iTSA
The Indian Thermal Spray Association
ITSA ASSOCIATION FOR THERMAL SPRAY TECHNOLOGY AND RESEARCH

March 2026| Vol. 6| Issue 1

SPRAYTODAY®

An INSCIENCEIN publication | Affiliated to The Indian Thermal Spray Association®

Celebrating Women in Thermal Spray Technology

Issue Highlights

- Women Shaping the Future of Thermal Spray Technology
- Tungsten Carbide Price Escalation and the Urgent Need for Alternatives
- Expanding the Frontiers of High-Pressure Cold Spray Technology: Industrial Applications and Pure Aluminum Repair Performance

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SPRAYCOLD
(COLD SPRAY SYSTEM)

Introducing a metal deposition process that requires no blast cleaning and no oxy-fuel gases. It works solely with air, providing a coating with high bond strength and density. You can apply almost any metal powder, including brass, copper, nickel, aluminum, zinc, tin, bronze, lead, stainless steel, aluminum - silicon carbide, aluminum-copper- zinc, nickel-zinc, copper-tin-lead and many more.

MCS - 23

Cold spray gun with heater installed.

MSC - 500

(MEC cold spray system with trolley, massflow controlled & pressurized powder feeder and PLC controlled panel.)

Advantages

- Green, solid-state process: No combustion flame, fumes, phase change during deposition.
- Ideal for in-situ repair, restoration & AM part correction.
- Delivers high deposition efficiency with minimal thermal impact.
- Enables coating of Al, Mg, Ti, and other reactive

Application of Cold Spray

- Repair, restore & AM part correction.
- Repair bearing seats.
- Cavitiation corrosion protection
- Hermetically seal rediators and air conditioner.
- Add electrical conductive layers to materials.
- Additive manufacturing and many more.

Special Features:

- The detachable type control screen can be removed and positioned on another stand or exterior wall of the spray chamber if user wants to spray using robot/manipulator.
- Working Gas: Air or Nitrogen
- Single Phase Electrical Supply Requirement.
- Operating pressure Temperature: 10 bar at 50 °C

Maximum power consumption:- 3.3kW

Power supply:- Single Phase 220v, 50/60Hz

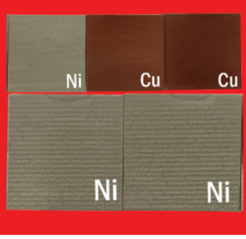
Powder consumption:- 10-20 gm/min
(compatible powder will be supplied by MEC)

Capacity of Powder Feeder:- 3350 CC (3.3 Liter)

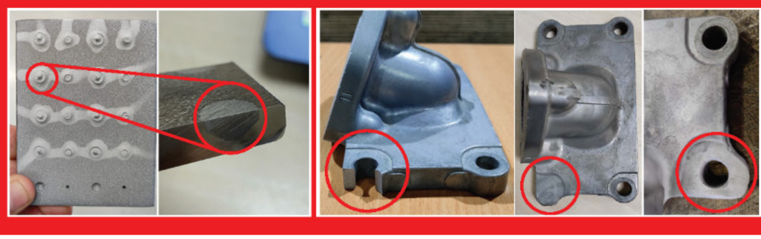
Dimensions and Weight of the System:-
Approx. 600(W) x 500(L) x 1400(H)
Approx. 110 kg

Compressed air consumption:- 0.3 - 0.4 m^3/min

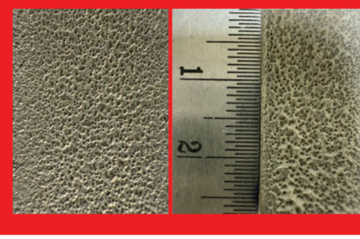
Ni and Cu coatings on CFRP sheet



Repair and Restore Part



Texture Driven Cold Sprayed Ni Coatings



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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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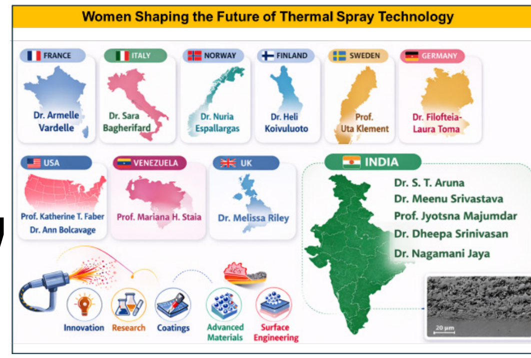

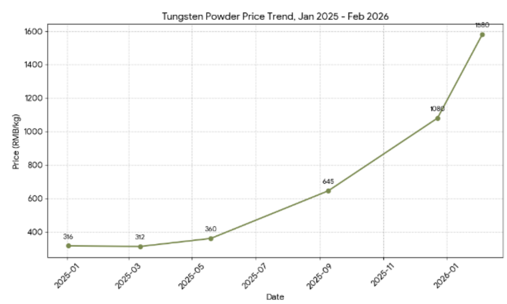

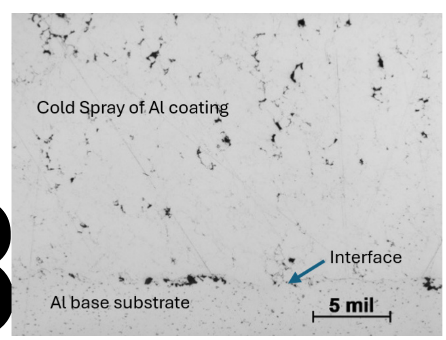

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ABOUT THE COVER

Women Shaping the Future of Thermal Spray Technology

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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 **"Women Shaping the Future of Thermal Spray Technology; Tungsten Carbide Price Escalation and the Urgent Need for Alternatives; and Expanding the Frontiers of High-Pressure Cold Spray Technology: Industrial Applications and Pure Aluminum Repair Performance",** that illustrate current research trends in thermal spray development.

We are excited to announce our upcoming event: **National Thermal Spray Conference and Expo (NTSC 2027), will be held in 2027.** The dates and the venue are to be decided soon! This conference will serve as a hub of innovation and collaboration for thermal spray technology. More than 400+delegates, including leading experts, researchers, and industry professionals from around the globe will attend the NTSC2027 to discuss cutting-edge developments, share insights, and explore the future of thermal 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 thermal spray technology.

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 Tailor | PhD)

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Women Shaping the Future of Thermal Spray Technology

By ***S.T. Aruna***
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HAL Airport Road, Kodihalli, Bangalore 560017.
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Abstract

Thermal spray technology has emerged as an important surface engineering tool for developing high-performance functional coatings for a plethora of applications in aerospace, biomedical, energy and industrial sectors. Among the different types of thermal spray techniques, atmospheric plasma spray, cold spray, and high-velocity oxy/air-fuel (HVOF/HVAF) have been most widely used by researchers worldwide. Many women scientists worldwide have contributed immensely to the advancements in thermal spray technology. In this mini review, an attempt is made to present the exemplary achievements of women researchers worldwide in the area of thermal spray science and engineering.

Introduction

Thermal spray has emerged as an important surface engineering technique for the modifications of surfaces [1-5]. The name thermal spray indicates the use of heat for spraying. There are several thermal spray techniques which are used for developing Thermal Barrier Coatings (TBCs), Environmental Barrier Coatings (EBCs), biomedical coatings, corrosion resistant coatings, wear resistant coatings, abrasion resistant coatings, etc. The advent of thermal spray dates to the early 1900s by Max Ulrich Schoop, a Swiss inventor. In 1909, he filed a patent for the use of a combustion process to melt wire and propel it onto surfaces. Later, he also filed a second patent in 1911 for employing electric arc as a heat source and it was named as wire arc spraying. In this process, the metal wires were melted using an electric arc and spraying the molten material onto substrates. Later different thermal spray techniques were developed and extensively used. The chronology of the various developments in thermal spray techniques is shown in Fig. 1. Figure 2 shows the different types of thermal spray techniques and their attributes. Among them, the important thermal spray techniques include flame spraying, plasma spraying, wire arc spraying, detonation D-gun spraying, cold spraying and high-velocity oxy/air fuel (HVOF/HVAF) spraying. Table 1 lists the major thermal spray techniques and their applications. Further, the plasma spraying has various variants like vacuum plasma, atmospheric plasma, solution precursor plasma spray (SPPS) and suspension plasma spray (SPS) techniques. There is a plethora of review articles dedicated to thermal spray techniques which cover the various aspects of different thermal spray techniques [6-9]. Hence in this mini review an attempt is made to highlight the significant contributions of women researchers.

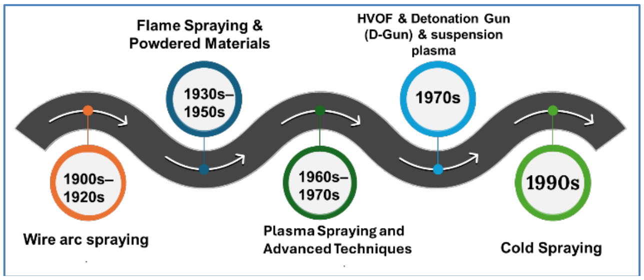

Figure 1: Chronology of evolution of thermal spray techniques

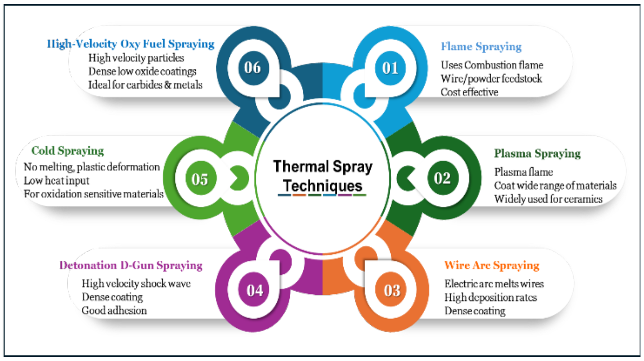

Figure 2: Different thermal spray techniques

Table 1: Popular thermal spray techniques and their applications

Technique	Applications		
Plasma Spray	Aerospace (Turbine Coatings)	Biomedical (Implant Coatings)	Energy SOFC
HVOF Spray	Oil& Gas (Wear Resistant Coatings)	Automotive (Engine Components)	Pulp & Paper (Roll Coatings)
Cold Spray	Defense (Component Repairs)	Electronics (EMI Shielding)	Space (Satellite Parts)
Flame Spray	Industrial (Corrosion Protection)	Marine (Ship Maintenance)	Infrastructure (Structural Coatings)

Leading Women researchers in thermal spray

Though thermal spray is a male dominated research domain, many women have made strides in the thermal spray arena by overcoming the challenging harsh working conditions of thermal spray processes (Fig. 3). A recent review article published in Surface and Coatings Technology highlights the tremendous contributions made by women researchers across the globe, the challenges and ways to bring more women into the thermal spray arena [10]. In this mini review the contributions made by women researchers across the globe are discussed in alphabetical order (Fig. 4).

Ann Bolcavage

Dr. Ann Bolcavage is a fellow of ASM and Engineering Fellow at Rolls-Royce Corporation. She has earned a place in the ASM Thermal Spray Society Hall of Fame. Her prolific contribution to thermal spray is evident from her 19 patents and over 20 technical publications. She also made pioneering contributions at Rolls-Royce. Her work spans MCrAlY bond coats and advanced ceramic TBCs and she has compared the properties of coatings obtained from APS, HVOF, diffusion aluminizing, and Electron Beam Physical Vapor Deposition processes [11].

Armelle Vardelle

Dr. Armelle Vardelle is one of the stalwarts in the area of thermal spray technology and at present she is a Distinguished Emeritus Professor at the University of Limoges, France, and is associated with the Institute of Ceramic Research (IRCER). She has made significant contributions to the area of APS, SPS and SPPS. She was the first woman to be inducted into the ASM Thermal Spray Society Hall of Fame in 2016. Her dedication to thermal spray growth is evident from taking the impact factor of the Journal of Thermal Spray Technology from 1.568 to 3.2 while serving as the Editor-in-Chief of the journal (2016 to 2023). Her impressive work has influenced the understanding and application of this versatile thermal spray technique for aerospace, energy and industrial sectors [12]. Her initial research was focused on the fundamental behaviour of particles in plasma spray processes, and she established the groundwork for coating microstructure prediction based on the plasma spray parameters and the in-flight particle behaviour. She has worked a lot on plasma torch dynamics, particle injection control, arc instabilities, etc. She has used SPS and SPPS extensively for developing finer functionally graded coatings. She has shaped the thermal spray arena life cycle assessment of thermal spray processes and is responsible for preparing the roadmap for thermal spray.

S T Aruna

Dr. S.T. Aruna, working as a Chief Scientist at CSIR-National Aerospace Laboratories, India has made pioneering contributions to the synthesis of thermal spray grade oxide feedstock materials using solution combustion and co-precipitation methods directly by avoiding the steps of spray drying [13]. She is the recipient of the first Indian Thermal Spray Excellence award. The developed powders have been used for developing TBCs, biomedical coatings, photocatalytic coatings and electrodes of SOFC application. She has developed single layer and multi-layered TBCs using conventional YSZ/cluster paired YSZ and $La_2Ce_2O_7$/$Gd_2Zr_2O_7$/$La_2Zr_2O_7$, etc over the YSZ layers. The coatings have shown lower thermal conductivity, better CMAS resistance and hot-corrosion properties. Further, she has developed plasma sprayed, SPS and SPPS based hydroxyapatite, titania and spinel coatings. She has also developed multi-layered ytterbium silicate based EBCs on ceramic matrix composite (CMC).

Dheepa Srinivasan

Dr. Dheepa Srinivasan has rich experience working in industry and academia. She served as a practicing Engineer at General Electric, Bangalore, Chief Technology Officer at INTECH DMLS, Chief Engineer, at Pratt and Whitney, United Technology Corporation India Private Limited, Indian Institute of Science. She also worked as R & D dean at Ramaiah University of Applied Sciences, Bangalore and currently she is placed at Baker Hughes. She has developed numerous technologies, and more than 50 technologies/process applications are currently running in several gas turbines. She has made outstanding contributions in new technology areas such

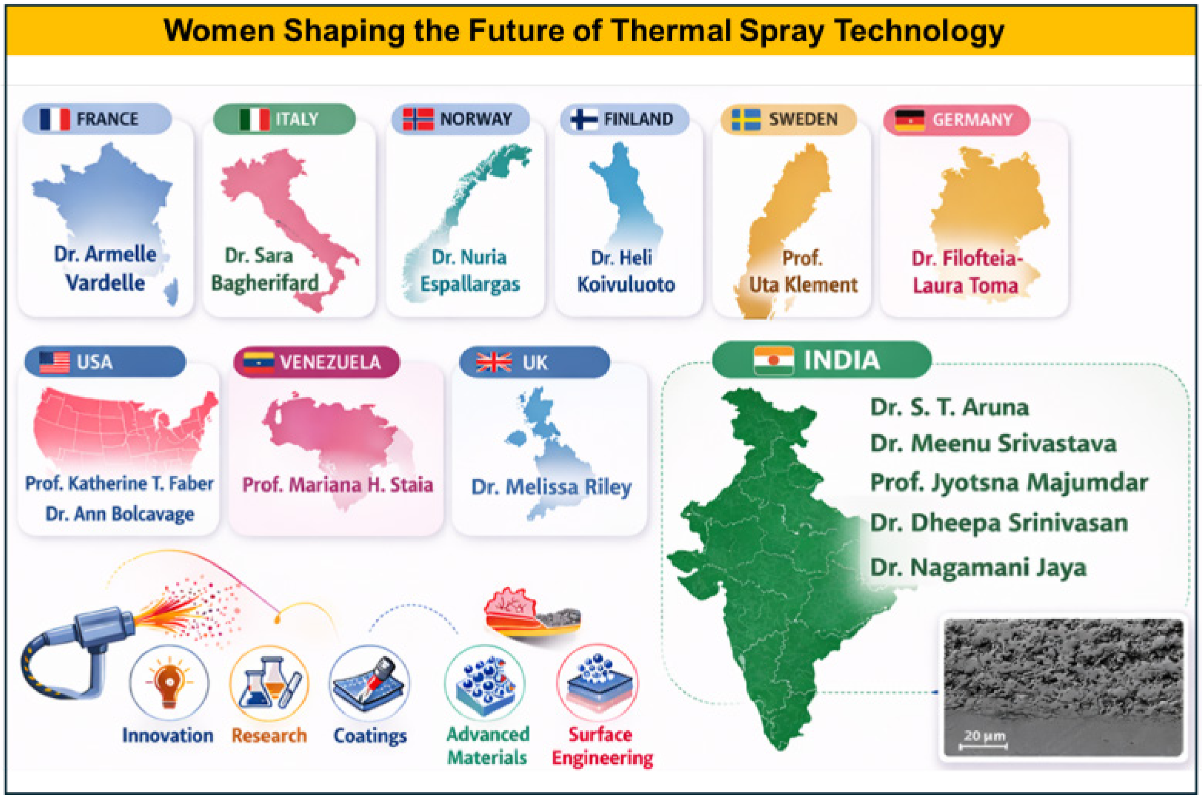

Figure 3: Schematic showing women thermal spray innovators across the globe

Figure 4: Collage of women thermal spray innovators across the globe

as Advanced Thermal Spray and Cold Spray Coatings and Turbine Component Lifing and has over 34 patents to her credit [14].

Filofteia-Laura Toma
Dr. Filofteia-Laura Toma is a Senior Research Scientist at the Fraunhofer Institute for Material and Beam Technology (IWS), Dresden, where she leads the development of advanced thermal spray coating technologies for aerospace, energy, and mechanical engineering applications [15]. She has investigated the microstructure and photocatalytic performance of titania coatings produced by atmospheric plasma spray (APS), SPS, and HVOF techniques. Her studies demonstrated superior performance of SPS-derived TiO_2 coatings in reducing gaseous pollutants such as NOx. She has served as an editor for Journal of Thermal Spray Technology.

Heli Koivuluoto
Dr. Heli Koivuluoto is an Associate Professor and Group Leader of the Coating Technologies Research Group at Tampere University, Finland. She has made inspiring contributions to cold spray, plasma spray and icephobic polymer coatings [16]. Her studies have shown superior corrosion behavior for cold-sprayed tantalum (Ta) coatings when compared to plasma-sprayed Ta coatings. She has also studied the tribological performance of HVOF and HVAF hard metal coatings and thermally sprayed polymer coatings, anti-icing and anti-fouling surfaces. She has developed polymer and ceramic coatings exhibiting anti-icing properties using the economical flame-spray method.

Jyotsna Dutta Majumdar
Professor Jyotsna Dutta Majumdar from Indian Institute of Technology Kharagpur, India has made remarkable contributions in thermal spray coatings and combined it with laser processing. The hybrid coatings have exhibited enhanced functional properties. Her work spans from TBCs for aerospace applications to wear resistant coatings for engineering surfaces to biomedical implants [17].

Katherine T. Faber
Prof. Katherine T. Faber is Simon Ramo Professor of Materials Science at Caltech and her contributions to the area of ceramics, fracture mechanics, and EBCs are exemplary [18]. Prof. Faber made significant contributions to thermal spray science, particularly in the development and optimization of TBCs and EBC systems for high-temperature applications. Her research established important relationships between deposition parameters, heat treatment protocols, and coating performance. She has used design of experiments to optimize the density and strength of plasma-sprayed alumina coatings. She has extensively used advanced diagnostics and 3D plasma-jet modeling. She has also made seminal contributions to the durability of high-temperature EBCs including barium-strontium aluminosilicate coatings.

Mariana H. Staia
Dr. Mariana H. Staia is a distinguished professor at the Universidad Central de Venezuela, known for her seminal work on thermal spray coatings, tribology, and surface engineering [19]. She has made pioneering contributions to HVOF sprayed WC-Co and WC-CoCr cermet coatings, vacuum plasma sprayed Cr3C2-NiCr coatings, residual stresses and adhesion of thermal sprayed coatings, hybrid PVD/HVOF coatings and sealing treatments for plasma-sprayed ceramic coating. The durability, wear resistance and corrosion resistance of the thermal sprayed coatings have been evaluated. Prof. Staia has played a key role in advancing thermal spray science in Latin America.

Meenu Srivastava
Dr. Meenu Srivastava, Chief Scientist, CSIR-NAL has led important studies on HVOF-based cermet and high-entropy alloy coatings, investigating their microstructural evolution, mechanical properties, and erosion–wear performance [20]. In addition, Dr. Srivastava has worked on low-pressure cold spray techniques to produce dense corrosion-resistant coatings on lightweight aluminum and magnesium alloys, including repair and dimensional restoration of aerospace components. She has also developed hybrid metal coatings on carbon-fiber-reinforced polymers for high-efficiency solar reflector applications.

Melissa Riley
Dr. Melissa Riley, Consultant in Surface Engineering at The Welding Institute (TWI), UK, is known for her pioneering contributions to thermal spray process development and industrial scale-up. Her work spans thermal-sprayed metallic coatings on CFRP aircraft components for lightning strike protection and HVOF based SiC coatings [21].

Nuria Espallargas
Dr. Nuria Espallargas is a Professor at the Norwegian University of Science and Technology (NTNU) and Chief Technology Officer of Seram Coatings. She has played a

key role in translating laboratory research into industrial technologies. Prof. Espallargas is internationally recognized for her pioneering contributions to thermal spray coatings, particularly for enabling the spray deposition of non-melting ceramics such as silicon carbide (SiC) [22]. Her research includes the development of $Y_3Al_5O_{12}$-modified SiC coatings using hybrid High-Frequency Pulse Detonation (HFPD) and SPS. She has also contributed to the advancement of HVOF-sprayed carbide coatings as hard chrome replacement coatings and thermally sprayed self-lubricating thermal spray coatings using oil-filled capsules within a metal matrix.

Sara Bagherifard

Dr. Sara Bagherifard is an Associate Professor in Mechanical Engineering at Politecnico di Milano, recognized for her pioneering work in solid-state deposition technologies, particularly cold spray coatings and hybrid additive manufacturing methods for structural and functional materials [23]. Her research has significantly advanced the understanding and application of cold spray technology, including the development of coatings based on high-entropy alloys, where she investigated their microstructure, wear, corrosion, and oxidation resistance along with post-treatment effects. Dr. Bagherifard has combined experimental studies with finite element modeling to analyze surface metallization of polymer substrates using cold spray. She has also explored the role of shot peening as a pre- and post-treatment for cold-sprayed aluminum coatings and additive manufacturing of challenging alloys such as Inconel 718 and stainless steel 316L using cold spray.

Uta Klement

Prof. Uta Klement is a Full Professor and Head of the Division of Materials and Manufacture at Chalmers University of Technology, Sweden. In collaboration with several research groups, she has extensively investigated suspension plasma spraying (SPS), conventional plasma spraying, and HVAF techniques to engineer coatings for wear, erosion, and thermal protection [24]. Her work has significantly advanced liquid and suspension feedstock approaches for thermal spraying. She has used axial SPS and liquid-feed HVAF/HVOF processes for developing fine ceramics and nanoscale additives. She has provided important insights into coating porosity and three-dimensional microstructure using advanced characterization techniques such as X-ray microscopy and NMR cryoporometry.

Conclusions

Thermal spray is an important surface engineering tool and globally many researchers have made greater strides on the fundamentals and applications of the various thermal spray techniques. Despite the challenges faced by women in the thermal spray R & D arena, many women have made remarkable contributions. This review has provided the amazing work carried out by women researchers globally in a nutshell.

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Tungsten Carbide Price Escalation and the Urgent Need for Alternatives

by ***Satish Tailor***

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Tungsten carbide (WC-Co) powders are critical to wear-resistant applications across thermal spray, cutting tools, mining, and aerospace sectors. Over the period 2024–2026, the global market has experienced an unprecedented surge in WC powder prices, exceeding 200% in some regions. This paper analyzes price trends, underlying causes including supply concentration, raw material inflation, and geopolitical constraints, and evaluates the industrial impact. It further discusses viable alternatives and proposes a roadmap for reducing dependency on tungsten-based systems. The study highlights that the current scenario is structural rather than cyclical, necessitating immediate material innovation and strategic adaptation.

Tungsten carbide (WC), particularly in cobalt-bonded form (WC-Co), is widely used due to its exceptional hardness, wear resistance, and thermal stability. It is a cornerstone material in thermal spray coatings (especially HVOF), cutting tools, and mining applications [1,2].

However, recent years have seen drastic price escalation driven by supply chain disruptions, geopolitical factors, and rising demand [3,4]. This trend poses a significant challenge to industries relying on WC-based materials.

Market Overview

Tungsten Carbide Powder Market was valued at USD 18,338.09 million in the year 2025. The size of this market is expected to increase to USD 25,632.00 million by the year 2032, while growing at a Compounded Annual Growth Rate (CAGR) of 4.9%. WC-Co compositions account for nearly 65–70% of total consumption, highlighting their industrial dominance [1].

Tungsten Carbide Powder Market is rapidly expanding due to its remarkable hardness, toughness, and resistance to wear. This material is indispensable in producing cutting tools, abrasives, and heavy-duty industrial components. The toolmaking sector alone accounts for nearly 45% of demand, underscoring its critical role in machining and drilling applications.

Expanding Use Across Industries

A broad range of sectors, including mining, oil & gas, and electronics, increasingly rely on tungsten carbide powder. Its durability and heat resistance make it ideal for harsh operational environments. With over 30% adoption in mining applications, it significantly boosts productivity while extending the lifespan of equipment.

Advances in Coatings

The integration of tungsten carbide powder in thermal spray and protective coatings is accelerating. These coatings deliver more than 40% improvement in wear resistance, making them especially valuable for aerospace and automotive industries. The focus on longer service life and lower maintenance costs is driving this segment upward.

Electronics and Medical Growth

Precision and miniaturization needs in electronics and medical devices are fueling fresh demand. Roughly 15% of consumption now comes from these sectors, where tungsten carbide powder ensures high precision and unmatched durability. This emerging usage is reinforcing the market's role in technology-oriented applications.

Sustainability and Recycling

Sustainability is shaping the market as recycling practices gain traction. Nearly 25% of supply originates

Tungsten Carbide Powder Market

*Market size in USD million

CAGR 4.9 %

Study Period	2026 - 2032
Base Year	2025
CAGR (%)	4.9 %
Market Size (2025)	USD 18,338.09 Million
Market Size (2032)	USD 25,632.00 Million
Market Concentration	High

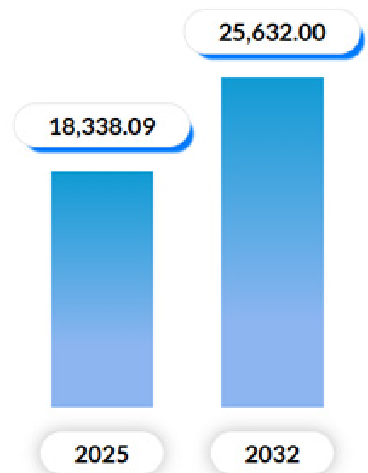

Figure 1: Global Tungsten Carbide Market Growth (2026–2032) [1]

from recycled tungsten carbide, lowering both production costs and environmental impact. This sustainable approach is enhancing resource efficiency and securing consistent supply for future industrial growth.

Tungsten Carbide Powder Market, Segmentation by Geography

In this section, Tungsten Carbide Powder Market has been segmented by Geography into five regions: North America, Europe, Asia Pacific, Middle East and Africa and Latin America.

North America

North America holds a substantial share of the global market due to the presence of advanced manufacturing and aerospace industries. The U.S. leads regional growth with investments in defense materials and precision tooling. Sustainable mining initiatives and recycling programs for tungsten are also strengthening the regional supply chain.

Europe

Europe demonstrates stable growth driven by its strong automotive, aerospace, and engineering sectors. Germany, the U.K., and France are key producers and consumers of tungsten carbide powders. The focus on circular economy principles and eco-efficient manufacturing continues to influence market trends in the region.

Asia Pacific

Asia Pacific dominates the global market, accounting for over 55% of production and consumption. China and India are major producers, supported by abundant raw materials and large-scale manufacturing capabilities. Rapid industrialization, infrastructure projects, and demand for durable tooling solutions drive continuous growth across the region.

Middle East and Africa

Middle East and Africa are emerging regions with increasing adoption of tungsten carbide powders in oil drilling, mining, and construction equipment. Expanding energy exploration projects and the development of regional manufacturing hubs are key drivers supporting market growth.

Latin America

Latin America is showing gradual expansion with rising investment in mining, automotive manufacturing, and industrial machining. Brazil and Mexico are leading consumers, benefiting from infrastructure development and the localization of tool production. Growing collaboration with global suppliers is fostering long-term market potential.

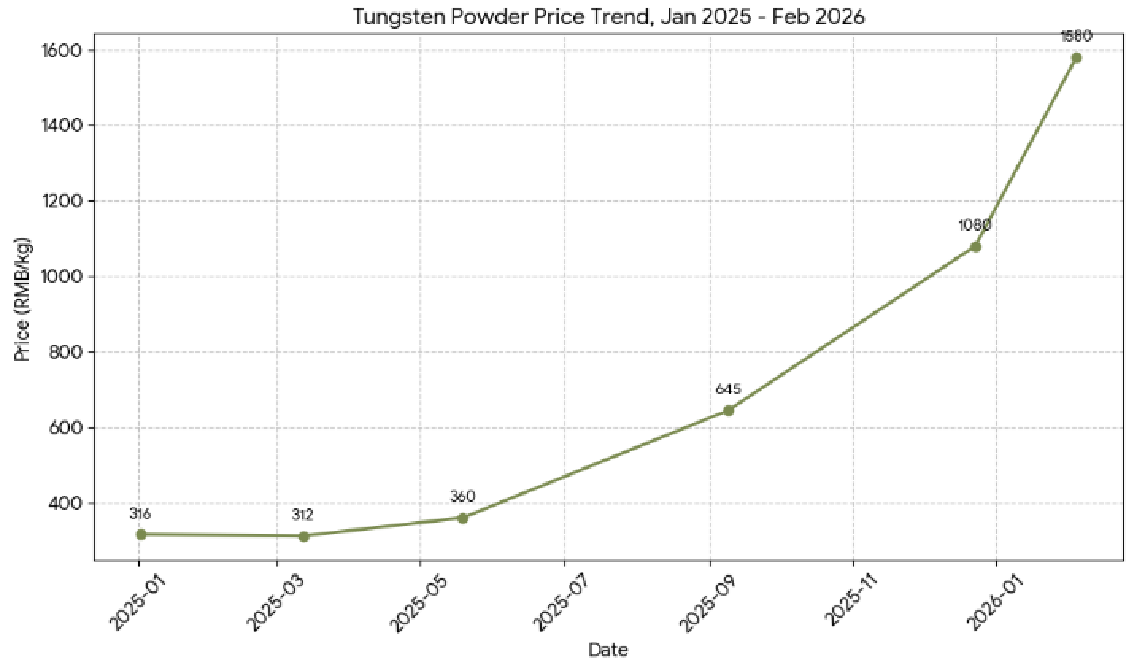

Figure 2: Tungsten Carbide Powder Price Trend (2025–2026)

Price Trends and Analysis

The tungsten carbide market has exhibited significant volatility in recent years, with sharp price increases driven by both supply-side and demand-side factors [3,5].

Historical Price Trends

The pricing trajectory of tungsten carbide powder over the period 2024–2026 shows an unprecedented escalation. In early 2024, WC powder prices were approximately ~47 USD/kg, which increased sharply to the range of ~110–150 USD/kg in 2025, and further surged to as high as 170–270 USD/kg in 2026 depending on region and grade [3,5]. This represents an overall increase exceeding 200% within a span of less than two years. Such a steep rise is highly unusual for a mature engineering material and indicates structural disruptions in supply-demand balance rather than short-term market fluctuations. The rapid price acceleration has created significant uncertainty for industries dependent on WC–Co systems.

Regional Variations

Significant regional disparities in tungsten carbide pricing have emerged due to differences in resource availability, import dependency, and processing infrastructure [5]. China, being the dominant producer, traditionally maintained lower baseline prices; however, recent export controls and domestic demand have led to sharp increases [4]. India, heavily reliant on imports, has experienced even higher price levels due to logistics costs, currency fluctuations, and supply constraints. In contrast, the USA and Europe face compounded challenges due to higher energy costs and stricter environmental regulations, which further elevate processing expenses. These regional variations highlight the vulnerability of global supply chains and the need for localized material strategies.

Root Causes of Price Escalation

Supply Concentration

The global tungsten supply chain is highly concentrated, with China accounting for over 65–70% of total production [4,6]. This dominance gives significant control over pricing and export policies. Recent measures such as export restrictions, environmental regulations, and mining quotas have limited the availability of tungsten in international markets [4]. As a result, downstream industries have faced supply shortages and increased procurement risks. The concentration of supply in a single geographical region makes tungsten a strategic material and exposes industries to geopolitical uncertainties.

Raw Material Inflation

The cost of tungsten carbide is directly influenced by upstream raw materials such as ammonium paratungstate (APT) and tungsten metal powder. Over the past two years, these inputs have experienced price increases in the range of ~90–100%, driven by mining constraints, environmental compliance costs, and increased global demand [6,8]. Since WC production involves multiple energy-intensive and material-dependent steps, any fluctuation in raw material pricing has a magnified impact on final powder cost. This inflationary trend has significantly contributed to the overall rise in WC-Co prices.

Cobalt Price Volatility

Cobalt, which serves as the primary binder in WC–Co systems, has also exhibited significant price volatility. Prices have increased by over 130%, largely due to growing demand from electric vehicle (EV) batteries and limited supply concentrated in politically sensitive regions such as the Democratic Republic of Congo [7]. The dual dependency on tungsten and cobalt creates a compounded risk for WC–Co systems, as fluctuations in either material directly impact overall cost. This volatility has accelerated the search for cobalt-free or reduced-cobalt alternatives.

Energy Costs

The production of tungsten carbide involves energy-intensive processes such as carburization, milling, and sintering at high temperatures. Rising global energy prices, particularly in Europe, have significantly increased the cost of manufacturing WC powders [5]. Additionally, stricter environmental regulations have led to higher compliance costs, further adding to production expenses. These factors collectively contribute to the overall price escalation and reduce the competitiveness of WC-based materials in cost-sensitive applications.

Demand Growth

The demand for tungsten carbide has increased substantially across multiple industries, including aerospace, defense, mining, oil and gas, and renewable energy sectors [2,5]. The expansion of these industries, coupled with the superior performance characteristics of WC–Co materials, has led to sustained high demand. However, supply has not kept pace with this growth, resulting in demand-driven price inflation. This imbalance between supply and demand is a key factor behind the current pricing crisis.

Impact on Thermal Spray Industry

Cost Implications

In thermal spray applications, WC–Co powders constitute a significant portion of the overall coating cost. With the sharp increase in powder prices, the cost of coating processes such as HVOF has risen substantially [3]. This has impacted on profitability for service providers and increased costs for end-users. In many cases, the material cost now dominates the total coating cost, making it imperative to explore cost optimization strategies or alternative materials.

Supply Chain Risks

The volatility in tungsten carbide pricing has introduced considerable uncertainty in supply chains [4]. Industries are experiencing longer lead times due to limited availability, while fluctuating prices make it difficult to establish stable procurement contracts. Inventory management has become more challenging, as holding large stocks carries financial risk, while insufficient inventory can disrupt operations. These risks necessitate a more resilient and diversified supply chain approach.

Industrial Response

Industries have begun to respond proactively to the challenges posed by rising WC prices. One common approach is reducing the tungsten carbide content in coatings without significantly compromising performance. Additionally, there is a growing emphasis on developing and adopting alternative materials such as chromium carbide and iron-based alloys [2]. Recycling of carbide scraps is also gaining importance as a means to recover valuable materials and reduce dependency on primary sources.

Alternatives to Tungsten Carbide

Chromium Carbide (Cr3C2-NiCr)

Chromium carbide-based coatings, particularly Cr3C2–NiCr, are widely considered as viable alternatives to WC–Co systems, especially in high-temperature applications. These coatings offer excellent oxidation and corrosion resistance and are well-suited for boiler components, gas turbines, and industrial heating systems. Although their hardness is lower than WC, their superior performance at elevated temperatures make them an attractive substitute in specific environments.

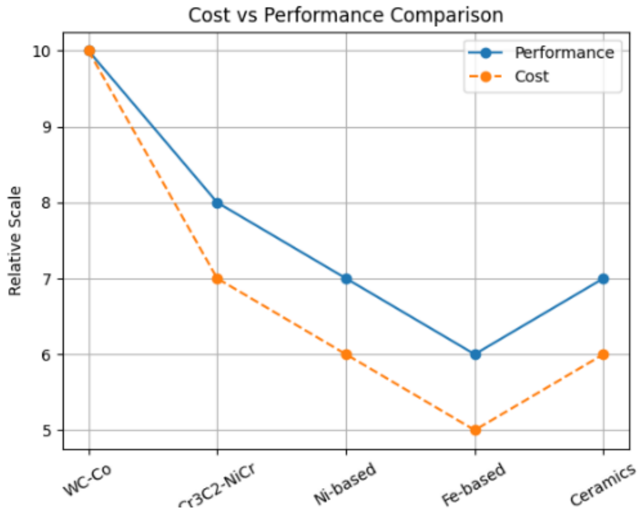

Figure 3: Performance vs Cost Comparison of WC Alternatives

WC-CoCr + SiC

WC-CoCr + SiC hybrid coating, engineered to maintain the performance of traditional carbide systems while addressing their key limitations [9].

From a performance standpoint:

- Hardness: 1250–1450 HV (consistent with high-performance WC coatings)
- Wear resistance: Comparable or improved (ASTM G65 comparative testing)
- Porosity & bond strength: Fully aligned with dense HVOF WC-CoCr coatings

By integrating silicon carbide (SiC) within the coating structure, it achieves: Reduced brittle fracture behaviour; Improved resistance to crack propagation; Enhanced performance in high-silica and aggressive abrasion environments. This is particularly relevant in sectors like mining and slurry handling, where traditional carbide coatings can suffer from micro-fracture and particle pull-out. Due to its lower apparent density, it delivers: Higher coating volume per kilogram; Reduced powder consumption per component; Lower cost per coated part. At the same time, Reduced tungsten content = less exposure to price volatility; More stable supply chain = greater predictability in operations.

Immediate Impact for End Users- For high-usage operations, this translates directly into: Lower coating costs; Extended component life (application dependent); Reduced maintenance frequency; Improved operational efficiency.

Iron-Based Alloys

Iron-based alloys, including FeCrAl and amorphous coatings, present a cost-effective alternative to tungsten carbide. These materials offer good wear and corrosion resistance and are significantly less expensive due to the abundance of iron. Advances in alloy design and processing techniques have improved their performance, making them suitable for a wider range of industrial applications.

Nickel-Based Alloys

Nickel-based alloys such as NiCrBSi are widely used in thermal spray applications due to their balanced combination of wear resistance, corrosion resistance, and toughness. While they may not match the hardness of WC-Co systems, their versatility and relatively lower cost make them suitable for many engineering applications where extreme wear resistance is not the primary requirement.

Ceramic Materials

Ceramic coatings such as $Al2O3–TiO2$ and $ZrO2$-based systems offer excellent thermal stability, oxidation resistance, and hardness. These materials are particularly suitable for applications involving high temperatures and corrosive environments. However, their brittleness and lower toughness compared to metallic systems limit their use in impact or fatigue-prone applications.

TiC-based Coatings (Critical Raw Material Free)

TiC-NiCr: These coatings are designed as completely free of Co, Cr, and W. They are especially suitable to replace WC-CoCr against wear and corrosion at room temperature.

Performance: TiC–40NiCr coatings exhibit hardness of 800–900 HV0.3, with superior corrosion resistance in acidic solutions (like 3.5% NaCl) compared to standard WC-CoCr. They also perform better than WC-CoCr at elevated temperatures (400°C) as they do not suffer from the same level of macro-cracking.

Advanced Materials

Emerging material systems such as high entropy alloys (HEAs), nano-structured coatings, and hybrid composites represent the future of wear-resistant coatings. These materials are designed to offer superior mechanical and thermal properties while reducing dependency on critical elements like tungsten and cobalt. Although still under development and limited in industrial adoption, they hold significant promises for next-generation applications.

Strategic Roadmap

Short-Term

In the short term, industries must focus on optimizing the use of tungsten carbide by reducing wastage and improving process efficiency. The development of blended powders, combining WC with alternative carbides, can help reduce overall material costs while maintaining acceptable performance levels. Immediate action should also include better inventory management and supplier diversification.

Medium-Term

Over the medium term, efforts should be directed toward the qualification and standardization of alternative materials for critical applications. This involves rigorous testing, certification, and collaboration between industry and research institutions. Additionally, developing localized supply chains can reduce dependency on imports and enhance supply security.

Long-Term

In the long term, sustained investment in research and development is essential to create WC-free coating systems with comparable or superior performance. This includes exploring novel material systems, advanced processing technologies, and digital tools such as AI for coating optimization. Establishing indigenous resources and recycling infrastructure will also play a crucial role in ensuring long-term sustainability.

Conclusions

The price surge is not temporary but reflects structural issues including resource concentration and growing demand. Industries must adapt through innovation, diversification, and strategic material substitution to remain competitive in the evolving global landscape.

Tungsten carbide price escalation has created a critical challenge across industries. With prices rising over 200% in two years and supply risks increasing, dependence on WC-Co systems are no longer sustainable [3,5].

The development and adoption of alternative materials is therefore the need of the hour.

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- Thermal Spray Zinc (TSZ)
- Twin Wire Arc Spray
- Wire Flame Spray
- Powder Flame Spray
- High Velocity Oxy-Fuel (HVOF)
- Plasma Spray
- Cold Spray

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Expanding the Frontiers of High-Pressure Cold Spray Technology: Industrial Applications and Pure Aluminum Repair Performance

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High-Pressure Cold Spray (HPCS) has emerged as a robust solid-state deposition technology capable of producing dense, low-porosity coatings with minimal thermal impact. Unlike conventional thermal spray processes, HPCS relies on supersonic particle impact rather than melting, thereby preserving substrate integrity and introducing beneficial compressive residual stresses. This article presents an overview of HPCS applications across aerospace, defense, automotive, and energy sectors, with a focus on repair and surface restoration. A case study on HPCS of pure aluminum for potential repair of industrial gas turbine fan components and housing demonstrates bond strength in the range of 4–6 KSI (ASTM C633-13) and compressive residual stresses measured via hole-drilling (ASTM E837-13a). Optical microstructural analysis confirms dense and uniform particle deposition. The results highlight the capability of HPCS as a reliable and scalable solution for high-value component repair.

Introduction

The increasing demand for high-performance materials and sustainable repair solutions has driven industries to explore alternatives to conventional thermal processes. Traditional methods such as welding and thermal spray often introduce heat-affected zones (HAZ), oxidation, and tensile residual stresses, limiting their applicability in critical components [1].

High-Pressure Cold Spray (HPCS), originally derived from cold spray technology in the 1980s and later industrialized in North America [2], is a solid-state coating and material deposition process in which metallic powders are accelerated to supersonic velocities and bonded to a substrate through plastic deformation. The absence of melting distinguishes HPCS from conventional thermal spray techniques, enabling coatings with minimal oxidation, low porosity, and preserved substrate properties [1–5].

Principle of High-Pressure Cold Spray (HPCS)

High Pressure Cold Spray (HPCS) utilizes compressed gases such as nitrogen or helium at pressures typically ranging from 20 to 50 bar, enabling particle velocities in the range of 800–1200 m/s. Upon impact, particles undergo severe plastic deformation and bond via adiabatic shear instability without melting [1, 3, 9, 10].

- Key Process Parameters:
- Gas type, pressure, and temperature
- Particle size and morphology
- Substrate condition and hardness
- Stand-off distance and spray angle

The high kinetic energy achieved in HPCS is critical for producing dense coatings with strong adhesion.

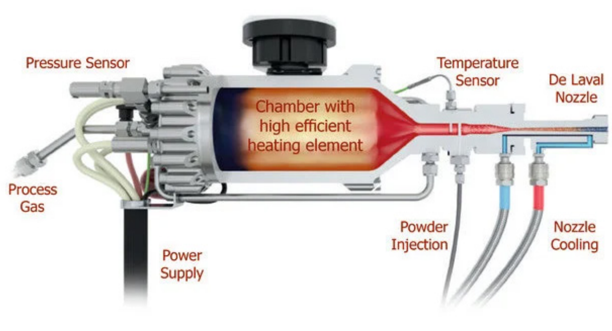


Figure 1: Schematic of High-Pressure Cold Spray Process (Source: Impact Innovations GmbH)

High-pressure gas accelerates powder particles through a De Laval nozzle, impacting the substrate at supersonic velocity and forming a bond via severe plastic deformation.

Comparative Advantage Over Conventional Techniques

Table 1: Comparison of HPCS with conventional processes

Parameter	HPCS (High Pressure Cold Spray)	Thermal Spray	Welding
Process Temperature	Low (solid-state)	High	Very High
Gas Pressure	High (20-50 bar)	Low	Not Applicable
Oxidation	Minimal	Moderate to High	High
Residual Stresses	Compressive	Tensile	High
Phase Transformation	Negligible	Significant	Significant
Property Retention	Excellent	Moderate	Limited
Distortion	Minimal	Moderate	High

Industrial Applications of High-Pressure Cold Spray (HPCS)

Aerospace and Defense

HPCS is widely adopted for structural repair and corrosion protection of aluminum and magnesium components. Applications: Turbine parts & housing, Gearbox housing restoration, Landing gear coating, In-field repair of military assets

HPCS enables restoration of high-value components with minimal thermal distortion, making it ideal for aerospace-grade materials [4 – 7].

Automotive and Electronics

The higher deposition efficiency of HPCS allows consistent coating quality required in production environments. Applications: Restoration of shaft and bearing surfaces, conductive coatings for EV connectors, wear-resistance surface enhancement etc.

Nuclear and Energy Sector

HPCS is particularly advantageous where thermal exposure must be strictly controlled. Applications: Repair of critical infrastructure components, Corrosion-resistant coatings in harsh environments, Life extension of safety-critical systems [3, 6].

Process Challenges and Opportunities

Challenges: High operational cost (helium usage) [3], Equipment complexity, Process parameter sensitivity

Opportunities: Nitrogen-based optimization, Advanced nozzle design, Integration with automated systems

Case Study: High-Pressure Cold Spray of Pure Aluminum

Materials & Methods

A controlled experimental study was conducted to evaluate HPCS of pure aluminum for repair of gas turbine fan components and housings. Aluminum alloy-based substrates, with dimensions 3"×4"×0.5" thick, were used to replicate real service conditions. Pure aluminum powder with a standard particle size distribution was used. Substrates were prepared through degreasing, grit blasting, and air cleaning. Coating deposition was performed using a 5/11-gun high-pressure cold spray system/equipment at Hannecard Roller Coating Inc., USA [10].

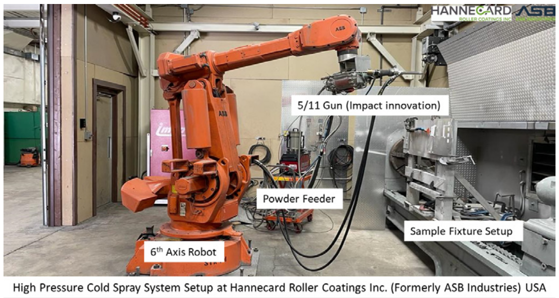
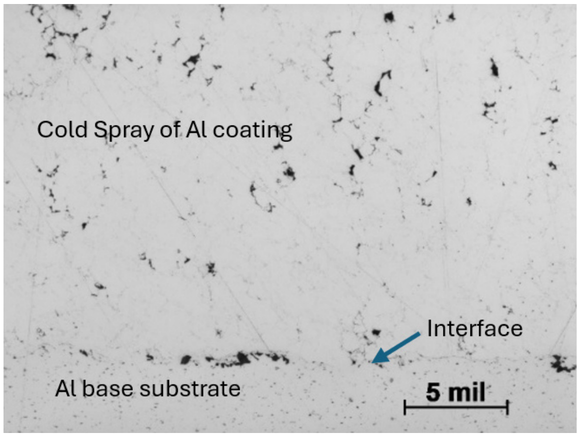


Figure 2: High-pressure cold spray system used for pure aluminum deposition at HRC USA.

Deposition was carried out using nitrogen gas (>20 bar, >300 °C) with controlled stand-off distance and multiple passes to achieve uniform coating thickness up to 0.06" (~1.5mm). Post-deposition, samples were prepared using standard metallographic techniques.

Microstructural Analysis

Optical microscopy shows dense, uniform coating structure with minimal porosity and strong interparticle bonding, characteristic of HPCS deposition (Figure 3)



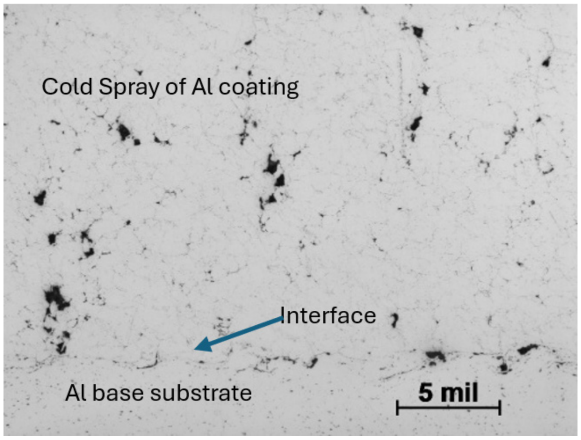


Figure 3: Optical microstructure of HPCS pure aluminum coating (Scale: 5 mil / 127 µm).

Mechanical Bond Strength

Bond strength testing was conducted per ASTM C633-13 using FM-100 adhesive. Results show 4–6 KSI, meeting or exceeding thermal spray benchmarks.

Table 2: Bond Strength Results (HPCS Pure Aluminum)

Parameter	Value
Process	HPCS
Material	Pure Aluminum
Bond Strength	4–6 KSI
Requirement (Thermal Spray)	≥4 KSI
Standard	ASTM C633-13

Residual Stress Measurements

Residual stress measurements were performed using the hole-drilling strain gauge method (ASTM E837-13a) under four test conditions as shown in Table 3. All measurements showed negative values, indicating compressive stress, which are beneficial for fatigue performance and structural integrity.

Table 3: Residual Stress Results (KSI) [Negative values indicate compressive residual stress]

Condition	Longitudinal	Transverse
As-Sprayed	-3.5	-4.4
Aged	-3.8	-3.2

Discussion

The results demonstrate that HPCS of pure aluminum produces coatings with strong mechanical bonding, dense microstructure, and beneficial compressive stresses. Compared to conventional thermal spray, HPCS offers improved substrate integrity and comparable or superior adhesion performance.

Conclusions

HPCS has emerged as a powerful industrial technology for repair and surface engineering. This study demonstrates:

- Bond strength meets/exceeds industry standards
- Compressive residual stress beneficial for performance
- Dense and uniform coating microstructure

These findings support the adoption of High-Pressure Cold Spray (HPCS) for industrial fan parts, component and housing repair applications.

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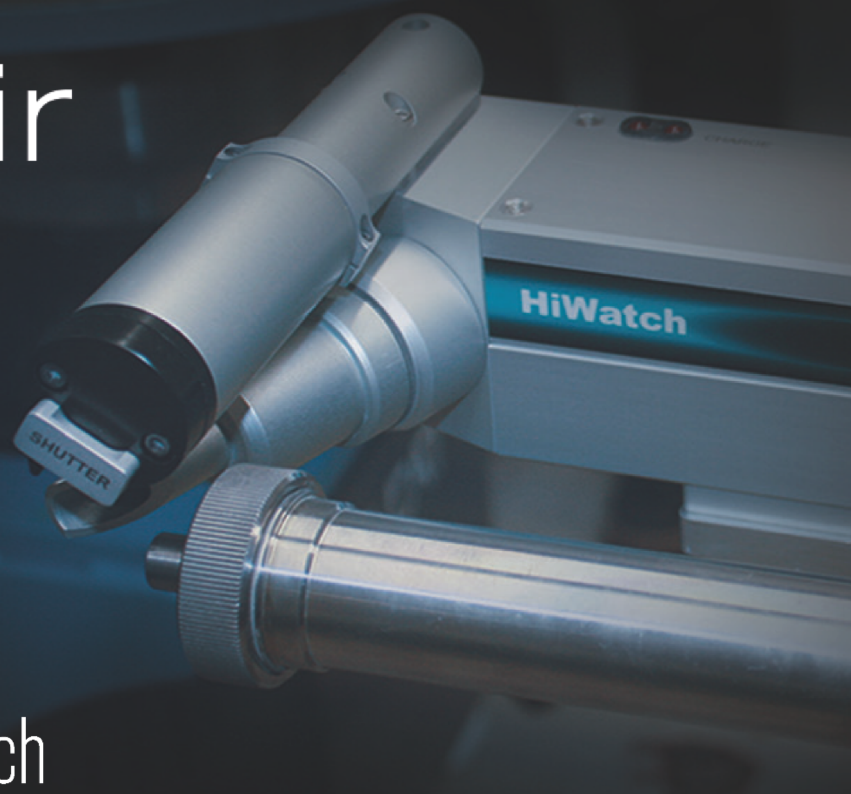

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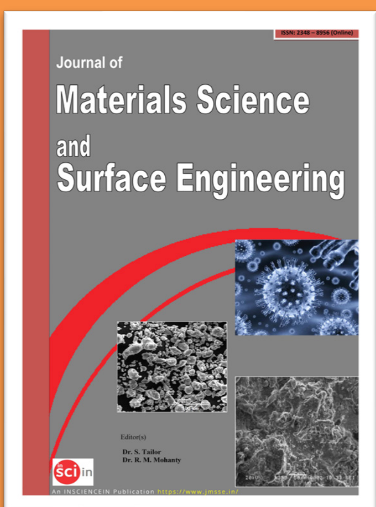

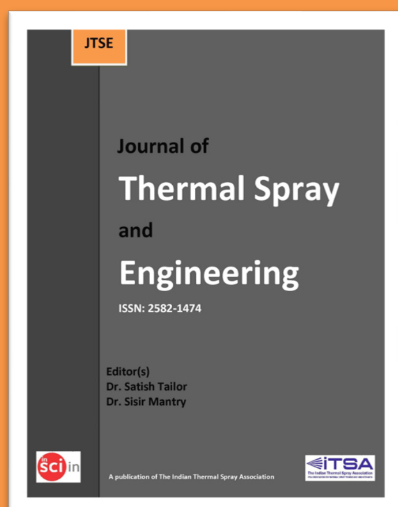

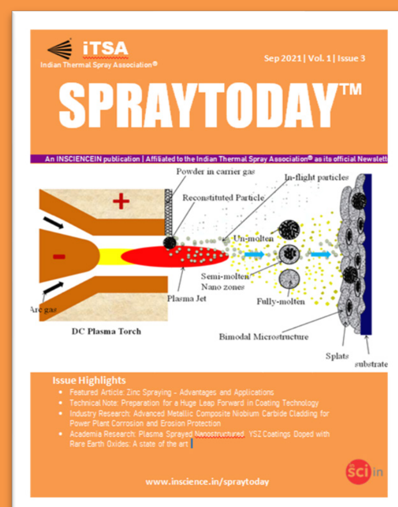

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