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ITSA ASSOCIATION FOR THERMAL SPRAY TECHNOLOGY AND RESEARCH

Sep 2025| Vol. 5| Issue 3

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PlasmaLite™ - TBC Coating Inside a 45 mm Internal Diameter (ID) Component

Issue Highlights

- Engineering Thermal Barrier Coatings (TBCs) for Gas Turbines Towards Sustainable Aviation: A Brief Overview
- Challenges in Cold Spraying Martensitic Nickel-Aluminum Bronze onto Soft Substrates
- Introducing PlasmaLite™ - TBC Coating Inside a 45 mm Internal Diameter (ID) Component
- Call for Papers - International Cold Spray Conference & Expo 2026

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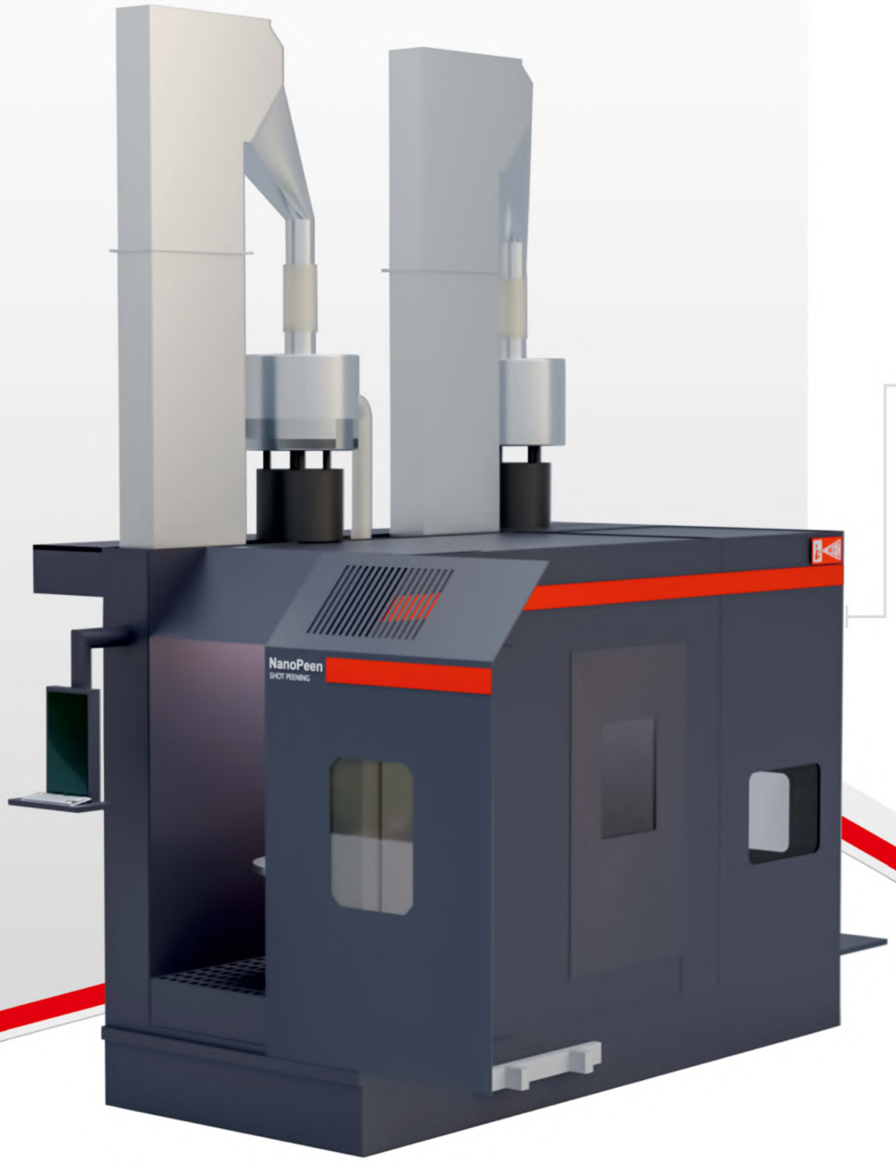

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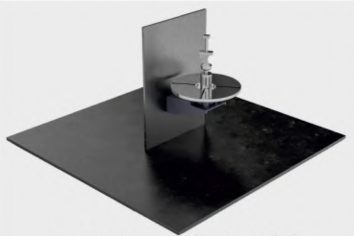

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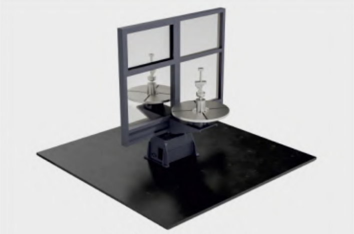

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Mission: Our mission is to deliver the most recent thermal spray industry news and keep up to date to the thermal spray community by providing company, event, people, product, research, and membership news of interest to industrial leaders, engineers, researchers, scholars, policymakers, and the public thermal spray community.

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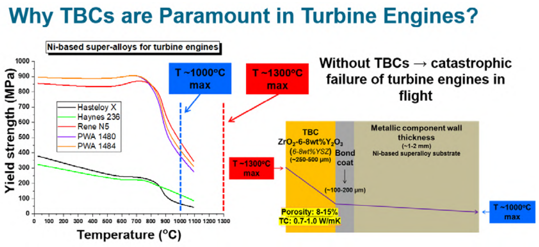

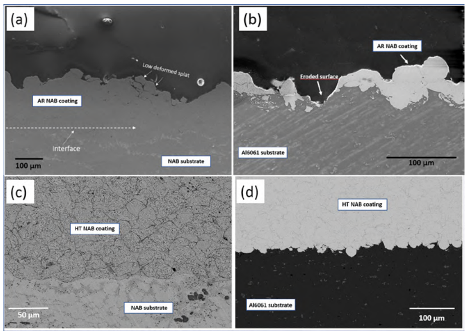

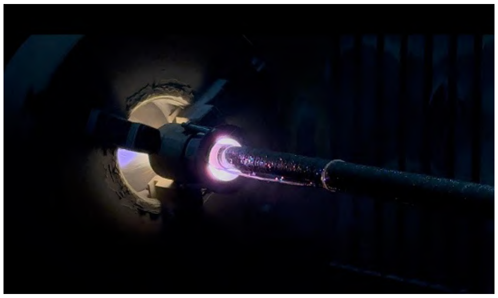

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ABOUT THE COVER

PlasmaLite™ – TBC Coating Inside a 45 mm Internal Diameter (ID) Component

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Editor’s Note

Dear Readers,

Welcome to the latest edition of SPRAYTODAY Magazine, your premier source for all things related to thermal spray technology. We are excited to bring you this issue, which reflects the latest advancements and trends in the thermal spray field.

I am particularly pleased to be allowed to recommend to you the latest issue of SPRAYTODAY. This issue includes invited innovative featured articles on “Engineering Thermal Barrier Coatings (TBCs) for Gas Turbines Towards Sustainable Aviation: A Brief Overview; Challenges in Cold Spraying Martensitic Nickel-Aluminum Bronze onto Soft Substrates; and Introducing PlasmaLiteTM - TBC Coating Inside a 45 mm Internal Diameter (ID) Component”, that illustrate current research trends in thermal spray development.

We are excited to announce our upcoming event on cold spray: The international cold Spray Conference and Expo (ICSC 2026), will be held on Jan 23-25, 2026, at the IITM Research Park IIT Madras, Chennai. This conference will serve as a hub of innovation and collaboration for cold spray technology. More than 350+delegates, including leading experts, researchers, and industry professionals from around the globe will attend the ICSC2026 to discuss cutting-edge developments, share insights, and explore the future of cold spray technology in the world. With a robust lineup of keynote speeches, technical sessions, and an expansive expo will be showcasing the latest equipment, materials and recent developments. The conference significantly will contribute to learning about the latest advancements and understanding the new applications of Cold spray technology. ICSC2026 website https://www.indtsa.org/icsc-2026

As we navigate the pages of this magazine, let's collectively embrace the spirit of innovation and collaboration. The thermal spray community in India is not just witnessing change; it is driving it. We hope this edition sparks inspiration, fosters knowledge exchange, and fuels the passion for pushing the boundaries of thermal spray technology.

Thank you for being part of our journey.

Be healthy, active, and curious! Happy Spraying!

Best Regards,

Satish

(Satish Tailor | PhD)

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Engineering Thermal Barrier Coatings (TBCs) for Gas Turbines Towards Sustainable Aviation: A Brief Overview

by ***Rogerio S. Lima***

National Research Council of Canada (NRC), Boucherville, QC, Canada.

Email: rogerio.lima@nrc-cnrc.gc.ca

Abstract

The current thermally sprayed state-of-the-art ZrO_2-6-8wt%Y_2O_3 (6-8wt%YSZ) TBC is located in the static hot metallic components of the turbine. Although there are many sets of information in the open literature (e.g., papers, books and websites) about the paramount importance of TBCs for gas turbine engines, they are generally not well explained on how together they come to be. This short article will show to the readers in a practical point-of-view, how TBCs are important and how they work towards sustainable aviation. It will (i) explain the non-stop driving force to keep increasing the turbine entry temperature (TET) along the years, (ii) explore the longevity of TBCs on the engines, (iii) the temperatures in which TBCs and the metallic components of turbines currently work and (iv) the evolution of the TETs. In addition, other key important topics will be discussed. For example, will electric engines replace gas turbines in aviation? This article will shine some light on this concept and clarify some "misconceptions" on this subject. Moreover, if we want to replace kerosene by hydrogen (H_2) as jet fuel for turbines, what potential challenges TBCs will need to face? Can the H_2 economy foster the "re-birth" of TBCs?

Introduction

Thermally sprayed TBCs have been used since the 1980s to protect the static hot-sections of aviation gas turbines engines, which are manufactured from Ni-based superalloys. These zones include the combustion chambers, transition ducts, nozzles vanes, thrust reversers and afterburners. A thermally sprayed TBC system typically exhibits a bi-layered structure which, besides the 6-8wt%YSZ ceramic topcoat also includes a metallic MCrAlY (M = Ni, Co, NiCo or CoNi) bond coat (BC). The metallic BC is an oxidation/corrosion-resistant metallic layer. It protects the underlying component and improves the adhesion of the ceramic YSZ topcoat on the part. The metallic wall thickness of the static hot-section components of aviation gas turbine engines (e.g., combustion chamber walls) typically varies from ~1-2 mm. The thickness of the BC is generally found within the 100-200 µm range; whereas the ceramic topcoat thickness has a range from ~250 to ~500 µm. The porosity levels for 6-8wt%YSZ topcoats are within the range of 8-15% for jet engines, and their thermal conductivity (TC) values are situated at 0.7-1.0 W/mK [1-6]. A TBC schematic is shown in Figure 1.

Why are TBCs Needed in Gas Turbine Engines?

The current maximum TBC surface temperature of a real engine in thermal gradient environment is reaching 1300°C; although this temperature can only be sustained for short peak operations. The metallic super-alloy substrates of the static parts are limited to operate at the maximum temperature of ~1000°C, also for short peak operations [1-3]. For component un-coated backside, a forced air film cooling (bled from the turbine compressor) flows over its surface to provide a "cooler shielding layer" to avoid overheating; thereby helping to create and maintain the thermal gradient depicted in Figure 1 (although to some degree this air film cooling can be also channeled – via engineered cooling holes - over the TBC surface to attenuate its temperature). For this reason, the TBC-coated components can operate in thermal gradients, with temperatures varying from ~1300°C at the TBC surface, going down to ~1000°C in the backside on the metallic part (during peak operations). Therefore, based on this premise, Figure 1 graphically exemplifies what would happen if low TC TBCs were not there to protect the Ni-based super-alloy components. The first property to be observed is the yield strength, which indicates the minimum stress level necessary to cause a material to

Why TBCs are Paramount in Turbine Engines?

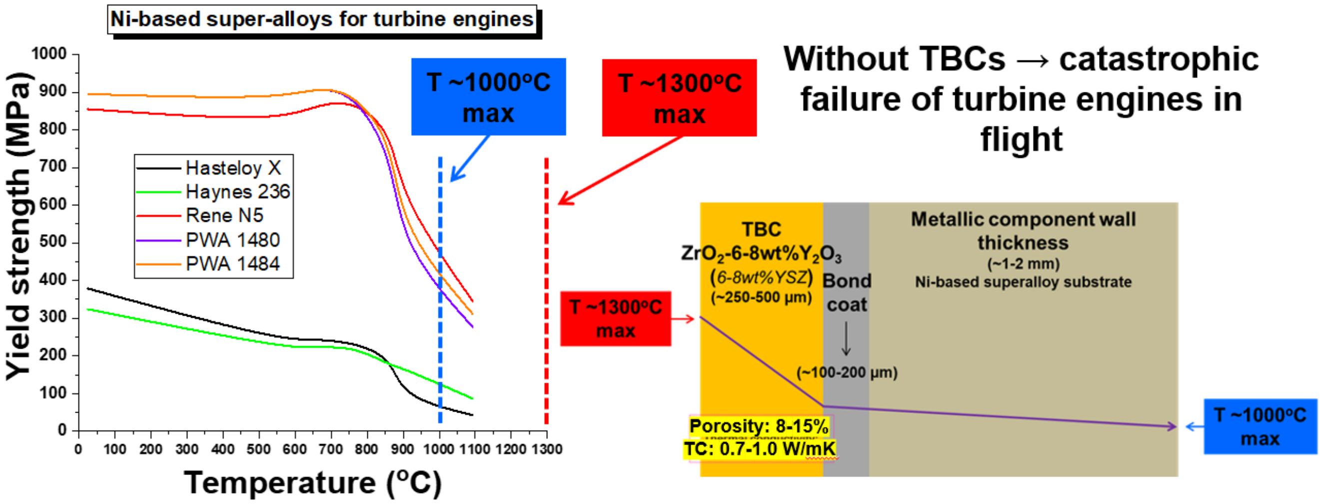

Figure 1: Schematic of the Maximum Peak Temperatures that TBC Architectures and Coated Components can Operate in Aviation Turbine Engines

Why Keep Increasing the Combustion Temperature: Turbine Entry Temperature (TET); a.k.a., *combustion chamber outlet temperature*

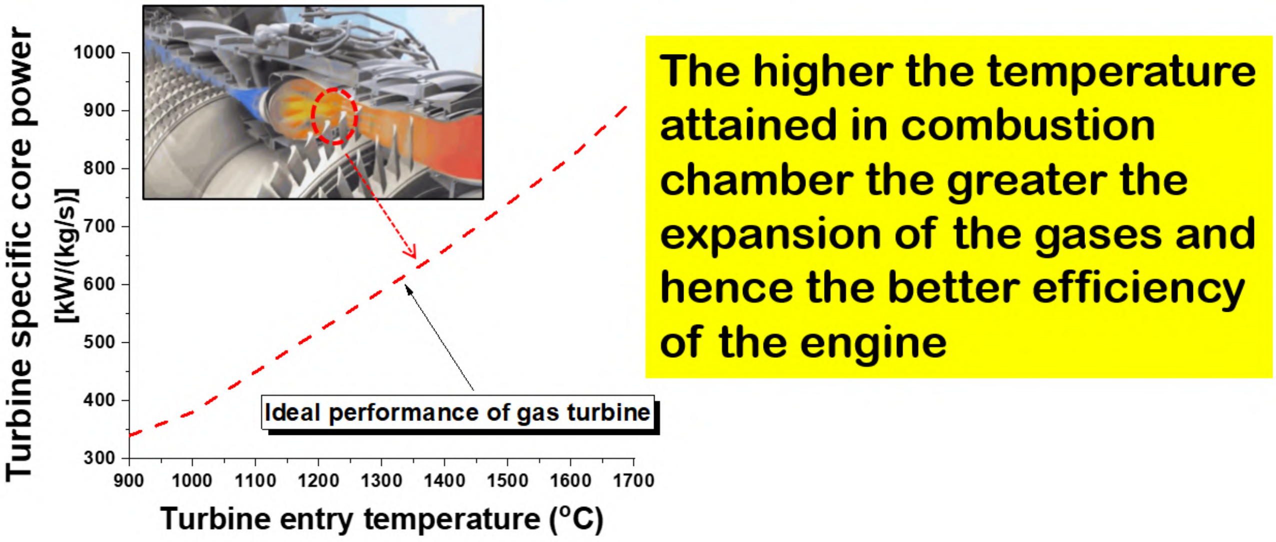

Figure 2: Ideal Performance of a Gas Turbine

deform permanently (i.e., plastic deformation). The yield strength values of these metallic aerospace alloys are drastically reduced when the operation temperature reaches ~1000°C. Henceforth, if a low thermal-conductive ceramic-based TBC (at least 10X less thermal conductive than Ni-based alloys) was not there protecting the metallic component during a peak temperature operation of 1300°C at the surface, one can imagine the catastrophic failure of the turbine in flight. This is the key reason why TBCs are needed.

Can Jet Engines be Effectively Operated without TBCs; i.e., are TBCs Mandatory?

Based on the schematic of Figure 1, someone could hypothesize and state that if the maximum peak

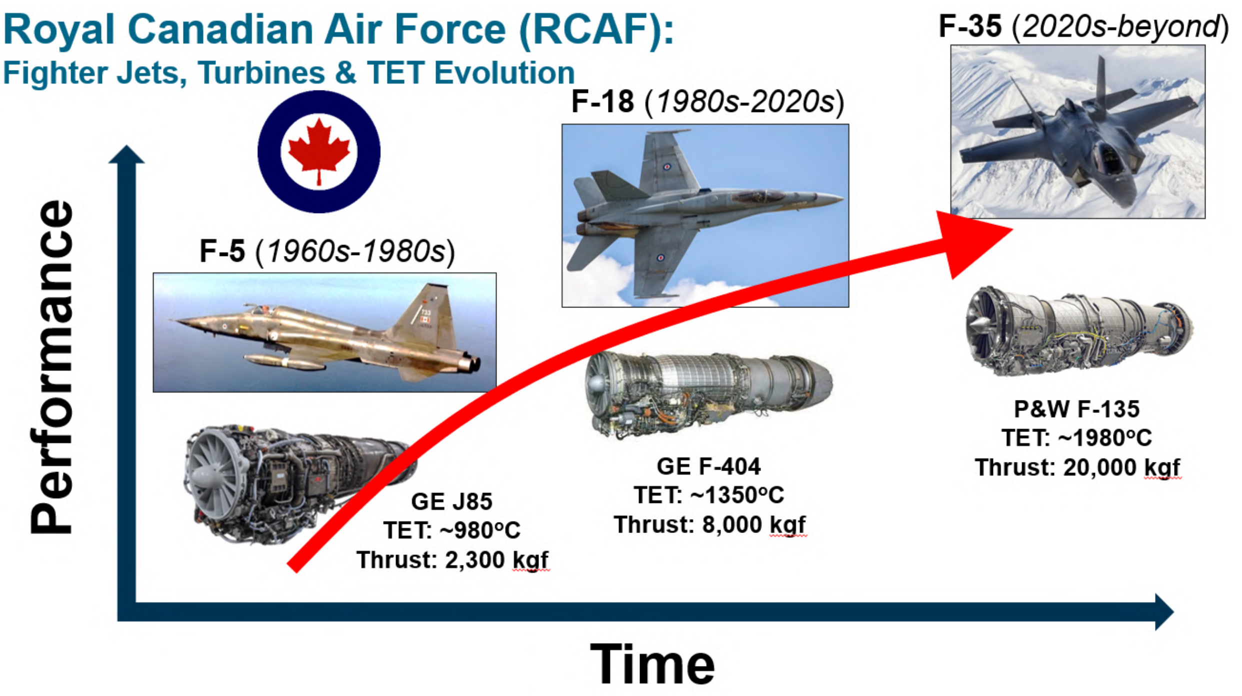

Figure 3: Approximate evolution of the TET and thrust of the turbine engines of fighter jets employed by the Royal Canadian Air Force (RCAF)

temperatures for turbine operation were limited to 1000°C, TBCs would not be needed. That said, during the 21st century, this is simply not acceptable, and it cannot be sustained. The driving force behind the development of TBCs is found to be in the non-stoppable demand for more efficient and environmentally friendly propulsion systems. And this is not based on a hype; this is based on thermodynamics. As depicted in Figure 2, the ideal relationship between the turbine specific core power with the TET is nearly linear from 900°C up to 1700°C [7]. Essentially, the higher the temperature attained in the combustion chamber, the greater the expansion of the gases and hence the better the efficiency of the engine. By improving engine efficiency, it translates to lower fuel consumption, and the reduction of the amount of greenhouse gases released to the atmosphere. These are paramount demands of today's society. Besides, more efficient turbines also mean that planes can fly (lift) larger numbers of passengers and cargo and reach longer distances without the need to re-fuel and layovers.

Consequently, since the implementation of TBCs in the 1980s, the turbine entry temperature (TET) levels continue to show incremental increases throughout the decades. As an example, Figure 3 shows a schematic ballpark evolution of the TET of the turbine engines of fighter jets employed by the Royal Canadian Air Force (RCAF).

Therefore, one can see that in the last 60 years, TETs have increased from ~1000°C to ~2000°C; and TBCs have had a major role in achieving this objective. Consequently, TBCs are imperative for improving performance and promoting sustainable aviation.

Longevity of Gas Turbine Engines in Aviation

Besides improving performance, TBCs also have a role in the longevity of gas turbines. Turbine engines are regularly scheduled to pass by the hot section inspection (HSI); which is a careful examination of the hot-sections of the engine [8-14]. It involves non-destructive testing based on visual inspection, borescope inspection (difficult to reach zones), thermal imaging devices, ultrasonic testing, and others. The HSIs are scheduled on pre-determined number of flight cycles (i.e., number of take-offs and landings) or pre-determined number of flight hours. Specifically, for TBCs, engineers and technicians will search for signs of partial delamination, wear and full spallation. Based on these findings, maintenance actions may be recommended to address identified issues and restore component functionality. If the TBC is still intact according to the specs, the engine keeps flying. However, if necessary, the removal of the part is carried out, followed by the complete stripping of the TBC from the component, and its re-application. On that account, the engine stops flying, which represents extras costs and/or loss of revenue. For this reason, in simple words, the "most durable the TBC is", the longer the time between overhauls (TBO). TBO is the number of flight cycles or running hours before a jet engine (or a section of it) requires an overhaul. Thus, one can understand that the R&D of TBCs has two major objectives, (i) to improve its capacity to operate at increasing higher temperatures and (ii) to increase its lifetime on the component.

The TBO was established by the turbine manufacturer. As some overall estimated examples, for business jets (e.g., Falcon 6X → P&WC 800) it is about 10,000 h. For large passenger jets (e.g., Boeing 777 → GE 90) it can reach 20,000 h. For fighter jets (e.g., F-18 → GE F414) as they typically operate at their limits, TBO is limited to about 6,000 h. The overhaul time can take up to two months, after that, the turbine is considered to be as good as new, and it costs about 5-20% of a new turbine [15]. It needs to be stressed that HSI and TBO are not only related to TBCs, but the overall components of the engine. This article highlights TBCs because they are the objective of this publication. As a matter of curiosity, the cost of a new turbine varies from US$15M (Boeing 737) to US$42M (Boeing 777X) and US$15M for fighter jets like the F-35 [16].

Finally, because of the overhauling and possible repair of many of the turbine components (TBCs included), jet engines can fly for up to 30 years [17]; adding another great contribution to sustainable aviation.

H_2-fueled Gas Turbines & Will Electric Motors Replace Gas Turbine Engines in Aircraft?

Two very important questions regarding sustainability of the aviation industry today are (i) about the use of hydrogen (H_2) to replace kerosene jet-fuel and (ii) the employment of electric-powered engines. Different misconceptions arise from the many sets of information available in open literature. Initially it is necessary to talk about the volumetric energy density, which is the amount of energy that can be stored within a specific volume of a substance or material; for example: kerosene (30 MJ/litre), liquid H_2 (10 MJ/litre) and lithium-ion batteries (2 MJ/litre) [18]. Thus, the volumetric energy density of kerosene (jet-fuel) is ~3X that of liquid H_2. Consequently, it will be necessary to store ~3X the volume of liquid H_2 in an aircraft to generate the same energy levels as that of kerosene. For sure it will represent a challenge in the design of airplanes and/or their capacity to carry passengers and/or cargo (to be partially used to carry H_2 fuel). Besides, the combustion of H_2 will generate ~3X the amount of water vapour than kerosene [19]. Moreover, the stoichiometric combustion of H_2 in air is ~2100°C, whereas that of H_2 is ~2250°C. As well as the higher combustion temperatures of H_2, generate great challenges but at the same time enormous R&D opportunities in TBC R&D for the next years.

In fact, Pratt & Whitney (P&W) is exploring two types of H_2 fueled gas turbines. The first approach is a H_2 steam-injection engine concept, called Hydrogen Steam-Injected, Intercooled Turbine Engine (HySIITE) [20-21]. According to the sources, the HySIITE concept is designed to exploit the full potential of H_2 by going beyond its use as a fuel to also maximize its cryogenic properties to lower emissions and improve thermodynamic performance. For the second approach, Pratt & Whitney Canada (P&WC) will demonstrate H_2 combustion technology on a PW100-based regional turboprop engine as part of a project supported by Canada's Initiative for Sustainable Aviation Technology (INSAT). Funding for the first phase of the project will include fuel nozzle and combustor rig testing using hydrogen fuel, while future phases will target full engine ground testing [23].

Another very interesting concept needs to be discussed. Lots of investments have been made in the last 30 years on the development of SiC/SiC ceramic matrix composites (CMCs) to replace the Ni-based superalloys applied in the hot sections of aviation turbines. As discussed, Ni-based alloys cannot (typically) operate at temperatures higher than ~1000°C; whereas, SiC/SiC-based CMCs can operate up to ~1300oC temperature levels. This is a major desire because, as also discussed (Figure 2), the hotter the engine, the better performance for gas turbines [7]. These CMCs are protected by a thermally sprayed silicate-based (e.g.; $Yb_2Si_2O_7$) environmental barrier coating (EBC), particularly against high temperature water vapour attack; resulting from the combustion reaction of hydrocarbons (i.e., kerosene jet fuel) in air [23]. Briefly, high temperature water vapour attacks the silica (SiO_2) layer formed on the CMC surface, and also corrodes the silicate-based protective EBC via the volatilization of SiO_2; i.e., via forming a $Si(OH)_4$ gas out of the CMC/EBC architecture. The formation of porous and/or cracked layers allows further gas penetration, increasing the oxidation rate and causing a loss of mechanical integrity. For this reason, in simplistic terms, one can say that "water vapour at high temperature is the greatest enemy of EBCs and CMCs". Hence, one can also wonder if EBCs and CMCs would "survive" if H_2 is used as jet fuel; meaning that, as previously stated, the combustion of H_2 will generate ~3X the amount of water vapour than kerosene [19]. Henceforth, it can be potentially hypothesized that EBCs/CMCs will not "endure" the use of H_2 as fuel for jet turbines. If proven true, this will lead to the re-birth of new oxide-based TBCs and new metallic-based alloys in terms of R&D and manufacturing; because both are not as affected by high temperature water vapour as CMCs and EBCs are. Besides, the perspective of using additive manufacturing for producing metallic turbine parts can bring new strides in this industry

The question remaining is about electric engines to power aircraft, i.e., will they replace jet engines? Due to the low energy density of the best lithium-ion batteries today available (2 MJ/litre), it will become unpractical to employ fully electric engines for long overhaul cross-country, transcontinental and transoceanic flights of large passenger planes. However, there is a good possibility for personal transportation, inter-city and regional flights of smaller aircraft, which includes the usage of hybrid-electric engines. For this reason, gas turbines for aviation will continue to be strong for decades, and it is a great opportunity for studies using H_2 as fuel, as well as sustainable aviation fuel (SAF).

Conclusions

Thermally sprayed TBCs are paramount for the sustainability of the aviation industry. They help (i) allow turbines to operate at increasingly higher temperatures (i.e., higher fuel economy + higher thrust) and (ii) enhance the longevity of the engine on the wing of the aircraft. Electric engines will not fully replace gas turbines anytime soon in aviation, mainly concerning cross-country, transcontinental and transoceanic flights. The H_2 economy leads to new challenges and possibilities for TBC R&D. New high temperature ceramic oxide materials, new superalloys and additive manufacturing provide many potential game changers for aviation. Finally, TBCs/superalloys may be able to compete with EBCs/CMCs in the future if H_2 is employed as jet-fuel.

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Challenges in Cold Spraying Martensitic Nickel-Aluminum Bronze onto Soft Substrates

*by **Gidla Vinay**[1,2], **Ravi Kant**[1], **Ashish Ganvir**[2], **Ermei Mäkilä**[3], **Harpreet Singh**[1]******

[1]*Department of Mechanical Engineering, IIT Ropar, India.*
[2]*Department of Mechanical and Materials Engineering, University of Turku, Finland.*
[3]*Department of Physics and Astronomy, University of Turku, Finland.*
Email: harpreetsingh@iitrpr.ac.in

Introduction

Thermal spray technologies have long been valued for extending the life of components operating in aggressive environments. Among them, cold sprays have attracted significant attention over the past two decades. Unlike conventional spraying techniques where feedstock is melted or partially melted, cold spray relies on the kinetic energy of supersonic particles with minimal thermal energy [1]. By avoiding high temperatures, coatings remain dense, oxide-free, and free of deleterious phase transformations often observed in plasma or flame spraying. This makes cold spray particularly attractive for repairing and enhancing high-value components. Yet this is very advantage, the absence of melting becomes a limitation when dealing with hard, brittle, or martensitic alloys. These materials resist plastic deformation, which is the fundamental bonding mechanism in cold spray. Without sufficient deformation, particles rebound instead of adhering, leading to low deposition efficiency (DE) or even complete failure to form a coating. Nickel-Aluminum Bronze (NAB) is one such material. NAB, a copper-based alloy enriched with aluminum, nickel, and iron, offers outstanding corrosion resistance, cavitation resistance, and mechanical strength. These qualities make it the material of choice for ship propellers, rudders, pumps, and marine hardware [2]. However, NAB powders produced via atomization are inherently martensitic and therefore hard. This microstructural state provides excellent in-service properties but makes them resistant to the deformation required for cold spray deposition. Researchers have attempted to overcome this challenge by heat treating NAB powders to transform martensite into softer α and κ phases. This reduces hardness and improves ductility, allowing better deposition efficiency, particularly when spraying onto hard substrates such as NAB plates or steels [3,4,5]. Until recently, however, there had been virtually no attempt to spray NAB onto soft substrates like aluminum alloys. The prevailing belief in the cold spray community has been that “hard-on-soft” combinations are favorable because the softer substrate should deform and promote mechanical interlocking. In our recently published study [6], we tested this assumption directly. We compared the deposition of as-received martensitic NAB powders and heat-treated powders onto two substrates: NAB (hard) and Al6061 (soft). The results were striking. As-received powders deposited, albeit with limited efficiency on NAB but failed almost entirely on Al6061. Only after heat treatment did successful deposition on Al6061 become possible. This article unpacks these findings, explains the underlying mechanisms, and highlights their implications for cold spray applications. The results discussed in this note are consolidated from our recently published article [6] for wider dissemination.

Why hard martensitic alloys are difficult to cold-spray

Bonding in cold spray depends on particle impact, deformation, and the localized melting of the deformed splat or mechanical interlocks. For ductile metals, this mechanism works efficiently: particles deform plastically, produce interfacial jetting, and adhere to the substrate and to previously deposited splats.

For hard martensitic alloys, three major challenges arise:

1. **High critical velocity**: harder materials require much higher impact velocities to achieve interfacial jetting and bonding.

2. **Limited plasticity**: martensitic phases fracture or rebound instead of deforming, reducing deposition efficiency.
3. **Surface oxides**: oxide films on powders act as barriers, requiring additional deformation to rupture and achieve metallic contact.

NAB powders produced by atomization typically exhibit hardness values around 340-360 HV, much higher than typical ductile feedstocks such as Al, Cu other common cold sprayed materials. This explains why as-received NAB powders generally yield poor coatings unless modified. Heat treatment offers a solution. By annealing around 700 °C, martensite transforms into α and κ phases, hardness drops to ~220 HV, and ductility improves lowering the critical velocity required for deposition.

Experimental Strategy

Spherical NAB powders (Cu-10Al-5Fe-5Ni) obtained from CNPC, China were used in as-received (AR) and heat-treated (HT) conditions. The AR powders contained martensitic phases, confirmed by XRD, and showed a hardness of ~346 HV0.025. Heat treatment at 700 °C for 7 h in argon transformed the martensite into α and κ phases, reducing hardness to ~224 HV0.025. Both powders were deposited using a nitrogen-based cold spray system operating at 40 bar and 900 °C. Two substrates were chosen: NAB representing hard-material for repair applications, and Al6061 representing lightweight alloys relevant to marine and aerospace structures. Coatings were characterized using SEM, microhardness testing, and electrochemical corrosion measurements (polarization and EIS). FEM simulations of particle impacts were conducted to analyze energy evolution between splats and substrates. Powder phases were verified by XRD, and surface chemistry was analyzed with XPS.

Results

When sprayed with AR powders, NAB substrates developed thin coatings with a deposition efficiency of ~20% and thicknesses of 150-200 µm (Fig.1a). By contrast, Al6061 substrates showed virtually no coating formation. After three spray passes, only scattered splats or thin traces could be seen, insufficient to form a continuous layer (Fig.1b). In contrast, HT powders exhibited nearly 100% deposition efficiency on both substrates. Coatings were continuous and dense, clearly demonstrating the beneficial effect of heat treatment in improving deformability (Fig.1c, 1d). NAB coating on Al6061 exhibited porosity of 2.24 ± 0.15 % while it is 1.48 ± 0.21 % for coating deposited on NAB. Hardness testing revealed that NAB-on-Al6061 coatings averaged ~219 HV, significantly higher than the substrate but lower than NAB-on-NAB coatings (~250 HV). Cracks from the inter-splat were visible around hardness indents in Al6061-based coatings, indicating weaker cohesion. Hardness variation was also greater, with standard deviations of ±47 HV compared to ±19 HV for NAB-on-NAB. Corrosion testing further confirmed this inter-splat difference. Polarization curves showed similar corrosion potentials for all coatings, but higher current densities for NAB-on-Al6061 (~35 µA·cm-2) compared to NAB-on-NAB (~20 µA·cm-2). Nyquist plots displayed larger arcs for NAB-on-NAB, reflecting superior charge transfer resistance and stronger bonding.

Discussion

The failure of AR powders to deposit on Al6061 alloy directly contradicts the assumption that spraying hard powders onto soft substrates is favorable. When AR powders impacted the hard NAB substrate, their limited deformability initially led to weak bonding. However, subsequent rebounding particles acted like hammers, deforming and densifying earlier splats (Fig.2a). This "hammering effect" raised interfacial temperatures enabling limited coating formation with superior inter-splat bonding [7] (Fig.2b). On the soft Al6061 substrate, the same mechanism was ineffective. Much of the impact energy was absorbed by plastic deformation of the substrate, leaving insufficient energy to deform the splats or rupture surface oxides. As a result, splats adhered only weakly and were eroded by subsequent impacts, preventing coating build-up (Fig.2c, 2d). Heat treatment transformed the powders into a more ductile state, enabling effective deformation and bonding even when the substrate absorbed some of the impact energy. This explains the near 100% deposition efficiency observed with HT powders on both NAB and Al6061. Nonetheless, coatings on Al6061 remained inferior in hardness and corrosion resistance compared to those on NAB, underscoring the persistent influence of substrate softness.

To further understand these differences, FEM simulations using multi-particles impact simulation were carried out. The results revealed that a significant fraction of impact energy was absorbed by substrate plastic deformation in the Al6061 case (Fig.3), reducing interfacial temperatures at splat boundaries compared to the NAB substrate. FEM showed lower fractions of boundary elements exceeding higher temperature thresholds (>0.7Tm) for Al6061,

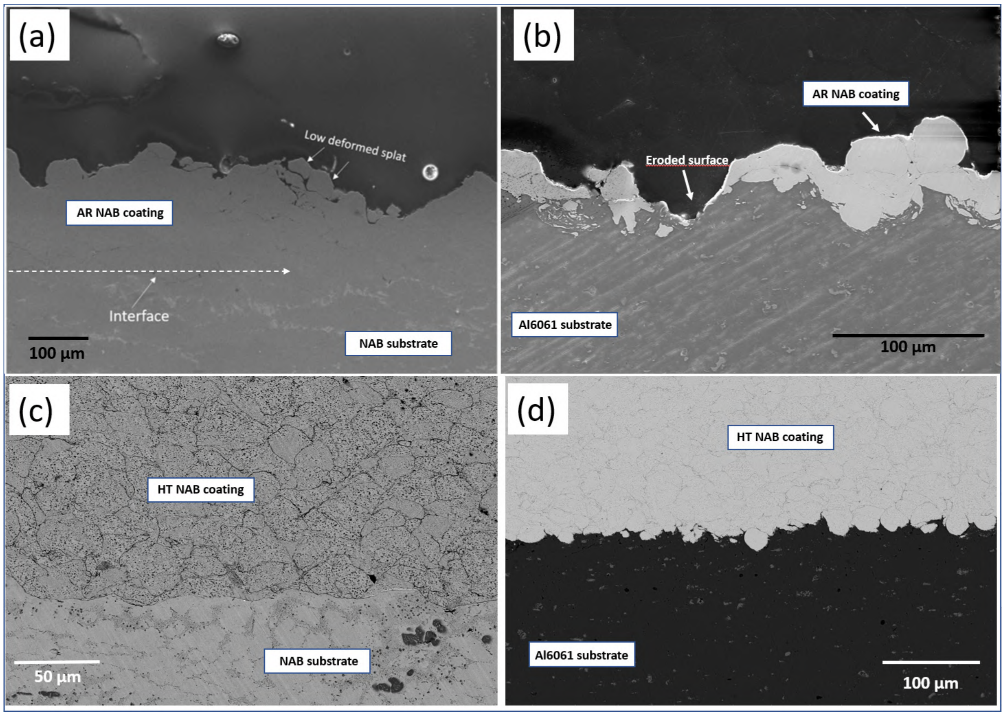

Figure 1: SEM cross section image of the coating generated with as received powder (a) deposited on NAB substrate (b) deposited on Al6061 substrate; Cross section image of the coating generated with heat received powder (c) deposited on NAB substrate (d) deposited on Al6061 substrate. This comparison highlights the dramatic improvement achieved through powder heat treatment

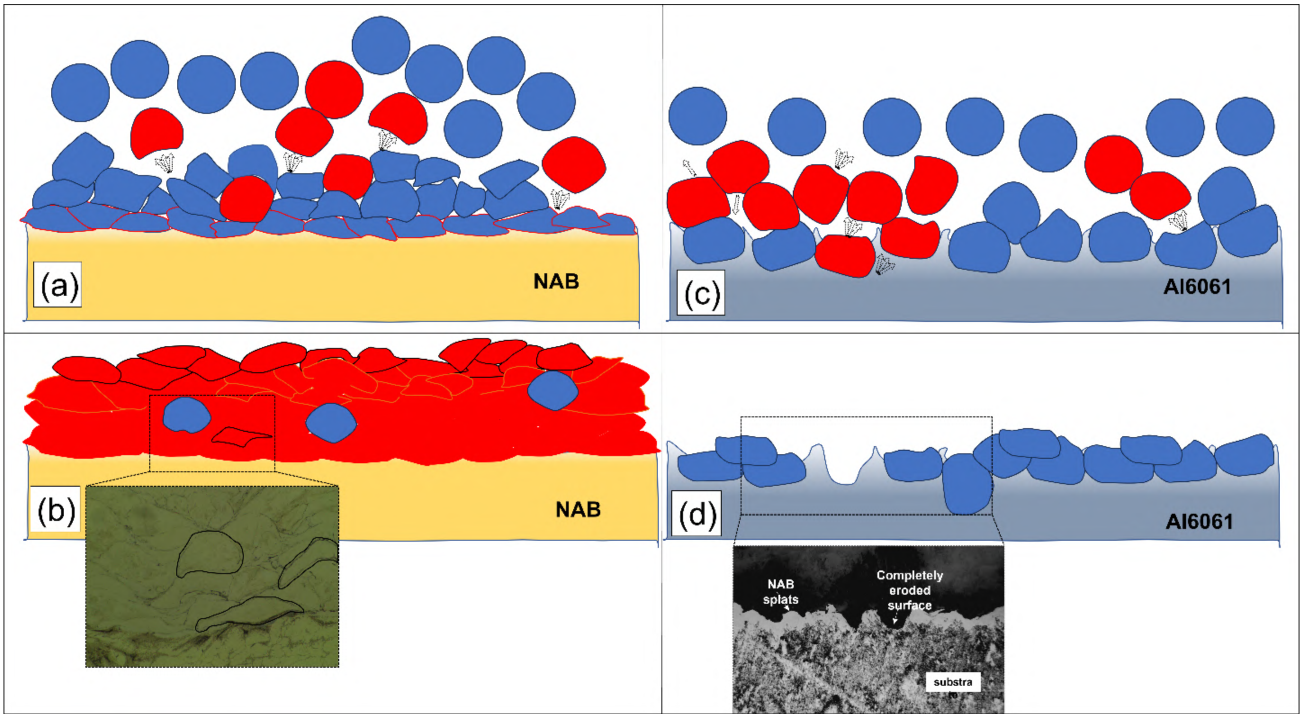

Figure 2: Proposed cold spray deposition mechanism of martensitic NAB powder on NAB and Al6061 substrates. Deposition on NAB substrate: (a) Incoming particles, whose motion is obstructed, become embedded in the coating with limited deformation, while overall deformation in the lower layers increases, (b) A highly deformed structure with strong inter-splat bonding is achieved, although some particles remain embedded with minimal deformation; Deposition on Al6061 substrate: (c) Continued impact leads to erosion of previously deposited layers while enhancing deformation in some interlocked particles, (d) Overall, only a few powder layers are retained, and in some areas, no particles remain, exposing a deformed substrate indicating particle erosion. The mechanism explains why deposition succeeds on NAB but fails on Al6061. [6]

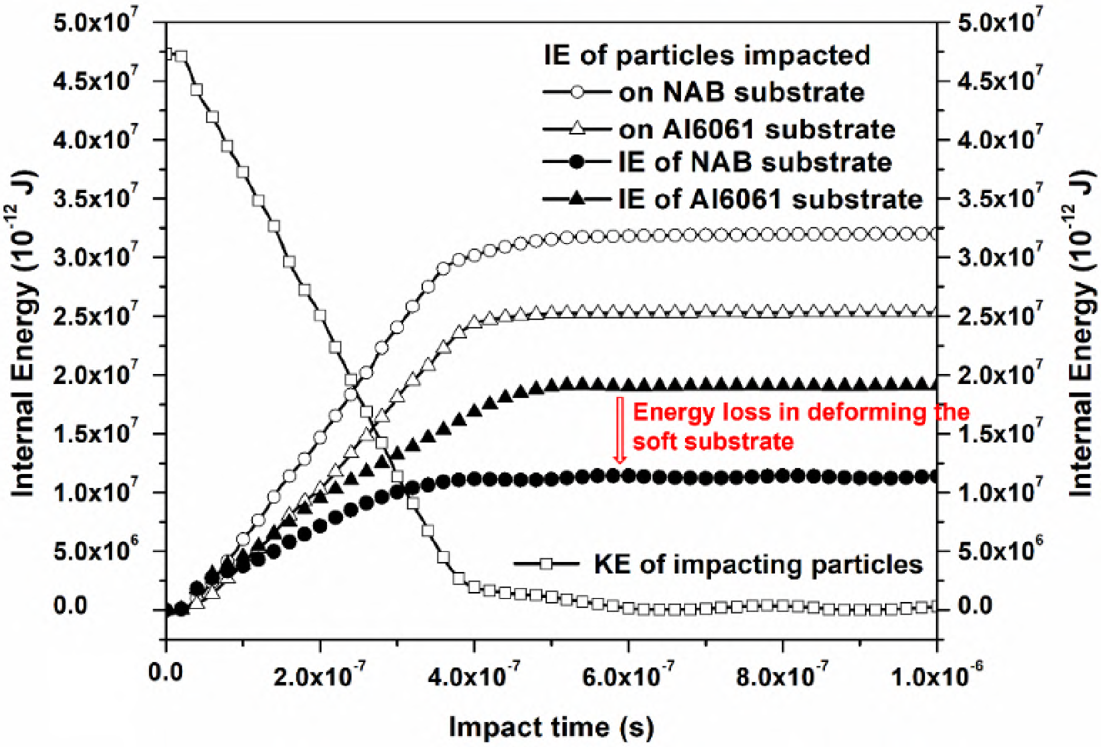

Figure 3: Kinetic energy to Internal energy conversions of impacting particle, substrate of multiparticle coating simulation comparing the loss of energy in deforming the softer substrate. This energy partitioning clarifies why coatings on Al6061 exhibit weaker inter-splat bonding. [6]

consistent with weaker inter-splat bonding. These predictions matched the experimental observations: coatings on Al6061 showed more cracks along hardness indents, wider scatter in hardness values, and poorer corrosion resistance compared to coatings on NAB.

XPS analysis added another layer of explanation. Both AR and HT powders carried thin Al2O3 surface films. During heat treatment, aluminum in the NAB diffuses to the surface and reacts even with residual oxygen in the argon atmosphere, thickening the oxide layer. Finer particles, with their higher surface-to-volume ratios, exhibited more pronounced oxidation. These oxides accumulated at splat boundaries, forming weak links. On Al6061 substrates, where energy losses were already significant, the additional barrier of surface oxides compounded the problem, producing weaker bonding and poorer electrochemical performance.

Together, these results demonstrate that substrate hardness plays a decisive role in deposition behavior. While hard NAB substrates enable rebound-driven hammering that can promote bonding even with martensitic powders, soft substrates dissipate impact energy, making bonding dependent on powder ductility and oxide break-up. FEM simulations for HT powders, combined with experimental property data, underline how substrate softness and oxide effects synergistically weaken inter-splat cohesion in NAB-on-Al6061 coatings. Complete results can be found from our works [6]. We believe that these results can be extended to the systems for deposition of very hard materials like Ti6Al4V and other martensite materials for deposition on softer substrates.

Conclusions

This study highlights the challenges of cold spraying martensitic alloys onto soft substrates. As-received NAB powders deposited on hard NAB substrates with limited efficiency but failed almost entirely on Al6061. Heat treatment of powders enabled successful deposition on both substrates, with nearly 100% efficiency. However, coatings on Al6061 were characterized by weaker inter-splat bonding, lower hardness, and inferior corrosion resistance compared to coatings on NAB.

- Hard substrates promote rebound-driven hammering effects that enhance splat deformation and bonding, while soft substrates dissipate energy into deformation for martensite materials.
- Powder ductility, achieved through heat treatment, is essential for deposition, though surface oxides remain a limiting factor.

- Substrate softness amplifies the effect of surface oxides, producing weaker coatings despite high deposition efficiency.

For practical applications, these findings suggest that heat-treated feedstock should be used for NAB-on-NAB repairs to ensure coating quality. NAB-on-Al6061 substrates are possible but may require additional optimization strategies along with the powder heat treatment such as powder surface conditioning or post processing of the coatings for better performance.

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By ***Satish Tailor, Ankur Modi***

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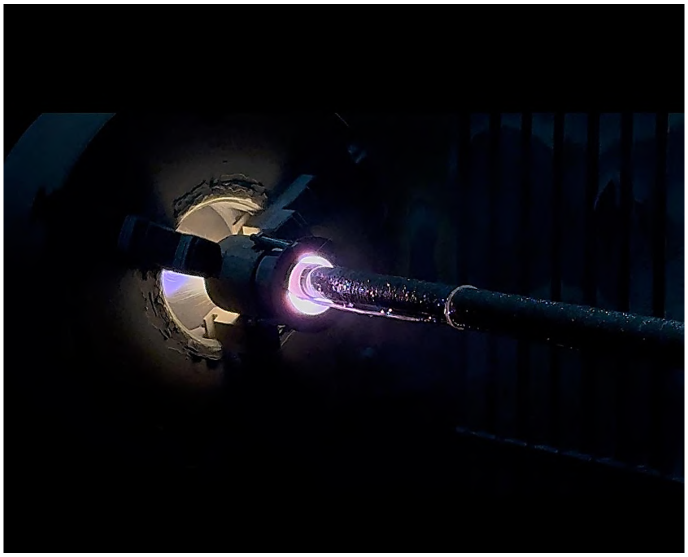

Figure 1: TBC Coating in progress Inside a 45 mm Internal Diameter (ID) by **PlasmaLite™**

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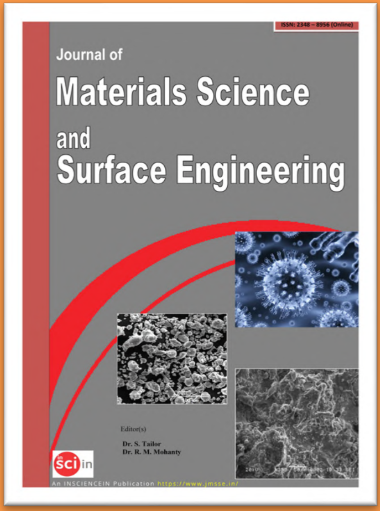

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