to improve the performance of gas turbine engines for aviation applications. A direct relationship exists between combustion temperature and turbine efficiency. The thermodynamic efficiency of the machine is enhanced by burning at higher temperatures, which results in a more favourable work-to-waste heat ratio. In order to prevent melting and heat cycling of nickel-based superalloys in aviation turbines, thermal barrier coatings are frequently utilised. TBCs raise the permissible gas temperature over the superalloy melting point when combined with cold air flow.

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