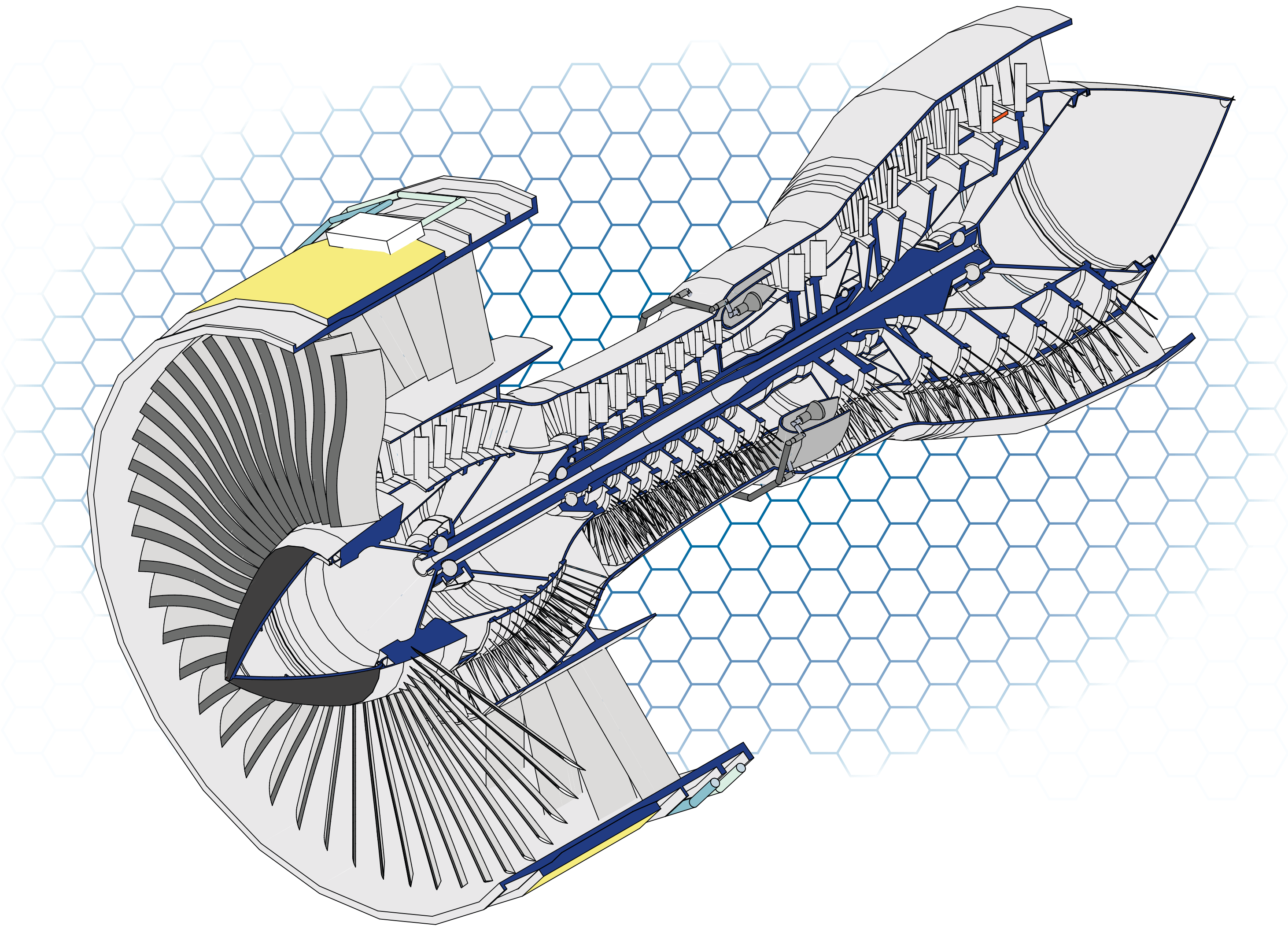
Protecting Critical Aircraft Engine Components with Ceramic Coatings

Thermal spray powders and their applications in thermal barrier coatings and wear-resistant coatings



Introduction

India has emerged as the third-largest civil aviation market and the fourth-largest in military fleet size. With a strategic roadmap aimed at achieving self-sufficiency in defence technology and production, as well as strengthening its position in the global marketplace, India's defence aerospace industry is undergoing a transformative phase. This includes aggressive expansion of the aircraft fleet and a focus on modernisation and indigenisation to build a combat-ready military fleet by 2047. A key ambition is also to establish the country as a hub for maintenance, repair, and overhaul (MRO) activities. The transformation of India's defence aviation sector involves building a future-ready ecosystem that integrates world-class R&D, overhaul facilities, aero-engineering talent, and capabilities. Indigenisation, supported by India's mature materials science expertise and access to key resources, strengthens the foundation of this transformation.

One area where materials science and indigenisation intersect with significant impact is in surface engineering using thermal spray powders (TSPs). This technique protects aircraft engine parts from extreme heat and corrosion, enhances efficiency, and extends service life while improving safety. As one of the fastest-growing aircraft markets globally, India is witnessing rising demand for thermal spray powders, not just for new engine components but also within airline and Air Force MRO facilities. However, supply is currently dominated by a few global players, owing to the complex manufacturing requirements and stringent certifications necessary for high-purity powders.

With a growing emphasis on performance, efficiency, and durability across aerospace, power generation, healthcare, automotive, steel, and pulp and paper sectors, the demand for TSPs continues to grow. From $12.26 billion in 2022, the global market is projected to reach $19.13 billion by 2031, growing at a CAGR of over 5%, with aerospace as the leading segment. This whitepaper explores the evolution of materials in surface engineering and the application of advanced ceramic thermal spray powders as protective coatings in aerospace.

Thermal Spray Powders

Ensuring safe and efficient operation of aircraft engines

The use of thermal spray powders in protecting aircraft engines varies by application. Civil aircraft engines are designed for long-haul flights, focusing on fuel efficiency and reduced noise. In contrast, military aircraft prioritise agility, acceleration, and combat readiness. Operating temperatures can reach up to 2000°C in military aircraft combustion chambers, and even higher with afterburners. These extreme conditions demand high-performance materials and thermal barrier coatings.

As the engine technology becomes more advanced, the cost and frequency of component replacement become significant concerns. Surface engineering has become essential, offering benefits such as base metal protection, reduced emissions, improved engine performance, and extended component lifespan. High-stress components such as turbine blades, vanes, and combustors are coated with ceramic materials to resist oxidation, creep, corrosion, and wear.

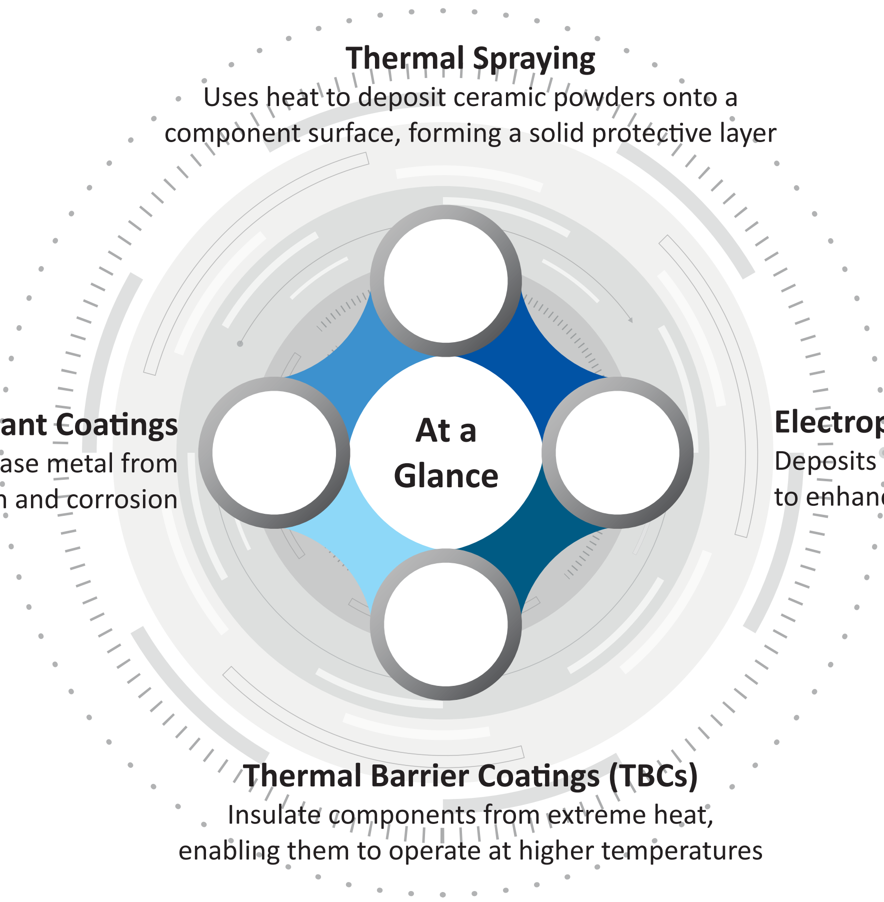
Surface Engineering Techniques

Thermal Spraying

Uses heat to deposit ceramic powders onto a component surface, forming a solid protective layer

Oxidation-Resistant Coatings

Protect the base metal from oxidation and corrosion



Electroplating

Deposits a thin metallic coat to enhance specific properties

Thermal Barrier Coatings (TBCs)

Insulate components from extreme heat, enabling them to operate at higher temperatures

Understanding

Thermal Barrier Coatings (TBCs)

Thermal Barrier Coatings or TBCs are used on hot-section components in aircraft engines, land-based turbines, and rocket chambers. Their primary role is to insulate the base materials from high temperatures, preventing corrosion, degradation, and wear.

TBCs are multilayered systems typically comprising:

1. Substrate
2. Bond coat
3. Thermally Grown Oxide (TGO)
4. Topcoat

TBCs are applied via two main methods: melt-and-spray using high-velocity plasma, or Electron Beam Physical Vapour Deposition (EB-PVD). Yttria-stabilized Zirconia (YSZ), Calcia-stabilized Zirconia (CSZ), and Magnesia-stabilized Zirconia (MgSZ) are commonly used thermal spray ceramic powders. For wear resistance applications, coatings formulated with Alumina, Titania, and Alumina-Titania are used.

Evolution of TBCs

1960s–1970s
Introduction of Air Plasma Spray (APS) coatings using Yttria-stabilized Zirconia (YSZ). These early coatings provided basic thermal insulation but had limitations in durability and oxidation resistance.

1980s–1990s
Introduction of bond coats (typically MCrAlY alloys) and Electron Beam Physical Vapor Deposition (EB-PVD) methods. These advancements significantly improved adhesion, thermal shock resistance, and resistance to oxidation and spallation.

2000s
Optimization of Yttria content (~7–8%) in YSZ for improved phase stability. Enhanced TGO (Thermally Grown Oxide) management, development of multi-layered and functionally graded coatings, and efforts to reduce thermal conductivity using dopants.

2010s
Introduction of rare-earth zirconates (like Gadolinium Zirconate, GZO) to address CMAS (Calcia-Magnesia-Alumino-Silicate) attack. Development of nanostructured and columnar microstructure for improved strain tolerance and performance longevity.

2020s–Present
Research into pyrochlores and high-entropy oxides (HEOs) for ultra-high temperature stability. Emergence of smart coatings (that can sense or respond to environmental changes) and self-healing coatings that repair microcracks or oxidation damage autonomously. Integration with additive manufacturing is also being explored.

Why Advanced Ceramic Thermal Barrier Coatings are Essential

Advanced ceramic coatings allow turbine engines to operate at elevated temperatures without degrading underlying materials. Bond coats are applied first to ensure adhesion with ceramic on the top. Then the ceramic powders are melted using plasma system and molten mass is rapidly solidified on the bond coat to form dense, protective coatings.

TBCs offer the following advantages

- Minimised heat transfer and thermal stress
- Protection from oxidation, creep, corrosion, and wear
- Enhanced durability and longer component life
- Support for higher operational temperatures and better engine efficiency
- Lower fuel consumption and reduced emissions

Common applications of TBCs in aircraft engines

- Turbine blades and vanes
- Combustion chambers
- Turbine housings
- Exhaust manifolds
- Nozzles

> Indigenisation of critical raw materials, like high-quality thermal spray powders, holds the key to India becoming a global manufacturing hub for aircraft engine components and aircraft engine MRO. Persistent effort to ensure these powders receive global certification will open up a host of opportunities for India – both, in the international materials marketplace and as a hub for aerospace-related activities.
>
> **Dr. S. Christopher,** Former Chairman, DRDO

CUMI's work in Thermal Spray Powders

CUMI is in the production of high-purity thermal spray powders for thermal barrier coatings and wear-resistant coatings. Under the CUMIPLAS brand, these powders are manufactured using world-class capabilities at CUMI's state-of-the-art facility in Kerala. Our product range includes Yttria-stabilized Zirconia (YSZ), Calcia-stabilized Zirconia (CSZ), Magnesia-stabilized Zirconia (MgSZ), Alumina, Titania, and Alumina-Titania.

CUMIPLAS YSZ supports long operational lifecycles (25,000–40,000 hours), while CUMIPLAS CSZ is suited for harsh environments. CUMIPLAS Alumina-Titania powders deliver dense, tough, wear-resistant coatings.

Typical Applications:

- Thermal barrier coatings in rocket and turbine combustion chambers
- Topcoats for aviation and industrial gas turbines
- Intermediate layers in thermal barrier coating systems
- Wear resistance for high-friction components

Powder selection depends on desired hardness, porosity, and surface finish.

8YSZ
Widely used for topcoats

20YSZ
Ideal for turbine applications

48YSZ
Offers CMAS corrosion resistance and low thermal conductivity

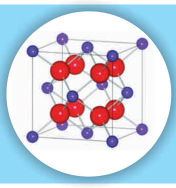
CSZ
Resists thermal shock and corrosion in rocket engines

CUMI has conducted application trials for our thermal spray powders with global agencies. Currently, they are in various stages of product validation for use in diverse aerospace applications.

> "Fully backward integrated, domestic suppliers of premium grade thermal spray powders, like CUMI, can help India attain self-reliance in critical unavailable materials for the Aerospace & Defence industry, while also significantly reducing costs. With captive raw material resources, extensive technical expertise, world-class powder manufacturing & processing capabilities, and a history of collaborative development with customers, we are well-positioned to fulfil current and anticipated demand."
>
> **Subbu Venkatachalam,** Head of Defence & Aerospace, Carborundum Universal Limited (CUMI)

Future Outlook

With increasing demand, CUMI is scaling up the production of thermal spray powders and developing custom formulations. Backed by R&D and the capability to rapidly scale-up, we have emerged as a reliable partner to the aerospace sector. Certified as per the AS9100D international quality management standard, we ensure consistent, world-class product quality. We also supply powders for thermal spray substrate blasting and nickel-based superalloy preparation.



Fast fact:
CUMI is among the few manufacturers of **Yttria-stabilized Zirconia (YSZ)** powder in India - the primary material for thermal barrier coating applications. India is currently 100% import-dependent for the supply of YSZ. CUMI's capabilities to meet this demand will bridge the supply gap for this critical unavailable material.

CARBORUNDUM UNIVERSAL LIMITED

Carborundum Universal Limited (CUMI), established as a tripartite joint venture in 1954, is a leading materials sciences engineering solutions provider. CUMI's consolidated sales is Rs. 4833 crores and PAT of Rs. 298 crores for the financial year 2025. CUMI, part of the 120-year-old Murugappa Group, is listed on the NSE and BSE.

CUMI is a Mines to Market Company whose integrated operations include mining, power generation, fusion, manufacturing, marketing and distribution. CUMI has over 5,500 employees worldwide who collaborate, innovate and develop high-quality material solutions and world-class services in abrasives, electrominerals, ceramics, refractories and energy storage materials, serving customers in diverse industries including engineering, fabrication, auto and auto components, infrastructure, steel, glass, power generation and distribution, mining and aerospace. CUMI has a wide geographical presence spanning six continents and exports products to over 50 countries

To know more about our complete range of solutions for Aerospace & Defence, download our brochure here or visit www.cumiaerodefence.com

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