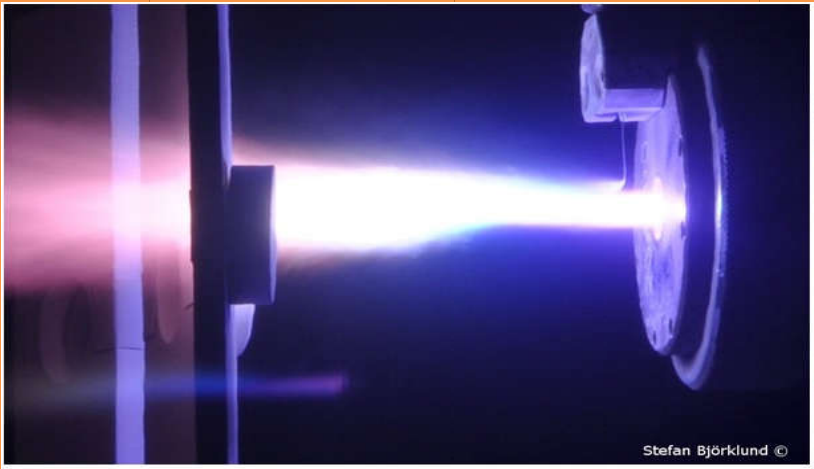
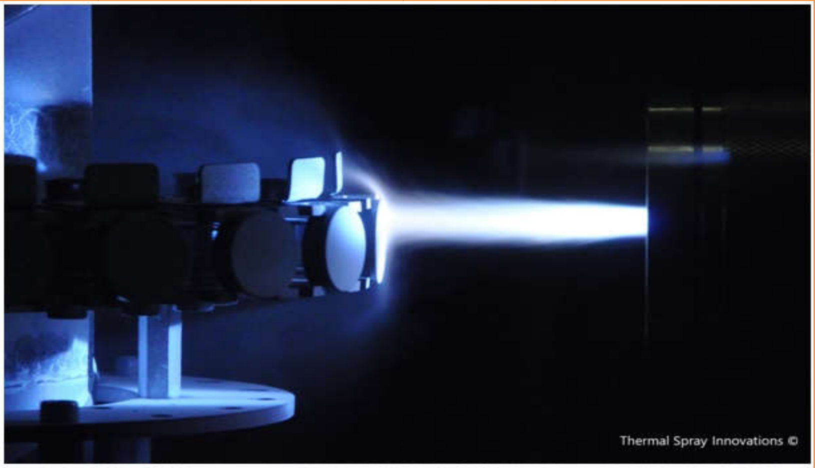
iTSA
Indian Thermal Spray Association®

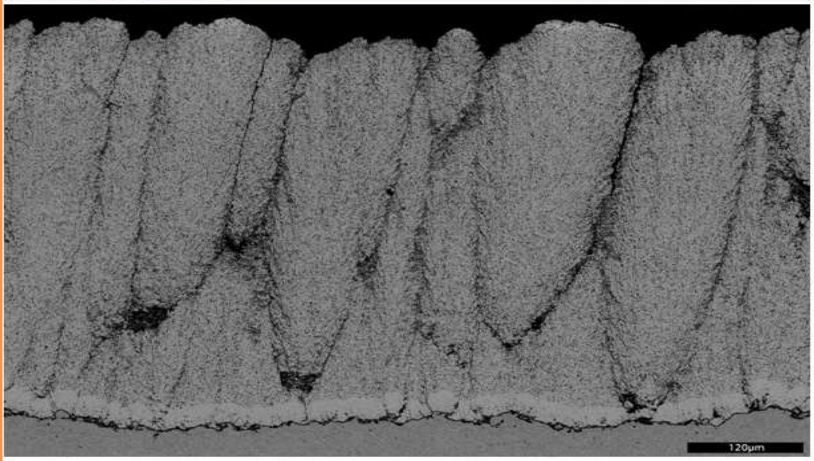
March 2022| Vol. 2| Issue 1

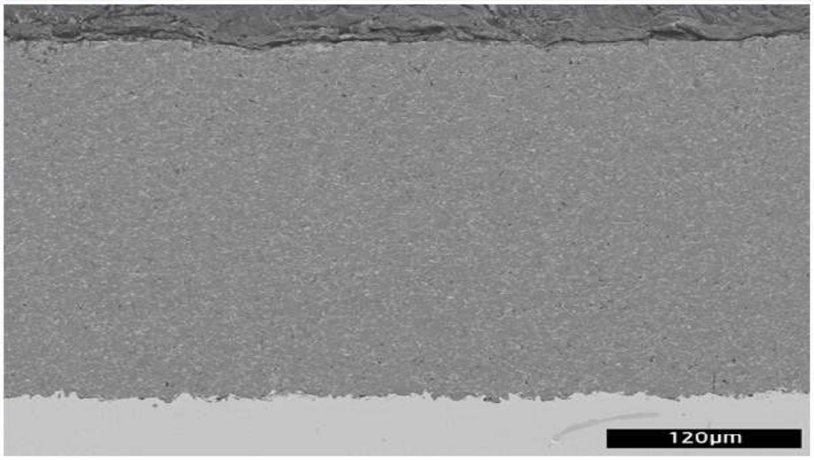
SPRAYTODAY™

An INSCIENCEIN publication | Affiliated to the Indian Thermal Spray Association® as its official Newsletter









Issue Highlights

- **Featured Article**: Anti-Corrosive, Anti-Wear, Decorative and Creative Thermal Spraying In Architecture and The Arts
- **Technical Note**: Suspension Thermal Spraying – Status and Future Directions
- **Industrial Research**: High-Performance Cold Gas Coating For Wear Protection and Emission Reduction for Brake Discs
- **Academia Research**: Overview Of Erosion-Corrosion Resistant Thermally Sprayed Carbide Coatings

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Mission: Our mission is to deliver the most recent thermal spray industry news and keep up to date to 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.

SPRAYTODAY™ is a quarterly publication of the INSCIENCEIN Publishing, affiliated to the Indian Thermal Spray Association® [iTSA] as its official newsletter. Published and distributed digitally INSCIENCEIN Publishing.

A subscription to **SPRAYTODAY™** is free for individuals interested in the thermal spray and coatings industry.
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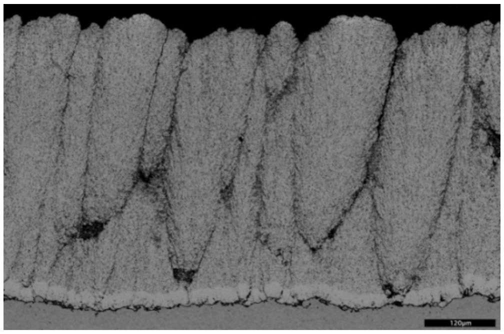

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ABOUT THE COVER

Suspension Thermal Spraying – Status and Future Directions

Editor's Note

Dear Readers,

Since the COVID-19 pandemic impacted the world from start of the year 2020, the disease has spread about every country around the world. The Thermal Spray market has experienced negative growth during the pandemic time; however it is expected to be back on track in 2022 with resumption of the economic activities.

Asia-Pacific Thermal Spray Market is expected to expand at a projected CAGR of almost 10% during the forecast period, 2022 to 2026. The demand in Asia-Pacific is estimated to lead the market owing to its rapid growth from the aviation, automotive and oil and gas sectors. In Asia, Thermal Spray Market will be dominated by the India, Japan, and China. The thermal spray equipment market in India is driven primarily with the increased use of thermal spray techniques in the aerospace sector, which has grown significantly in the last few years with advancements in technology and R&D, supported by the government.

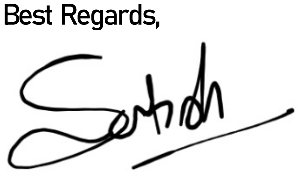
The increasing use of thermal spray coating in the automotive industry sector is also expected to drive the thermal spray market in coming years. In recent years, governments across the world are concentrating on minimizing carbon dioxide, particulate matter and nitrogen oxide emissions, and enhancing fuel economy (as per Corporate Average Fuel Economy standards) of the vehicles. Consequently, engine manufacturers are focusing on thermal spray coatings for cylinder bores and other key areas within the engine.

The growing use of thermal spray processes in aviation, automotive and oil and gas sectors, along with the advancements in spraying technology (Suspension Thermal Spraying and Cold Spray process) will offer numerous opportunities in the growth of the global thermal spray market.

I am particularly pleased to be allowed to recommend to you the latest issue of the **SPRAYTODAY**. This issue includes invited innovative featured articles on Anti-Corrosive, Anti-Wear, Decorative and Creative Thermal Spraying In Architecture and The Arts, Suspension Thermal Spraying – Status and Future Directions, High-Performance Cold Gas Coating For Wear Protection and Emission Reduction for Brake Discs, Overview Of Erosion-Corrosion Resistant Thermally Sprayed Carbide Coatings received from industry and academia experts that illustrate current research trends in thermal spray development.

Looking at the future of thermal spray in India, it will be pleasing if SPRAYTODAY can also inspire the spirit of thermal spray research in the country by providing the latest information on thermal spray technology.

Be healthy, active and curious.
Best Regards,



(Dr. Satish Tailor)

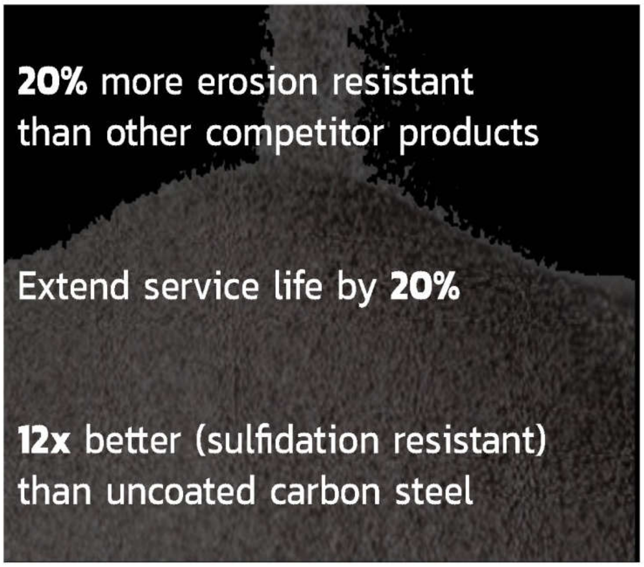
ADVANCED METALLIC COMPOSITE NIOBIUM CARBIDE CLADDING

US Patent Application No: 63/248,885 (patent pending)

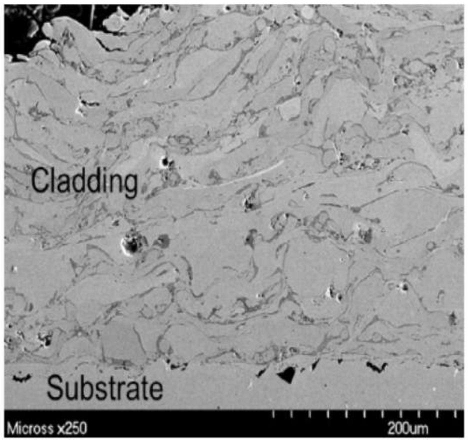
Composite Cored Wire Cladding Containing Hard Niobium Carbide

Key Features of this New Innovative Cladding

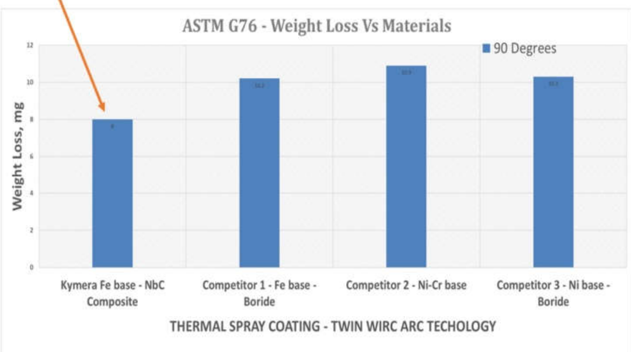
- Corrosion & erosion resistant
- Non-permeable with treatment
- Cladding easily measurable - Ni base
- High bond strength: > 4000 psi
- Easily repairable
- Porosity: < 4%
- Total oxide content: < 3%
- Hardness: average 56 HRC
- Deposition efficiency: ≈ 68%
- Cladding thickness typically between 6 mils to 125 mils



Innovative Wire Feed Stock



LESS WEIGHT LOSS - BETTER EROSION RESISTANCE



20% MORE EROSION RESISTANT THAN COMPETITOR PRODUCTS IN THE MARKET

NC100 CLADDING - EROSION RESISTANCE	
DISTANCE	10 MM
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PRESSURE	8 PSI
SCFH	15
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Anti-Corrosive, Anti-Wear, Decorative and Creative Thermal Spraying In Architecture and The Arts

*By **Luiz Cláudio de Oliveira Couto**, Technical Consulting, Training and Metallization Courses, Brazil.*
Email: metalizacao@metalizacao.eng.br Web: www.metalizacao.eng.br

What is thermal spray?
Thermal spraying, also known as metallization, is a process in which various types of materials in the form of wire, cord, rod or powder are melted or semi-melted and released in the form of a spray towards the surface to be coated, forming thus a metallized layer.
Once deposited, the layer can be ground, polished, used as applied or sealed or given a patina finish.
The thermal spray process, researched since 1896 by the Swiss engineer, Max Ulrich Schoop, including the author of several process patents, was initially aimed at industrial solutions.

The types of thermal spraying processes
In general, thermal spraying processes are divided into: flame, electric arc, plasma, high speed (HVOF/HVAF), detonation and cold thermal spraying.
The process is chosen taking into account the use of the surface to be coated, the material to be applied and the objective of the coating, that is, the solution sought.

Your universe of materials and applications
Materials
The material options for deposition through thermal spraying processes are numerous and range from metals and their most diverse alloys, to ceramic materials, carbides, composites and plastics, applied on the most diverse types of substrates. This provides thermal spray processes with a vast universe of solutions in the most diverse areas.

Applications
As a result of the diversity of material options that can be applied through thermal spraying processes, there were a huge variety of possible applications, aimed at the most diverse problem solutions, such as: corrosion, wear, dimensional recovery, thermal or electrical insulation, electrical conductivity, thermal conductivity, moldability, anti-adhesion, anti-friction, reflectivity, biocompatibility, decoration, etc.
These solutions cover approximately 50 industrial segments such as aeronautics, defense and aerospace, chemical, electricity and electronics, transportation, automotive, oil and gas, pulp and paper, naval and port, equipment in general, mining, construction and dredging, rubber and plastics, steel and metallurgy, food, textiles, turbines, hydroelectric, thermal and nuclear plants, among many others.
Although it has its origins in the late 19th century and has since been used in approximately 50 industrial segments, the application of thermal spray processes in architecture and the arts has become important in the last 80 years.

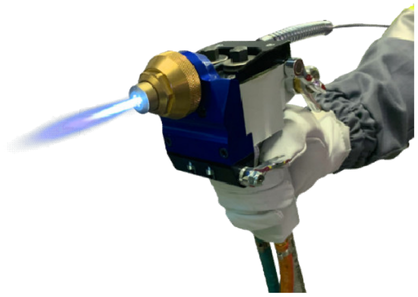
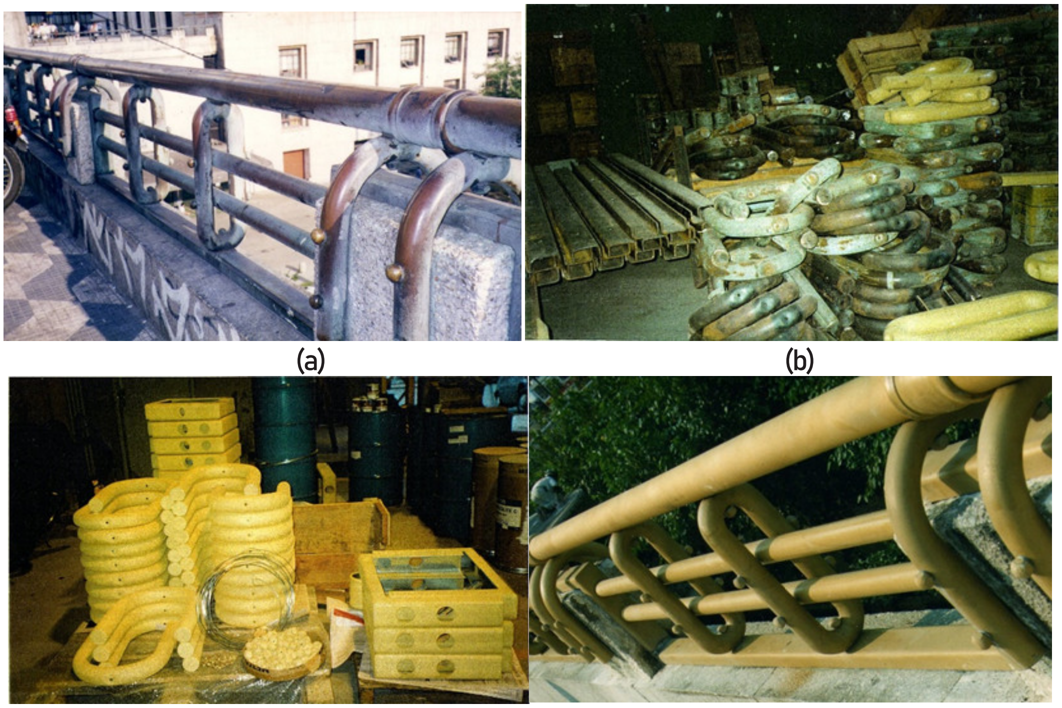


Figure 1: Example of flame thermal spray equipment

Figure 2: Protective and decorative metallization applied to a grid

(Saint-Gobain Coating Solutions - Equipment (1) Z-Jet and (2) Master Jet.)



(a) (b) (b) (d)

Figure 3: (a) Part of the grid assembled before coating, (b) Parts of the grid dismantled before coating, (c) Parts of the grille dismantled after coating, (d) Part of the grille assembled after coating

Some cases of applications in the architecture

Burj Al Arab (Tower of Arabia) - Dubai / United Arab Emirates

Considered at the time, the largest hotel in the world, the Burj Al Arab, began construction in 1994 and was completed in 1999. It has 10,000 m² of steel coated through the electric arc thermal spraying process, with aluminum, for an intermittent period of six months.

The metallized structures included: the helipad deck, the roof-mounted mast and six diagonal supports, weighing over 200 tons each.

The aluminum layer applied by thermal spray was complemented by an epoxy sealant, followed by a three coat paint system for aesthetics and finally a 50 µm polyurethane topcoat.

This protective layer took into account both aesthetic beauty and functionality in vital components of the structure, which reaches 321 m in height, in a construction installed on an artificial island of 280 m, off Jumeirah beach, connected to the main island by a private curved bridge, with the shape of the hotel structure imitating the sail of a boat and exposed to the many winds, typical of the place, in addition to the highly corrosive environment of the arabian coast.

Viaduto do Chá - São Paulo / Brazil

Conceived by the Frenchman Jules Martin and inaugurated in 1892, the Viaduto do Chá had its original metallic structure, with wooden floors, in 1938, replaced by a new viaduct of reinforced concrete, twice as wide.

Recovered in 2000, Viaduto do Chá, located in the city of São Paulo, capital of the state of São Paulo, Brazil, had its railings originally made of carbon steel, coated with bronze, through the thermal spraying process.

At the time, I was responsible for capturing the coating service for the historic restoration of this heritage, together with the São Paulo City Hall.

The contractor responsible for the entire work, removed all the bars, recovered the structure of some of them, replacing the damaged parts, and sent us all the dismantled parts to be coated.

The tubular parts had all their original coating removed and their surfaces, after having received an abrasive blast, were then coated through the thermal spray process, with a previous layer of zinc for anti-corrosion protection and a decorative layer of bronze, which in turn this time it was followed by a layer of varnish specified by the contractor, and after its assembly in the field, a new layer of varnish was applied.

Canton Tower - Guangzhou / China
Also known as the Guangzhou Television Tower, it is a multipurpose building located in Guangzhou, Guangdong Province in China. Inaugurated in 2010 for the Asian Games of that year, the Canton Tower is now considered the fifth tallest structure in the world, the second tallest freestanding structure in the world and the tallest concrete tower in the world, with a total of 612 m in height. height.

The construction has a concrete core and an external metallic structure, in a main structure with a height of 450 m and a 150 m TV antenna, coated in aluminum by the thermal spraying process.

Shiva statue - Nathdwara / India
Nathdwara, a holy city in Rajasthan, India, has since June 2020, a 107 m high statue of Lord Shiva. It is the largest statue of Shiva in the world and is among the five largest statues in the world.

The statue of Shiva, also known as the "Statue of Belief" was envisioned by Madan Paliwal, Chairman of Miraj Group, Udaipur, the concept developed by studio Maturam Art, the structural design rendered by Skeleton Consultants and the construction contract awarded to Shapoorji Pallonji E&C, with the works started in 2016.

The statue of Shiva seated on a pedestal, was designed for a three-tiered structure. The central core formed by four walls in reinforced concrete, the second layer a structural steel structure and the third, a 200 mm layer of ultra-high performance concrete, molded to the profile of the statue.

The surface of the concrete layer was completely cleaned by abrasive blasting and then a protective layer of zinc was applied, with 99.9% purity, through the thermal spraying process and finally received a copper layer as a finishing.

Among the various awards, the work received the Excellence in Concrete Structures from the American Concrete Institute, the Outstanding Structure from the Indian Concrete Institute and theGolden Peacock National Quality Award from the Institute of Directors.

Some cases of applications in the arts
Although more recent than industrial applications, the use of the thermal spray process in the arts is already quite vast, both as a coating to protect against corrosion, extending the useful life of the work or installation, and as a quick-use material for sculptors, when compared to molten metals, such as bronze. In addition, thermal spraying was also creatively applied on canvas canvases.

Coloana fără sfârșit (Endless Column) by Constantin Brâncuși
The Endless Column, completed in 1938, was created by Constantin Brâncuși and is part of a sculptural ensemble situated in Târgu Jiu, Romania, built as a memorial to honor the Romanian soldiers who died defending the city during the First World War, symbolizing the concept of infinity and the infinite sacrifice of these soldiers.

The 293 m high column is made up of fifteen identical cast iron elements, in the form of rhomboidal diamonds and a half module on top, threaded into a central steel core, originally coated with brass through the thermal spray process.

Due to acid rain, as a result of operations at a local factory, the deteriorated brass allowed the steel core to oxidize. In the 1950s, the romanian government planned to demolish the work and turn it into scrap metal, which did not happen. In the 1960s and 1970s, attempts were made to repair the set, but to no avail.

The work, which featured unstable foundation, tilting, cracking and metal corrosion, was integrated into the Word Monuments Watch List of 100 Endangered Sites in 1996 by the Words Monuments Fund, which facilitated and provided funding, along with other contributors to its restoration between 1998 and 2000.

The column was then dismantled, repaired and the parts now coated with bronze by thermal spray and the column finally reassembled.

Alexander Calder's untitled mobile
Installed in the atrium of the East Building at the National Gallery of Art in Washington, USA, the mobile opened in 1977 and has become an icon of the gallery.

Calder created a model of the mobile, which was enlarged by artist and engineer Paul Matisse, grandson of painter Henri Matisse. Elderly at the time, and due to the weight of the work, Calder asked Matisse to make the sculpture. Matisse used advanced materials such as aluminum honeycomb panels, heat-treatable 6061 aluminum alloy tubes and steel tubes to support the five heaviest elements.

In order to reduce the wear on the surfaces where the hook and the ring join the structure's weight, Matisse applied a molybdenum-based hard coating through the plasma thermal spray process.Eleven years later, in 1988, depressions in the aluminum tubes, at the hook x ring interfaces, led to a major conservation treatment carried out the following year. A new coating, now with an alloy based on nickel, molybdenum and aluminum, plus a layer of titanium dioxide was applied by thermal spraying to the flame.

Fifteen years later, in 2004, a new inspection was carried out and in 2005/2006, and due to the longer time between inspections, a recovery coating with aluminum TIG weld on the worn depressions was applied and after several abrasion tests, a layer of tungsten carbide with cobalt was deposited using a high speed oxygen fuel (HVOF) thermal spray equipment, finally followed by painting according to the process and type of original paints.

Garatuja by Marcello Nitsche

Garatuja by Marcello Nitsche from 1978 is a large modulated steel sculpture that mimics a painting gesture of the same name.

Originally installed in Praça da Sé, in the center of the capital of São Paulo, it was later transferred (in 2004) to the inner garden of the Sé Station of the São Paulo Metro.

Figure 4: General view of Scrawl in its current location and Detail of Scrawl's structure

Garatuja is an abstract work, with its structure built in iron sheet and creased steel plate weighing three tons and measuring 3.35 x 3.83 x 4.44 m, coated internally and externally with zinc, through the sprinkling process. thermal, followed by painting with polyurethane.

Until about thirty years after its construction, the facility did not show any signs of rust spots.

Jeff's Metallizing

Jeff Russell, an American born in 1942, known as Jeff after he abandoned woodcarving, watercolors and acrylics in the 1970s and 1.980s, discovered the application of the thermal spray process as his new way of making art.

Using his new technique called “metallizing”, he achieved his first successful result in 1977, in New York, with his work “State”, a canvas measuring 75” x 75” x 12”. In this work, he himself initially applied zinc by thermal spray on a stretched and textured canvas with thick acrylic, to give adhesion to the coating, on a curved form of 1.80 x 1.80 m, and then sanded and polished the layer.

Jeff created, in addition to “State”, other works using his “metallizing” technique, applying different materials through the thermal spray process:
- "Un/Structure No. 7" 1977, sprayed molten steel on canvas, patinaed, 94" x 136" x 9"
- "Un/Structure No. 9" 1977, sprayed molten steel on canvas, 8' x 16' x 14-1/4"
- "Arck" 1977, sprayed steel on canvas, rusted, 96" x 130" x 14" (Coll: Norton Museum, West Palm Beach, Florida)
-"Installation Sprayed Steel Works" 1978, Westbroadway Gallery, N.Y.C.
- "Un/Structure No. 59" 1979, sprayed molten steel on canvas, 92" x 82" x 9-1/2"
- "Installation Sprayed Steel & Copper Works" O.K. Harris Works of Art, N.Y.C., 1.979
- "Steel No. 83" 1979-80, sprayed molten steel on canvas, 13" x 120" x 8"
- "Copper No. 89" 1980, sprayed molten copper on canvas, 11" x 120" x 8"
- "Steel Painting No. 102" 1980, Rust-Oleum paint over sprayed molten steel on canvas, 90" x 165" x 18" (Coll: Coumbia Museum of Art, South Carolina)
- "Serious Art" 1981, flashing electrical w/ sprayed molten steel on canvas, 71" x 121" (Coll: Neuberger Museum of Art, Purchase, N.Y.)

The creative and economical options for Siena Porta bronze foundry

Artist Siena Porta in 1994 stated “Metallizing offers creative options and an economical alternative to bronze casting”Using thermal spray metallization, the artist covered the most diverse materials, such as: acrylic, burnt clay, cement, wood, Mylar® (polyester film), polystyrene and cast resin.

Siena Porta had her sculptor work as the subject of the video "Me and the Mirror"

Vulcan by Guiseppe Moretti
The 17m Vulcan sculpture by Guiseppe Moretti in its 1904 setting is located in Birmingham, Alabama, USA. In 2001 it had its interior reinforced, coated and reassembled the statue on the restored plinth of 1938.

The Robinson Iron company carried out its restoration, creating a new spearhead and hammer, applying zinc by the thermal spray process to prevent corrosion on the internal and external surfaces, and then applying a primer and a polyurethane coating.

Bronze Seed by Kathryn Lipke-Vigessa
Kathryn Lipke-Vigessa opted for the thermal spray process in her 2004 bronze sculpture, The Bronze Seed, as this would achieve a unique effect and meet her budget constraints and affordability at the time.

The work Bronze Seed was executed by Bauer Art Metal and is part of the installation of the garden / environmental sculpture "Life Cycle". It is a bronze seed divided into three parts, with a tree being planted between them.

Each of the pieces was executed using large blocks of Styrofoam with stainless steel skeletons and molded copper mesh, and the front half coated with zinc by thermal spraying, for solidification of the form.

Front and back were assembled and thermal spray coated together, on the skeleton. The final shape was also coated by thermal spraying, now with silicon bronze, later polished and reinforced with chemical patina.

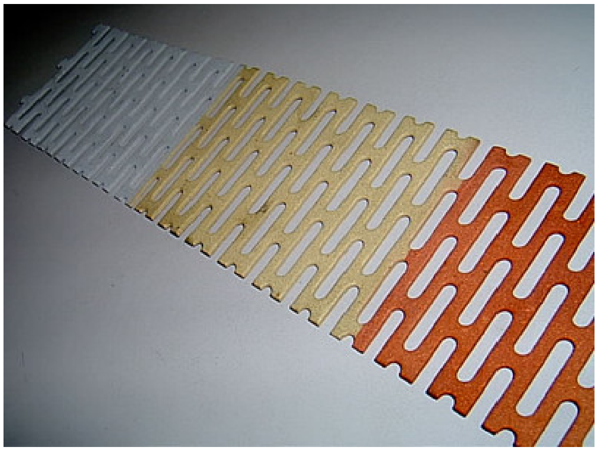
3D Thermal Spray, the bridge between the worlds of art and architecture
Eric Bauer of Bauer Fabrication & Art Metal has brought together the worlds of art and architecture through fabrication techniques utilizing the thermal spray process.

Patented as the "Bauer Process" in the USA, it used thermal spray on wire mesh to build three-dimensional objects. In this way, he managed to use various types of metal, from aluminum to zinc, since the 100% metallic coating maintains its basic characteristics "such as color, durability, corrosion resistance or a pleasant appearance to the weather" (8.9).

The patina can be used later to give it a special color and then its metallic surface is sealed to protect the finish and create a moisture-proof barrier impervious to most solvents and liquids.

According to Bauer, "there is almost no limit to what you can do with this process".

Conclusion
Since the thermal spray processes depend on numerous materials, from metals, ceramics, carbides, compounds and plastics, which can be applied and their various characteristics, on the most diverse substrate materials, in the field, at the customer or in their own workshops. metallized layers have been used for the most diverse solutions, in the most diverse industrial segments, as well as in apparently unexpected segments, such as architecture and the arts.



That is, in addition to protective coatings, the thermal spraying process is being used as a creative expression by artists. In this way, they can create durable works with infinite alternatives for inspiration.

As a result, the greater durability of the parts is added to the replacement of the casting processes, which are much more expensive and time-consuming, to the enormous universe of creative possibilities.

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Suspension Thermal Spraying – Status and Future Directions

By ***Dr Nicholas Curry***, *Consultant, Thermal Spray Innovations, Austria.*
Email: nicholas.curry@thermalsprayinnovations.com

What is suspension thermal spray?

Traditional thermal spray processes involve the deposition of particles that range in size from some tens of microns to several hundred microns. We have long understood the advantage of finer structured materials for the improvement in coating properties; be it hardness, wear resistance, chemical resistance. There has therefore been a drive to investigate the use of ever finer feedstock materials to produce coatings. A barrier to further reduction in particle size occurs around the 5-10μm range as dry powders become difficult, if not impossible to feed and inject into thermal spray heat sources.

Suspension thermal spraying overcomes this limitation in feedstock size by using powder particles suspended in a liquid phase, to carry the material from the feed system and enable successful injection into the plasma or combustion jet. Powders for suspension spraying may vary from nano-metric, sub-micron to even fine micrometric sizes and can be ceramic, metallic or mixtures. The liquid phase, based on water or an organic solvent, provides the necessary momentum for the fine particles to enter the plasma jet, where the liquid phase evaporates and the particles are heated and accelerated towards the substrate.

Working with suspensions is more complex than working with conventional spray powders as it requires specific processing equipment and process knowledge. For the preparation of suspensions you must consider the chemical and physical interactions between the solid powder and liquid phase. Suspensions by their nature are not stable indefinitely; the solid phases will sediment out of suspension given time. This makes their manufacture, transportation, storage and reactivation before use, more difficult than conventional thermal spray powders.

The thermal spray equipment requires a feeding system designed for viscous liquids, together with the critical injection system in order to work successfully.

The interaction of the suspension liquid with the plasma or combustion jet is more complex than with powders, involving more reactions and steps.

How did we get here?

Suspension thermal spraying is a relatively recent addition to the thermal spray coatings toolbox; being first explored in the early 90's. The first patent on suspension spraying with the radio frequency plasma process was applied for in 1994 by Gitzhofer et al. at Sherbrooke University in Canada; more or less marks the beginning of the development of suspension thermal spray[1]. For approximately the first decade of its development, suspension spraying had been considered a curiosity with only exploratory work carried out in research laboratories. Initial efforts had been performed with home built feeding equipment and lab made suspensions.

This changed with the first 'accidental' discovery of columnar coatings[2]. These coatings suspension sprayed coatings replicated the columnar structure of an Electron beam physical vapour deposition (EB-PVD) coating commonly used as a protective thermal barrier in gas turbine systems. Being able to produce a columnar coating using an atmospheric process at potentially thousands of thermal spray workshops versus the limited number of EB-PVD facilities, spurred both academic and corporate research in the field.

A second application area that has arguably triggered development acceleration was the production of the first high quality dense coatings with suspension plasma spray. The potential for coatings with higher density and more refined grain structure attracted the attention of the semiconductor manufacturing field. Reactive ion etching equipment, that utilises a dry plasma etching process, require dense coatings to protect the equipment from plasma erosion and to prevent the formation of chip defects.Suspension plasma spray allowed for the manufacture of higher density yttrium oxide coatings for plasma etching chamber protection, enabling further advances in semiconductor development[3,4].

Current status

As of 2022, the major industrial applications of suspension spraying is in the manufacture of columnar thermal barrier coatings for gas turbines and the production of reactive ion etching chamber coatings for the semiconductor manufacturing sector. Other possible areas of industrial application are being explored.

Research into suspension thermal spray is as active as it's ever been, with multiple research groups from the Americas, Europe and Asia working in the field. The scope of applications has widened as more experience has been generated. Researchers now look at abroad spectrum of materials for applications such as high temperature wear and corrosion, hydrogen generation, electric batteries, to name a few. Such a focus can be seen in the number of patents applied for in the area of suspension spraying over the last decade [5].There are also a number of detailed overviews on the suspension thermal spray research field that are helpful for further detailed reading [6–9].

A practical sense of the progress made in the last decade can be noted in the accepted solids content of suspension used. Solids content is an important measure of how much of the actual coating material, the powder, there is in the suspension by weight. It can also be thought of as a measure of how productive the process has become. In early experiments this was limited to levels of 5 to 10weight percent. Industrially this has risen to 25% for ethanol based suspensions and 40% for water based suspensions. Coatings have been demonstrated from suspensions in the 50 to 60% range, indeed as high as 80% solids load has been demonstrated for chrome oxide suspension in recent years. This goes to show that the suspension thermal spray field is advancing rapidly as materials and equipment improve as well as the knowledge of how to work with them. On the thermal spray equipment side, currently there are a number of 'fully integrated' suspension thermal spray systems available on the market:-

- 100HE plasma torch and Liquid Feeder from Progressive Surface, USA
- Axial III Plus plasma torch and Nanofeed 350 from Northwest Mettech Corporation, Canada
- TopGun Suspension HVOF system and suspension feeder from GTV, Germany

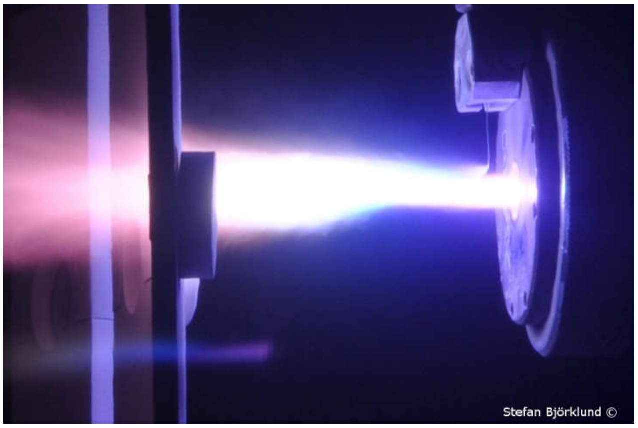

Figure 1: Suspension plasma spray with the 100HE plasma torch, Progressive Surface

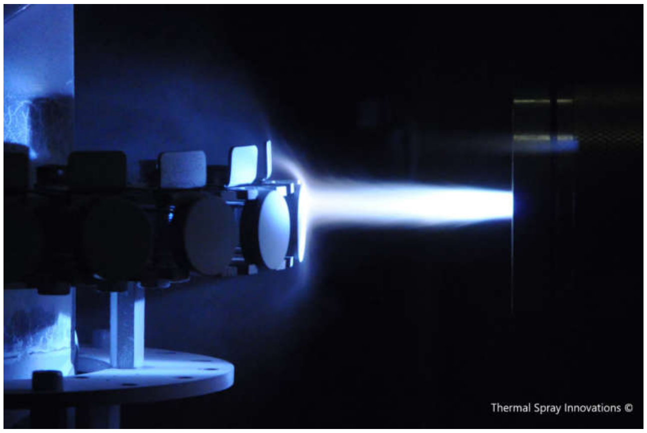

Figure 2: Suspension plasma spray with the Axial III plasma torch, Northwest Mettech

These systems consider the handling of suspensions from feeding to process injection and plasma or combustion jet treatment. Such integrated systems have been a key enabler for industrially practical application of suspension sprayed coatings as well as enhance the rate at which research projects can make large steps forward in development.

In some respects we should consider the suspension thermal spray fields like that of the air plasma spray during its early introduction back as the 1980's. Though we have seen the first industrial applications enter use, the process is still early in its development with much scope for further research and advancement. Different kinds of microstructures we may fabricate for different applications in suspension plasma spraying as shown in Fig. 2 and 3.

Challenges

What are then the challenges facing current development and future adoption of suspension thermal spraying? It can be argued that this lies on two broad interconnected aspects that enable development of new coatings and applications; the availability of equipment and feedstock for suspension spraying.

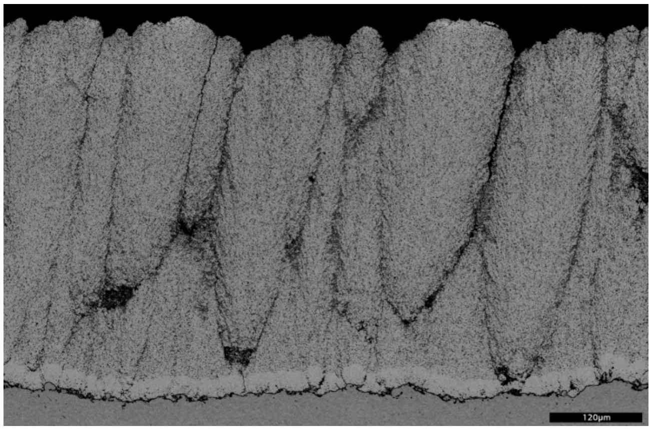

Figure 3: Columnar 8wt% YSZ SPS coating, courtesy of Northwest Mettech Corp.

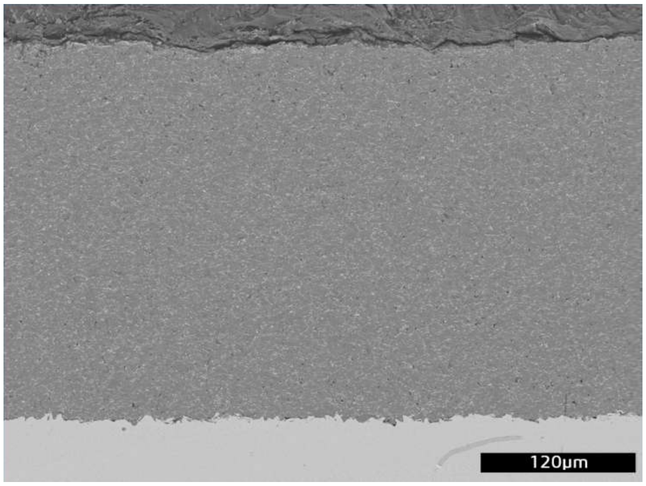

Figure 4: Alumina Zirconia composite SPS coating, courtesy of University West, Sweden

Suspensions

Feedstock for suspension spraying is perhaps the greatest challenge to its industrial adoption today. Currently there are not many industrial suspension suppliers and those suspensions that are made are produced in smaller volumes. This results in relatively high cost of suspension materials for thermal spray in both the research and production areas. Costs for industrial suspensions are expected to drop with time.

Manufacturing of a functional and reliable suspension is not a trivial issue, being as much about chemistry as it is about powder manufacture. The added challenges with the development of these new suspensions do not necessarily favour the established thermal spray materials suppliers.

It is possible that suspensions can be manufactured in laboratories and workshops at the development stage. However, great care should be taken with this approach as even the best equipment may not make a good coating from a poor performing suspension. A multi-disciplinary approach is needed for suspension spray development that incorporates chemists, materials scientists with thermal spray process experts.

An understood bottleneck for suspension spray rates and process economics is the utilised solids content of suspensions. The higher the solids load of the suspension, the less process energy is lost in evaporating the solvent. This can lead to higher achievable feeding rates of suspension as well as improvements in process efficiency. Limitations in coating rate and deposition efficiency can prevent the process from competing with more traditional coating processes.

Spray Equipment

Another limitation for the development of suspension spraying is the current generation of equipment in place at coating facilities and research centres. Many of these development centres are equipped with low power, older generation equipment that was not built for spraying suspensions. Even when such equipment is adapted with liquid feeders and injection systems, the results have often failed to meet expectations.

Purpose designed and built suspension spray equipment will incorporate a fully integrated approach to the spray system, from suspension feeder to control system, injection system and spray torch. Suspension feeders should be capable of closed loop control of the feed process and handle automated cleaning of the system. The feeder and injection system needs to be capable of spraying high viscosity liquids at high feed rates. Equipment designed for suspension spraying has the benefit of being easier and more practical to use, reducing workload on the operator. For industrial adoption, integrated suspension spray equipment is a necessity for viable coating applications. Also in the research and development area, having coating equipment that is designed for suspension spraying, can greatly increase the chances of successful research projects.

A second area for spray equipment that is important for success, is the available process energy of the system. During the spray process, the liquid carrier needs to be heated and evaporated before the powder particles themselves are heated. A proportion of the spray process energy is therefore consumed on the solvent rather than treating the powder. This leads to the need for high energy spraying processes to be able to spray higher feed rates of suspension efficiently.

Overall it means successful future work in suspension spraying will require investment in next generation spray equipment; presenting an entry barrier to prospective industrial and research adoption.

Future direction

Where can we expect the development of suspension spraying to go in the next decade of development and industrialisation?

- The number of applications will continue to grow as research labs gain further understanding of suspension plasma and HVOF spraying. We may see that some of the new applications come from fields not traditionally approached by thermal spray.
- There are some exciting possibilities for novel materials use as well as hybrid processing (combining powders and suspensions) to form new types of coatings that were not previously possible.
- As suspension spray scales up in adoption and industrial roll-out, the cost of suspensions will reduce, allowing more applications of the technology.
- There will be a general move to spray processing of higher solids content suspensions to achieve competitiveness with other coating methods.
- We may see new entrants to the market for materials supply. Since suspension manufacturing is as much about chemistry as powder fabrication and there are limited providers currently; this can favour new entrants with a strength in chemistry that the other suppliers lack.
- There are likely to be continuing advancements in suspension thermal spray equipment technology and we may expect more fully integrated suspension spray equipment to reach the market in line with the demands from industry.

Conclusions

Suspension spraying as a technology is now approaching its initial industrial maturity. While much groundwork has been laid in the area of research, there remains a lot of interesting and exciting work to gain the most out of the field. We can say that the future outlook for suspension thermal spraying looks bright!

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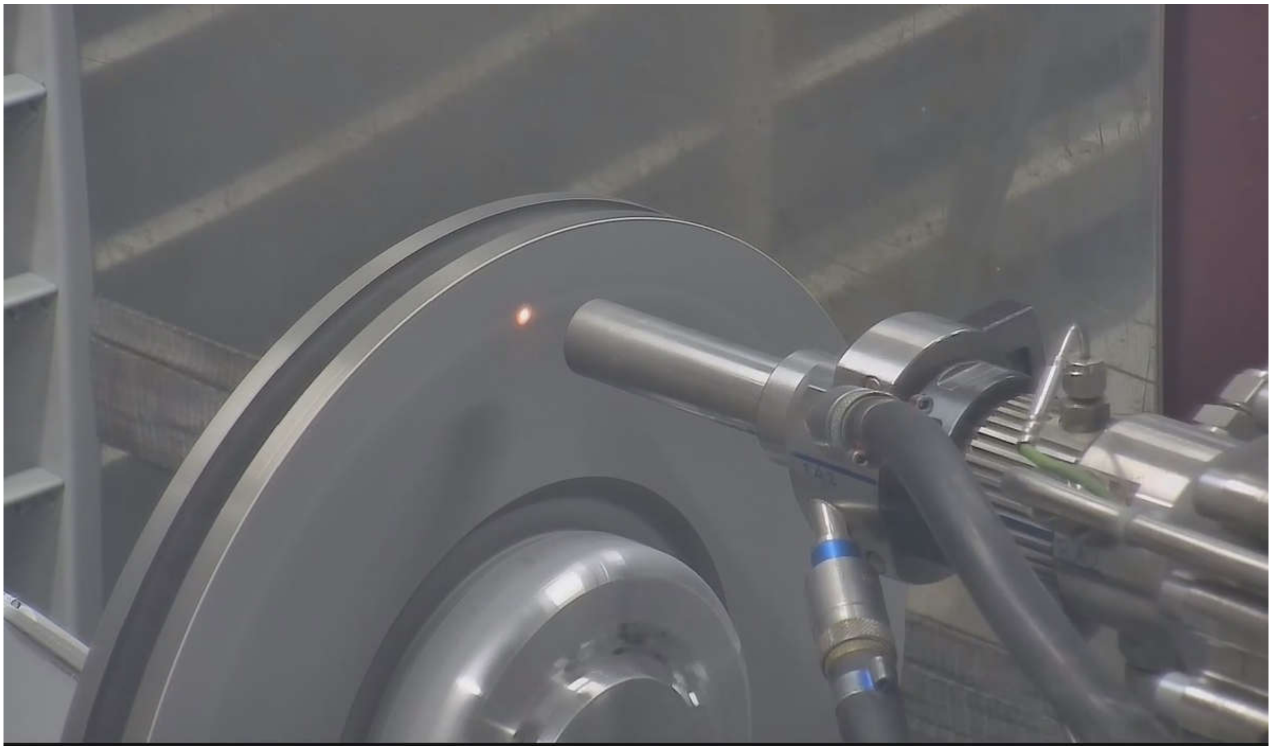
High-Performance Cold Gas Coating for Wear Protection and Emission Reduction for Brake Discs

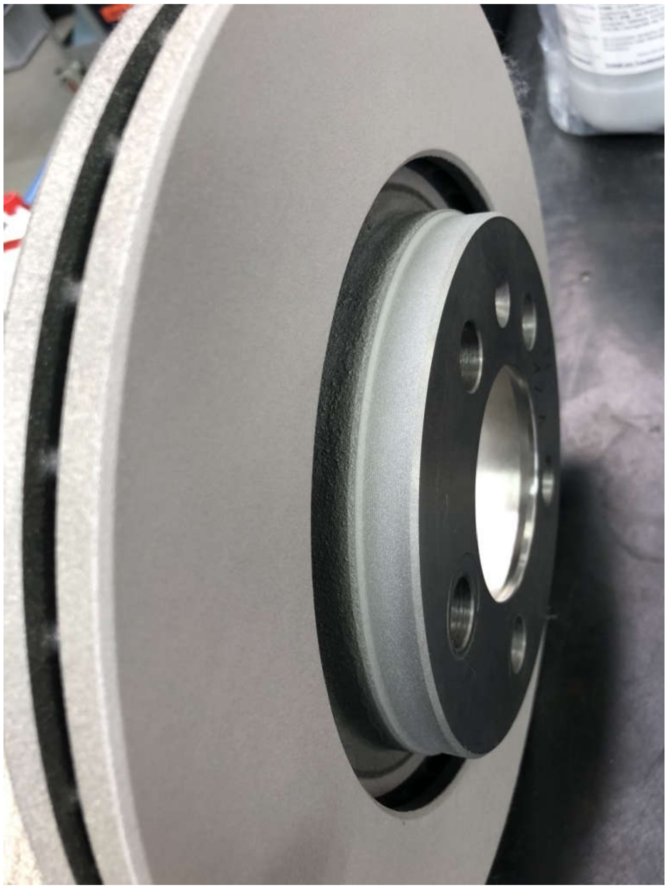
By ***Dr. Reeti Singh****,* ***Ján Kondás****,* ***Max Meinicke****, and* ***Leonhard Holzgaßner****,*
Impact Innovations GmbH, Bürgermeister-Steinberger-Ring 1, 84431 Haun/Rattenkirchen, Germany.
Email: rs@impact-innovations.com

Brake discs are subjected to extremely high loads and are among the most stressed parts of a car. Not only do they have to be replaced at relatively short intervals, due to the high level of wear and tear they create an **immense environmental impact** through particulate matter. Thanks to improved emission control, a reduction in exhaust gas emissions can be achieved in modern cars. However, it is still neglected how much particulate matter is caused by **the abrasion of tires and brakes**. A good half of the particulate matter in German road traffic is caused by tire and road abrasion and another quarter by brake pad abrasion. Emissions from brake wear, such as brake dust and particulate matter, are a growing concern for the automotive industry due to more stringent and environmental EU regulations.

Gray cast iron with embedded graphite is the most common material from which brake discs are produced. **Gray cast iron brake discs** are not only cheap to manufacture, they also have all the necessary mechanical properties that are required. However, poor corrosion resistance and excessive wear of the brake disc during operation are the main problem areas. Since no material can yet compete with gray cast iron for vehicle brake discs from a cost perspective, **the coating of cast iron discs** represents a practical and cost-efficient solution. But conventional thermal coating processes are still very material- and cost-intensive and the required properties in terms of coating adhesion, corrosion resistance and cracking behavior cannot yet be fulfilled.



With a high-performance cold gas coating with the **Impact Cold Spray System EvoCSII**, there is no delamination or severe cracking in the coating and the particle emission is reduced drastically. The performance of the coating was evaluated in terms of corrosion resistance, wear resistance, and tensile bond strength between the coating and the brake disc. The cold gas sprayed composite coating of the cast iron brake disc showed a **95% reduction in wear** in the SAE J2522 test; In addition, the coating showed excellent adhesion even after extreme bench test runs without any delamination. In addition, 720 hours of salt spray tests were successfully completed **without corrosion.**



The cold spray process wins over other coating technologies with its simplicity, high performance and low costs. As it is a cold process all process parameters are always constant independent of the dimensions and shape of the brake discs. There is **no thermal distortion of the discs**, and the layer build-up stands out with its uniformity. Thus, the coating thickness can be reduced to a minimum and the subsequent grinding costs are minimized. A standard brake disc can also be coated in a **one-layer system** (no intermediate layer) in less than 30 seconds. The present results show a cost-effective and resource-saving solution for the brake disc application with cold sprayed composite coatings.

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Overview of Erosion-Corrosion Resistant Thermally Sprayed Carbide Coatings

By ***Akshay R. Govande*** and ***Ravikumar Dumpala***, *Department of Mechanical Engineering, Visvesvaraya National Institute of Technology, Nagpur 440010, India.*
Email: govandeakshay@gmail.com

Introduction

The industries demanding minimize the cost associated with the equipment working in harsh environments where corrosion and erosion act simultaneously, such as propulsion equipment and fluid handling equipment. This corrosion-erosion is most of the time found where the slurries can be transferred in a pipe or the marine and offshore industries that use the seawater propulsion systems [1]. It is also a severe problem in the oil and gas industries. In high-temperature industrial equipment such as heat exchanger tubes, coal-based fluidized bed combustors, evaporator tubes, and turbine blades erosion-corrosion phenomenon has become the major material damage performance criteria. Erosion is due to the impingement of solid particles or the solid particles immersed in the liquid called slurry on the surfaces of the slurry handling parts or equipment, which causes the material removal or plastic deformation. In the actual scenario, slurries are frequently corrosive in nature, which means the surface of the parts or equipment will degrade due to the corrosive action also of the slurry [2]. The material loss is normally more due to the synergetic effect of erosion and corrosion.

Carbides are a promising material that has undoubtedly shown their potential against various degradation behaviour such as wear, erosion, cavitation, and corrosion. Carbide-based coatings can be deposited by various thermal spray techniques such as D-gun, plasma spraying, HVOF, and HVAF. High velocity oxygen fuel (HVOF) is so far the best coating deposition technique for carbide-based coatings to fulfill the requirements of the industries. HVOF coatings possess good mechanical and microstructural properties. Due to the low temperature and high velocity, the porosity is reduced, and the decarburization is also minimised, resulting in higher hardness, toughness, and higher wear resistance. Tungsten and chromium-based coatings are one of the major carbide-based coatings that industries prefer over other carbides because of their high hardness, high wear, and corrosion resistance. Chromium-based coatings possess high corrosion resistance, and tungsten-based coatings have higher wear and erosion resistance. Generally, WC-based coatings with metal cobalt as a binder are preferred, but this composition is less corrosion resistant [2]. Some studies suggested that the binder plays a crucial role in increasing the corrosion resistance of the tungsten-based coatings so that it can minimize the loss of material as a result of the erosion-corrosion. The addition of chromium to the WC-Co coatings has enhanced the corrosion resistance of the WC-Co coatings, and replacing some amount of tungsten carbide with other hard particles such as Cr3C2 can enhance the resistance of the material [3]. Ni is less resistant to erosion-corrosion than chromium carbides. Vulnerability of Ni to the pitting corrosion in the de-passivators contains mediums that restrict its application [4]. It has become increasingly important to understand the effects of erosion and corrosion in combination due to the rise in utilization of cermet coatings and solid cermet in applications that are susceptible to corrosion-mediated degradation. Wentzel and Allen had concluded that no simple relationship existed in any one property, and the erosion-corrosion characteristic and also no enhancement in erosion-corrosion has been observed due to improving the passivation of the metal binder [5].

WC-based and Cr3C2 based thermally sprayed coatings for erosion-corrosion resistant application has been briefly reviewed. The erosion-corrosion behaviour of these coatings and the material removal mechanism at room temperature and higher temperature have been briefly discussed.

Erosion-corrosion at ambient temperature

Tungsten carbide-based coatings developed by HVOF are used for the engineering parts such as gas turbine blades, pump impellers, ball valves, and other components that generally come across erosion-corrosion degradation. The effect of matrix composition, hard phase size, feedstock powder size, velocity, corrosion medium, and erodent proportion on the erosion-corrosion performance of the WC coatings has been investigated. The WC hard particle size plays a substantial role in influencing the erosion-corrosion rate of the WC-CoCr coatings. Finer WC size particles homogeneously dispersed in the matrix; as a result, the dislocation of the WC particles during the test was reduced, which was not noticed in WC coarser particles. When compared to the finer WC particles, the coarser WC particles coatings perform worst in erosion-corrosion behaviour [6]. Fig. 1 shows the comparative material loss during the erosion-corrosion test for chromium-based coatings (CC) and WC-based coatings (WC). WC-based coatings possess higher erosion resistance than chromium-based coatings, whereas chromium-based coatings have higher corrosion resistance than WC-based coatings. Further, better corrosion resistance was observed when cobalt was replaced with Ni, but the erosion resistance of the Ni as binder coatings was inferior to the cobalt-based coatings [6]. The nanocrystalline WC-17Co coating was prepared and deposited by the HVOF process and compared with conventional coatings. As a result of a reduction in porosity and micro-cracks, more compact structure, and more hardness, the erosion-corrosion rate was decreased by 30 % than the conventional WC-17Co coatings. Fig.2 shows the cracks formed in the conventional coatings and the compact structure of nanocrystalline coatings. Furthermore, the material loss was reduced by 22% as compared to substrate material when the WC-17Co coating was tested in the liquid, which contains 3.5 wt% NaCl + 1 wt% silica + 1000 ppm NaHCo3. But, due to the corrosion-prone tendency of binder cobalt, resistance to corrosion of the coatings had not reached up to mark [7].

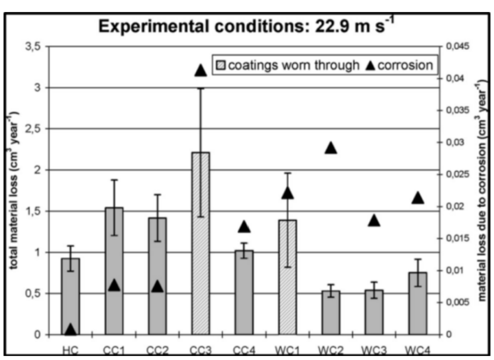

Figure 1: Material loss in the erosion-corrosion test conducted at a velocity of 22.9 m/s in 3.4 wt % NaCl containing 0.25 wt% silica sand [6]

Matrix composition has to be given priority because when coated parts are surrounded with higher passive materials like steel, the coatings become anodic, and galvanic couple formation takes place among the surrounding parts and coatings; as a result, corrosion damage improved [6, 8].

So, to overcome this problem, the Cr is normally added to the Ni or Co to boost the corrosion resistance of the coatings by making the coating more cathodic and protecting the substrates like steel [9, 10]. The size of the Cr also had a substantial role in the erosion and corrosion resistance of the coatings along with CoCr or NiCr. Due to uniform heating during spraying and high retention of tungsten carbide phase in the coatings for the size of 36-45 µm possess better erosion-corrosion resistance than the coatings having higher particle size distribution like 15-45 µm and 25-38 µm. In a less aggressive medium, the high chromium content is beneficial to control the mass loss by improving corrosion resistance, but in the aggressive medium, the erosion decides the material loss of the coatings [9].

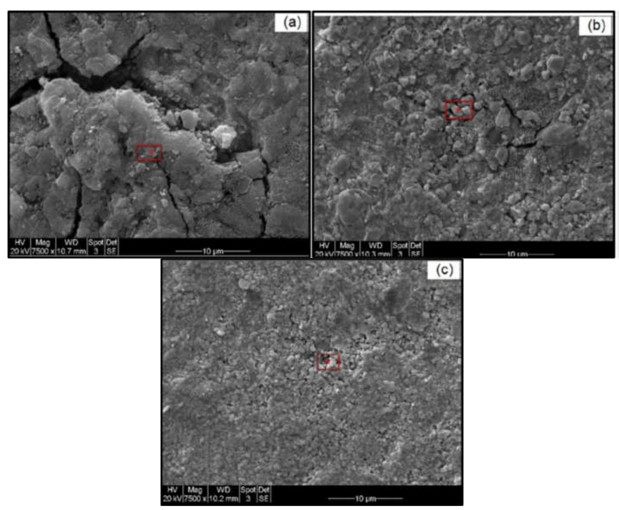

Figure 2: SEM image of (a) substrate material (AISI 1018), (b) micro-crystalline coating and (c) nanocrystalline coatings after erosion-corrosion test [7].

The coating microstructure decides the coating removal in the erosion-corrosion. The binder matrix phase dissolution followed by hard phase removal causes the failure of the coating. The loss of integrity among the hard particle and the matrix is responsible for improving the material loss in erosion-corrosion. The material removal in WC-Co-Cr and WC-Co coating is nearly similar. But the formation of the protective layer Cr2O3 enhances the erosion-corrosion resistance of the coating in a low aggressive erosion medium [9, 11, 12].

Erosion-corrosion at elevated temperature

In many energy systems, at elevated temperatures due to impingement of small solid particles on the surfaces and corrosion may cause material damage. The steam turbine nozzle, the heat exchanger tubes in the fluidized bed combustor, and blades are some components that experience this phenomenon. So, the life of the systems can be enhanced by applying some protective coatings,

which are cheaper, rather than changing the parts, which may increase the cost to the industries. The morphology of the coatings plays an important role against the aggressive environment, particularly where the material loss is due to the impingement of particles or abrading the surface rather than the hardness or the composition of the coatings [13]. Various components of boilers limit steam temperatures due to corrosion and creep resistance. A boiler's steam temperature is usually limited to 560 °C when using low-chlorine fuels, such as coal, whereas steam temperatures are usually lower for fuels that contain high levels of chlorine. Higher steam temperatures are required for high-efficiency electricity production consequently high corrosion-resistant superheaters. The bed material in the fluidized bed combustors is improved by the addition of sand in low ash fuel. Hence, fluidized bed combustor burns high-chorine fuel; as a result, the area exposed to the higher temperatures and the steam of corrosive fuel gas that contains erosion medium also suffer from the severe erosion-corrosion problem. The Cr3C2- based coatings had a good erosion resistance at higher temperatures, but the coatings wore out easily in the E-C test conducted at the higher temperatures. Formation of porous and weak chromium oxide layers was found on exposing in E-C test under this oxide layer the coatings were found to be porous and depleted of chromium. Selective oxidation and formation of the porous and weak corrosive products was the main reason for the higher material loss in carbide coatings exposed to the E-C test at higher temperatures. Weak and porous corrosion products were simply detached by the impact of particles, as shown in Fig. 3 [14]. Table 1 provides the information related to erosion and erosion-corrosion material loss of the various materials at a higher temperature.

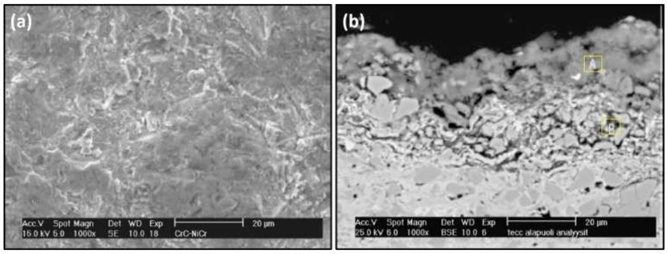

Figure 3: Surfaces after erosion test (a) WC-17Co coating (b) cross-sectional view of the coatings after erosion-corrosion. Point A and point B show the porous oxide layer and chromium depleted coating, respectively [14].

The influence of process parameters of the erosion, mostly the velocity, angle of impact, and the erodent medium, on the erosion-corrosion performance of the coatings have been focused on recently. At higher temperatures, the oxide layer formations on the surface of the components are an important factor that decides the material loss. As it is expected that the formed oxide layers are removed by the impingement of the erodent partially or completely. The formed oxide layer removal is reliant on the velocity of erodent, and when these oxide layers are detached, the mass loss was found to be linear [15]. Oxidation influence on the erosion performance of various boiler steel has been carried out in protected environments at high temperatures, and it is found that a quick healing layer is formed on the boiler steel [16]. In most of the cases, it was found that the material loss in steel was attributed to erosion that the than the corrosion or oxidation. The formation of the oxide layers generally enhances the erosion-corrosion resistance of the coatings at inclined angles. The WC-based carbide coatings can be useful up to 550 °C for higher erosion and moderate corrosion resistance application, but Cr3C2-based coatings can be applied up to 850 °C, which provides better erosion and higher corrosion resistance [17].

Table 1: Erosion-corrosion (E-C) losses for the different compositions along with coating deposition technique [14]

Material	Nominal composition	Material type	Coating thickness (μm)	Microhardness (μm)	Erosion loss (μm)	E-C loss (μm)
Fe3Al	Fe–17Al–2.25Cr	HVOF coating	275	348–454	98	161
TE-50	Ni–50Cr		210	459–533	63	120
Tafa 1265	Ni–21.5Cr–9Mo–Fe–Nb		270	269–366	148	186
TE-55	Ni–55Cr		235	311–550	104	133
TE-19E	Ni–16Cr–4Si–4B–4Fe	Spray & fuse coating	700	648–946	1C56	168
TiC-Ni	TiC–NiCo	Plasma coating	230	618–695	74	Wore through
TE-MC	CrC–WCo	HVOF coating	265	720–942	34	
TE-CC	Cr3C2–NiCr		255	695–905	70	
Cr3C2–NiCr			285	467–869	110	
UTEx 1004			225	598–905	121	
DS 200A			200	631–849	93	

The erosion-corrosion performance of the Cr3C2-NiCr and WC-CrNi coatings at higher temperature was studied, and found that erosion and corrosion resistance of the Cr3C2-based coating was higher up to 850 °C than WC based coatings. After 550 °C, the WC experienced higher material loss as compared to that of Cr3C2-based coatings [18-20].

Summary

Thermal sprayed carbide coatings are mostly utilized to enhance the erosion-corrosion resistance of components in the aerospace, oil, and power industries. For high-temperature erosion and corrosion resistance, WC-based and chromium-based coatings are preferred by industries mostly in the energy sector. Resistance to erosion and corrosion depends on the composition of feedstock powder, deposition technique, the process parameters used, the microstructure, and the formation of phases in the coatings. Reinforcement addition and addition of different elements to the matrix improve the erosion-corrosion resistance of the coatings due to some protective layer formation. For erosion-corrosion application, up to 550 °C, the WC-Co-Cr coatings are more effective than WC-Co and WC-Ni coatings. The addition of some reinforcements can enhance the coatings performances above 550 °C. Mostly above 550 °C, chromium carbide-based coatings are preferred for erosion-corrosion-resistant applications.

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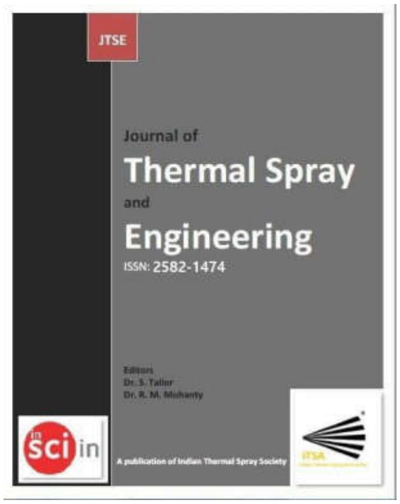

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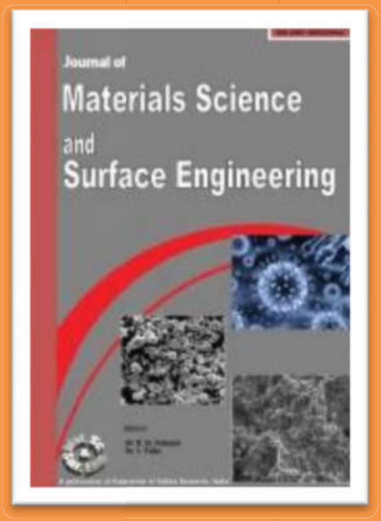

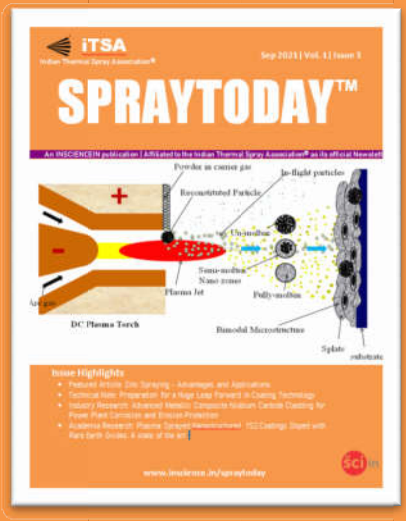

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