iTSA
Indian Thermal Spray Association®

Sep 2022| Vol. 2| Issue 3

SPRAYTODAY™

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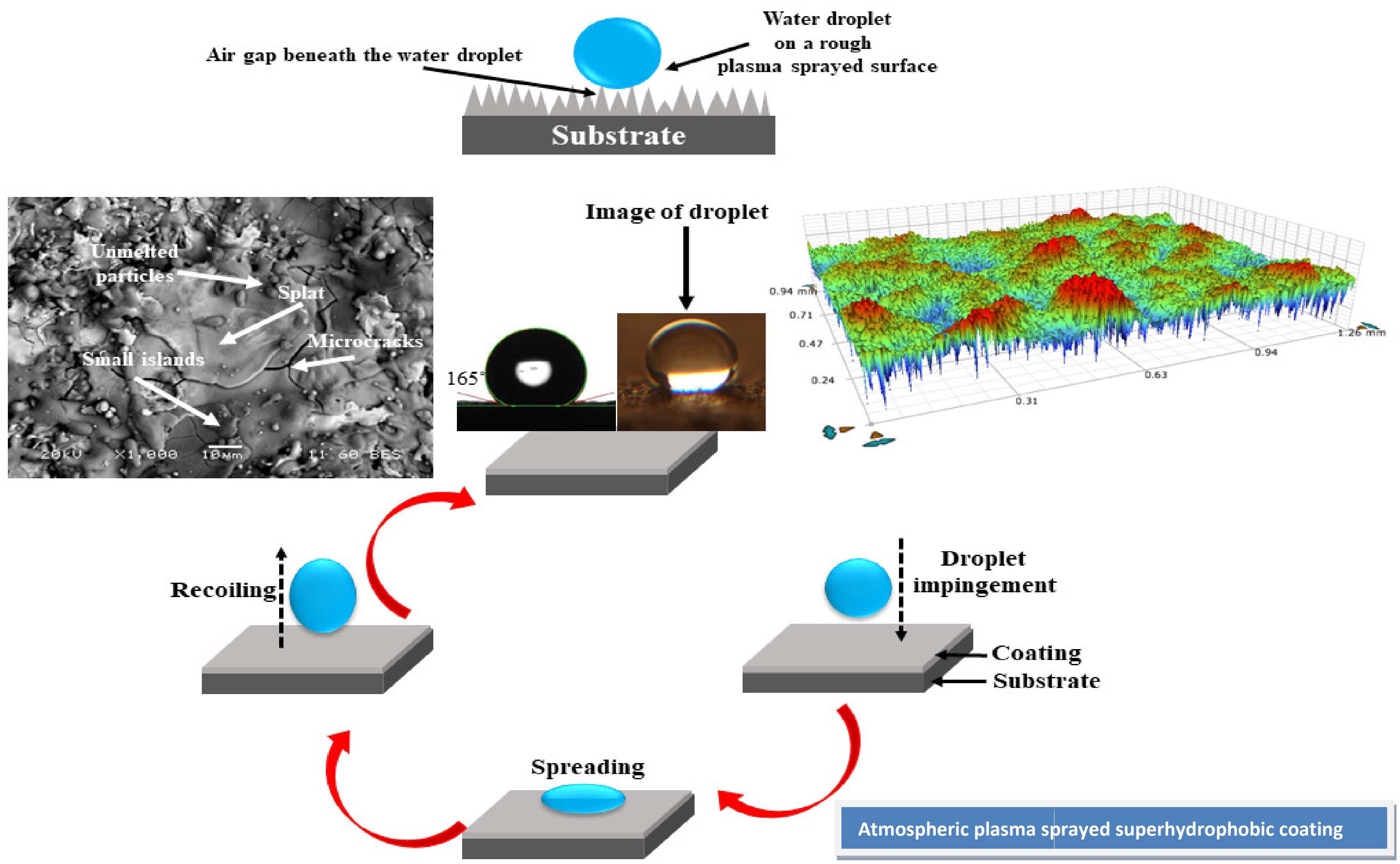

Atmospheric plasma sprayed superhydrophobic coating

Issue Highlights

- **Featured Article**: Introduction to Cold Spray Additive Manufacturing
- **Technical Note** : Superhydrophobic Surface Development by Thermal Spray Route
- **Industrial Research**: Cold Spray Additive Manufacturing (CSAM) Process for Ti-6Al-4V Using N_2 as Propelling Gas
- **Academia Research**: Micro-Mechanical Characterisation of Thermal Spray Coatings
- **Knowledge Point**: Thermal Spray Powder Types, Manufacturing Process & Characteristics

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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.

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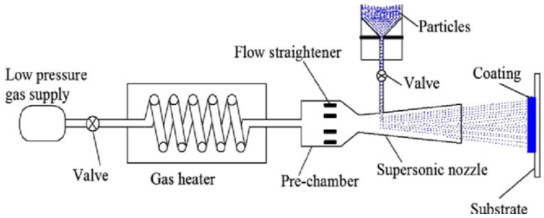

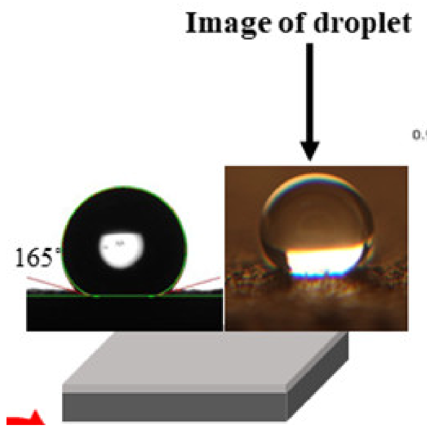

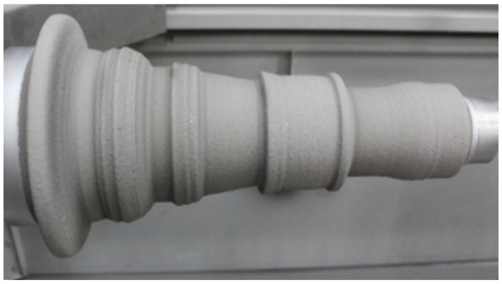

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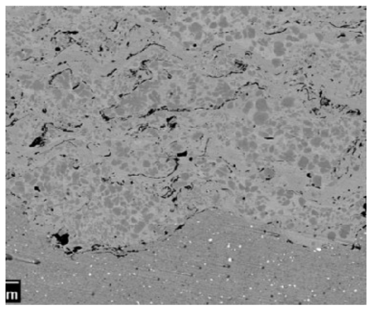

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ABOUT THE COVER

Atmospheric plasma sprayed superhydrophobic coating

Editor's Note

Dear Readers,

The global Thermal Spray Market is projected to be worth USD 17.68 Billion by 2027, registering a CAGR of 8.0% during the forecast period (2021 - 2027). During this forecast period Asia-Pacific Thermal Spray Market is expected to expand at a projected CAGR of almost 11.5%. India has a growing economy and thermal spray has a bright future. Due to the global conditions all the key players are investing in India for their future projects which will definitely increase the thermal spray market in the country.

Now there is few thermal spray OEMs as well as manufacturers of thermal spray grade powders & wire in India. Tata group has come forward to produce indigenous HAP powder for orthopedic implants. There are also some good companies producing quality thermal spray grade ceramic powders. The need of the hour is to produce carbide powders now as market share is higher than all other feedstock materials. I hope we will achieve this in the near future. Government of India is promoting Atmanirbhar Bharat and Made in India campaign.

I am particularly pleased to be allowed to recommend to you the latest issue of the **SPRAYTODAY**. This issue includes invited innovative featured articles from industry and academia experts on the Introduction to Cold Spray Additive Manufacturing, Superhydrophobic Surface Development by Thermal Spray Route, Cold Spray Additive Manufacturing (CSAM) Process for Ti-6Al-4V Using N2 as Propelling Gas, Micro-Mechanical Characterisation of Thermal Spray Coatings, that illustrate current research trends in thermal spray development.

Looking at the future of thermal spray in India, it will be pleasing if the **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)

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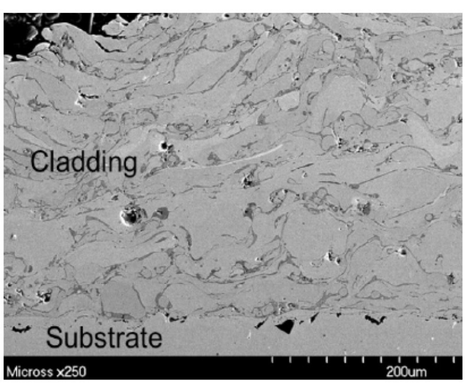

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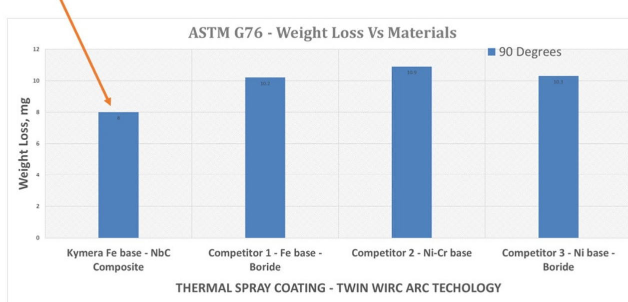

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Introduction to Cold Spray Additive Manufacturing

Is Cold Spray Additive Manufacturing the next massive thing in AM (Additive Manufacturing)!

*By **Manoj Pillai,** Falcon Technologies International, RAK UAE.*
Email: manoj.pillai@falconrak.ae

Introduction

My experience in shifting from polymer machine sales to leading the service bureau industry in middle east have given a new perspective to the entire 3D Printing market scenario in UAE. I have been interacting a lot with Oil and Gas clients and started getting requests for coating and repair of used parts. In addition, there is an interest for multi material components. The quest for a solution to these two requests is leading towards either DED (Direct Energy Deposition) or cold spray. I am inclined more towards cold spray, mainly due to two reasons, one deposition speed is high, and second there is availability of portable machines. This article is a summary of the market research done on the Cold Spray Technology. Here is what I stumbled upon. I am yet waiting for my first direct interaction with an end use application of the technology, which will happen soon. The article will have its limitation in depth of technicality (intentionally); but should serve as a summary for someone who is interested in the basics and developing it further. Will write another one once the first part made of Cold Spray is installed at a customer location.

Low pressure cold spray can deposit upto 5kg/hr of material and high pressure cold spray can deposit material at a rate of upto10 kg/hr. A major aerospace company saved upto 18 million USD in replacement costs and lead times worth 6 months per casing by adopting cold spray and repairing the same. Another company saw huge saving by salvaging a component where the repair cost was only $2850 vs $38,000 new component cost. The lead time was cut short to 4 hours from 3 months.

Technology

CSAM or cold spray additive manufacturing is a new term. Cold spray as a technology was developed accidently by two Erstwhile Soviet Union scientists in 1980.

They were studying multiphase flow around solid objects wind tunnels. At low velocity, the solid particles cause erosion of metals, like Grit or sand blasting. However, at high velocity, they noticed that instead of eroding; the particles stick together and form a solid bond [1]. Then this was investigated further by the researchers and lead to an interesting discovery and patent. Metal particles accelerated at high speeds hitting any surface will form a plastic bond almost equivalent in strength to the original material. This phenomenon of making deposits is called cold spraying because the entire process of forming the bond or layer happens below the melting point of the material. Cold spray will achieve a near net shape by depositing the material and the component will have to be machined to the final dimensional required. Unlike LPBF or other AM processes this technology cannot produce fine features.

There are a few companies around the world making the machines for cold spray application. Lets take a look at the companies making cold spray machines.

Figure 1: Cold Spray Repairs [2]

Table 1: Cold Spray Equipment Manufacturers

Company Name	Location	Portability	Remarks
Impact innovation Systems GmBH	Germany	No	High pressure cold spray systems
Super Sonic a division of Centerline	Canada	Yes	2 systems, both high and low pressure
Innovati	USA	No	Uses Kinetic Metallization . It is the only cold spray process which uses low pressure helium or nitrogen (70-130psi) and a sonic nozzle to accelerate particles. This means that Kinetic Metallization can successfully deposit most materials, including tungsten carbide-cobalt and niobium.
Dymet Cold spray systems	Russia	Yes	Portable low pressure cold spray systems
VRC Metal Systems	USA	Yes	Have 3 systems. GEN111, Raptor mobile systems, Automated Additive, and subtractive systems
Plasma Japan	Japan	No	cold spray 1000 and cold spray 800.
Rus Sonic Technology	USA	Yes	The only Cold Gas Dynamic Spray (CGDS) equipment manufacturer to offer solutions for coating and fabricating using compressed air.
Titomic (Dycomet)	Australia	Yes for smaller size	Two systems, TKF1000 and TKF 9000. They acquired Dycomet from Netherlands who were producing low pressure D523 portable system
Spee3D	Australia	Yes	SPEE3D developed 'Supersonic 3D Deposition'. patented process in which a rocket nozzle accelerates air up to three times the speed of sound, into which metal powder is injected then deposited onto a substrate maneuvered by a six-axis robotic arm
MECPL	India	Yes	Low and High Cold Spray system, SPRAYCOLD 500, SPRAYCOLD 800 and SPRAYCOLD 1000
Obninsk Center for Powder Spraying (OCPS)	Russia	Yes	Research organization for cold spray equipment

Latest in the news

One of the latest news in the industry is about the company Titomic with ticker (TTT-AX) installing their latest machine at TWI. This is a TKF 1000 which can build parts up to 5 meters. This will further develop the UK civil aerospace and defence industry [3]. RC Metal Systems, a leading developer of advanced cold spray technologies, announced today that they have been selected by the U.S. Navy to take part in the 2022 Navy REPTX, sponsored by NAVSEA 05T to provide solutions for pier-side and shipboard cold spray corrosion and battle damage repair and mitigation [4].

Types of Systems

There are two kinds of systems in cold spray and the classification is based on the pressure at which the gas operates. Below 500 Psi inlet pressure is called the low-pressure system and those systems above 500 Psi is the high-pressure system. In low pressure system the particle velocity reaches around 600 m/s vs. 1000 m/s in high pressure system. Both uses de Laval nozzle to accelerate and direct the powder to the substrate. In low pressure system the powder injected after the gas is accelerated in the nozzle, in the high-pressure system the powder is injected before the acceleration in the nozzle.

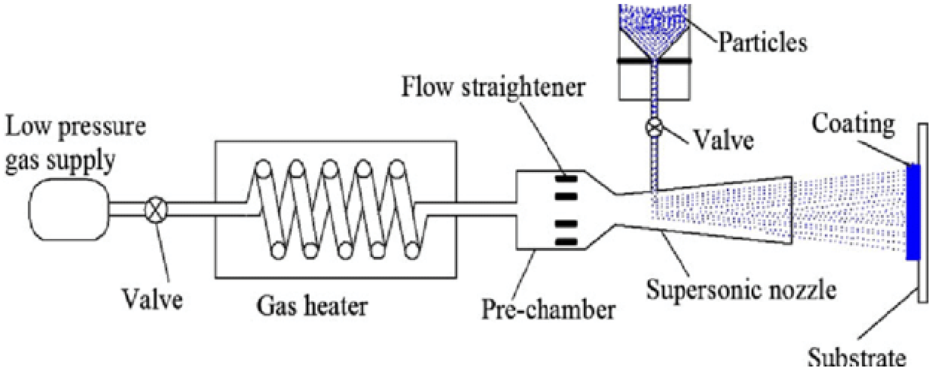


Figure 2: Low Pressure Cold Spray System Schematic [5]

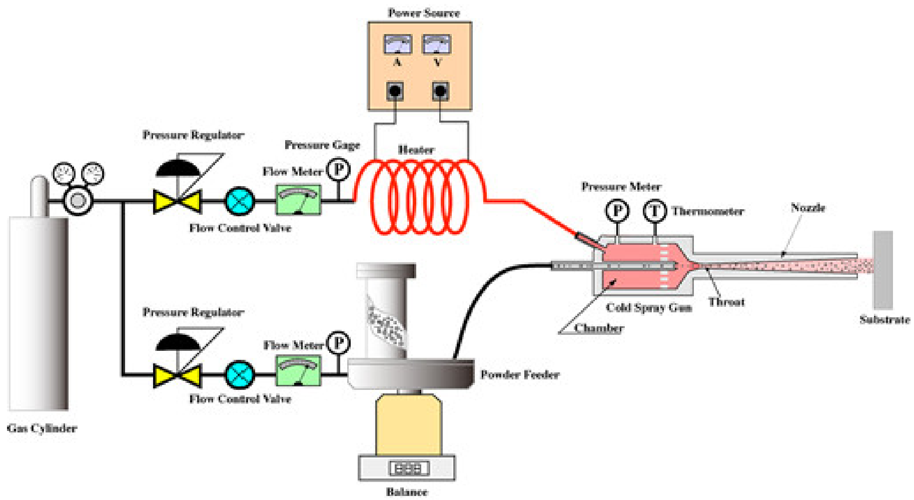


Figure 3: High Pressure Cold Spray (Credit: Dycomet)

Application of Cold Spray

Cold spray finds several industrial applications. A few are listed below.

- Anti-Corrosion coating in Marine and industrial
- Repair of parts in Wind Turbines, Military, Aerospace , Oil and Gas
- Whether coating
- Manufacturing of parts

Advantages of Cold Spray system

- Easy repair
- Faster build rates.
- No residual Stresses
- No Heat Affected zones
- Very minimal surface preparation required
- Improved mechanical properties and fatigue life of the coating
- Faster powder feed rates and 100% reuse of particles
- Multi material buildup

With all this advantages, it is natural to think why this is still not taking over the entire AM spectrum. There are a few disadvantages. One is the cost of the system, second is that the low-pressure system cannot deposit all the materials. Also high pressure system will need Helium or other rare gas to carry the material.

However with the new developments happening with gas control and materials that can be sprayed, and the applications being developed in repair of components, this technology will start getting used in various industries.

Figure 4: Cold Spray rebuilding of turbine Blade- GE [6]

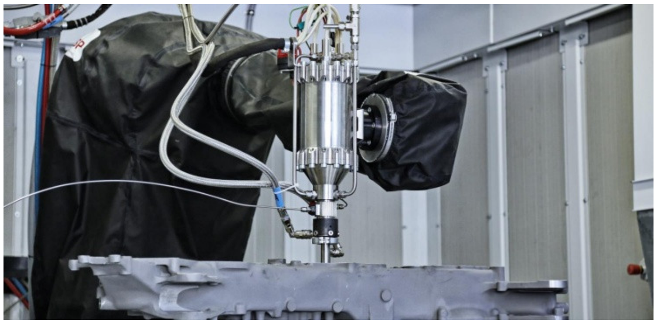
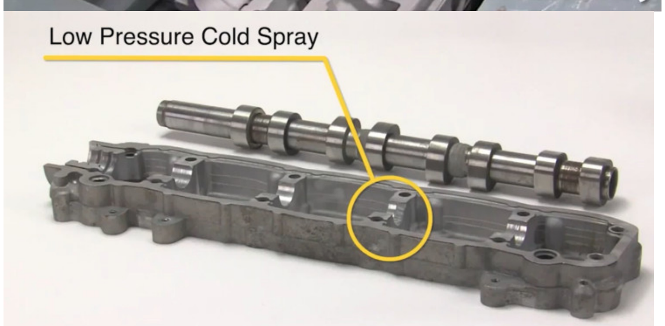


Figure 5: Cold Spray – GE [6]



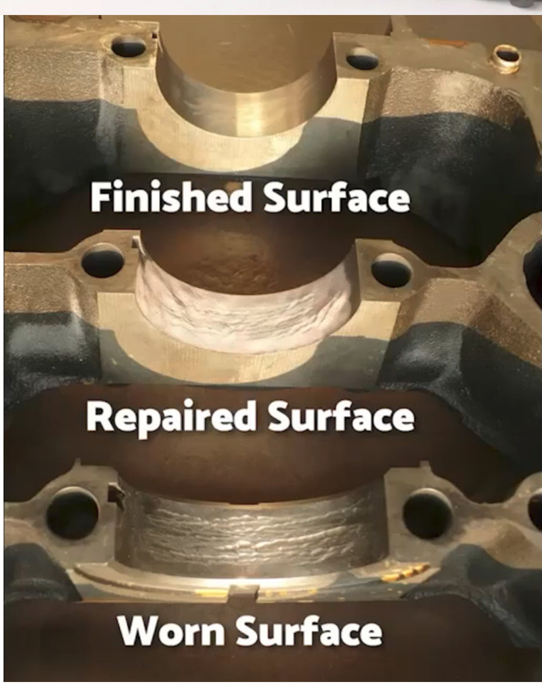


Figure 6: Cold Spray Repair [7]

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Superhydrophobic Surface Development by Thermal Spray Route

By ***Biswajit Swain*[1], *Soumya Sanjeeb Mohapatra*[2] and *Ajit Behera*[1]**
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[2] Department of Chemical Engineering, National Institute of Technology, Rourkela, India, 769008
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Introduction

Superhydrophobic surfaces have attracted the researchers since 1907, when Ollivier observed a high contact angle up to 180° soot, arsenic trioxide and lycopodium powder coated surfaces [1]. Again, in 1923, the abovementioned surface characteristic has been observed on a rough galena surface coated with stearic acids in a work reported by Coghill and Anderson [2]. Furthermore, with the help of experimental evidence, Wenzel [3] and Cassie-Baxter [4,5] have proposed mathematical models. These models revealed the dependency of the superhydrophobic characteristic of a surface on surface roughness and chemical composition (presence of low surface energy materials). In the follow up research, Neinhuis and Barthlott in 1997 [6,7] have revealed that epicuticular wax crystalloids of the lotus leaf are responsible for the self-cleaning property. Several methods have been approached to develop superhydrophobic surface such as wax solidification [8], lithography [9], vapour deposition [10], template method [11], polymer reconformation [12], sublimation [13], electrospinning [14], plasma technique [15], sol-gel processing [16], electrochemical methods [17], layer by layer methods [18], one pot reaction [19] etc. In addition to the above techniques, the superhydrophobic coatings developed by thermal spray technique grab the attention of current generation researcher due to its wide variety of applications in the harsh environment. Therefore, in the current work, the investigation of the superhydrophobic surface developed by one-step plasma spray technique has been performed.

Materials and Methods

For the current investigation, an elemental mixture of the equiatomic Ni and Ti powders have been considered as feedstock material. The coating has been developed using atmospheric plasma spray equipment. All the spray parameters have been presented in the Table 1.

Table 1: Atmospheric plasma spray parameters

APS parameters	Values
Substrate temperature	120 °C
Powder feed rate	60 g/min
Primary gas (Ar) flow rate	45 L/min
Carrier gas (Ar) flow rate	3.5 L/min
Secondary gas (H2) flow rate	8 L/min
Stand-off distance	120 mm
Number of cycles	7
Current	550 A
Voltage	70 V

After the successful deposition, the characterization of the coating has been carried out using scanning electron microscope (model: JEOL 6480LV) and 3D optical profilometer (Contour GT-K (Bruker make) USA). The contact angle and sliding angle have been measured by using Goniometer ((Model no: Kruss DSA 25)).

Results and discussion

In the current investigation, the main responsible factor which is affecting the superhydrophobic characteristic of the developed coating is the surface profile. The roughness value of the developed coating is 12.4 µm.Fig 1 depicts the schematic of droplet behaviour on the superhydrophobic surface, SEM image of the coating surface, 3D optical image of the coating, water contact angle, droplet image and the mechanism of the formation of superhydrophobic characteristic on the rough uneven surface. From the SEM image, the small islands, unmelted particles, splat formation and microcracks have been observed. These small islands and unmelted particles helps in creating surface irregularities which leads to the formation of rough surface.

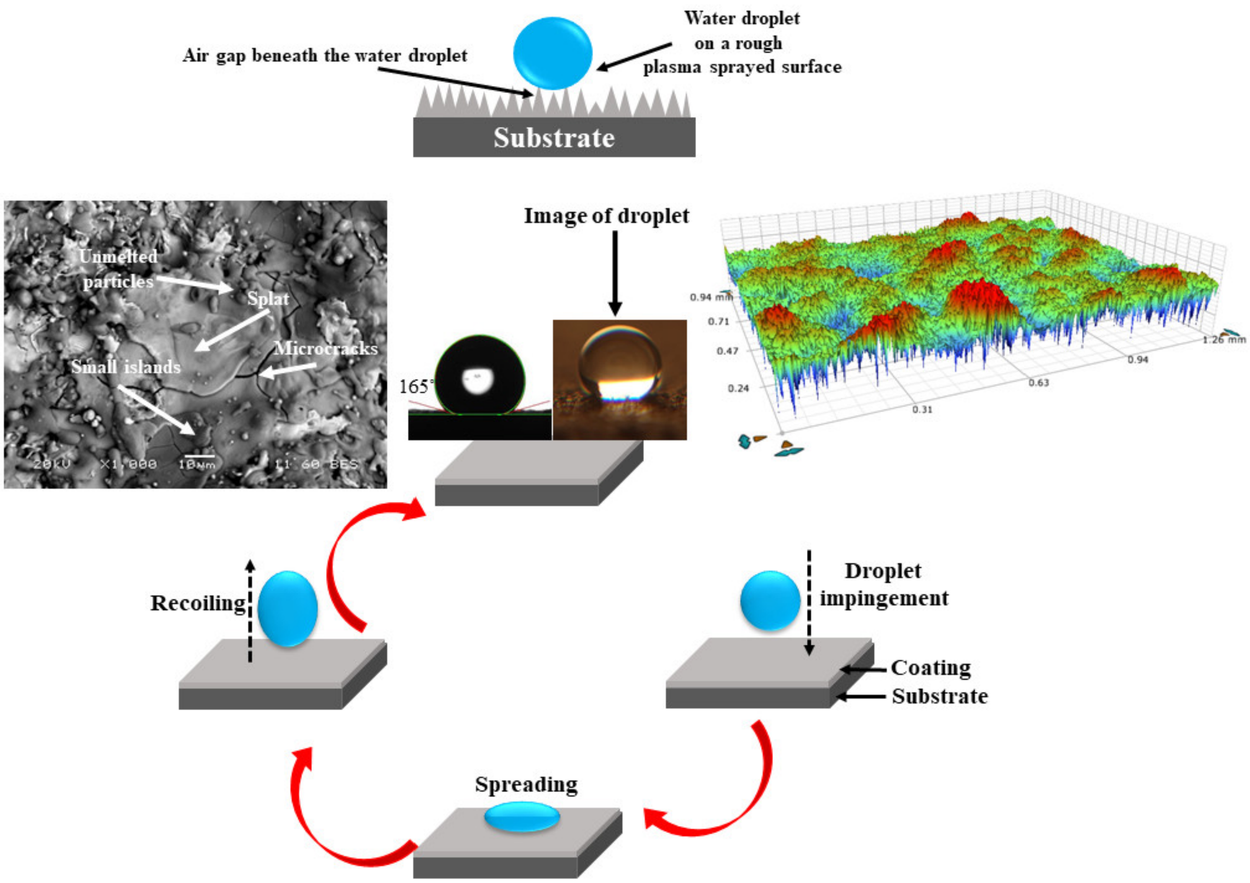

Figure 1: Schematic depicting the droplet behaviour on superhydrophobic surface with SEM, 3D optical profile, contact angle, droplet image and schematic of mechanism depicting the formation of superhydrophobic characteristic due to roughness

The abovementioned small islands are the result of splashing of fully molten particles. Furthermore, the air gap present between the roughness peaks which is beneath the water droplet supports the superhydrophobic characteristic. According to the fluid dynamics theory these micro-roughness creates the partially slip condition which supports the repellency characteristics of the surface and satisfies the Cassie-Baxter theory. The abovementioned phenomenon is believed to be the responsible factor for the development of the superhydrophobic characteristic. The aforesaid claim has been validated by measuring the water contact angle 165±1.5° and sliding angle 8±1°.

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Impact Innovations GmbH demonstrates its unique Cold Spray Additive Manufa-cturing (CSAM) process for Ti-6Al-4V using N2 as propelling gas

*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

The Cold Spray Additive Manufacturing technology is particularly attractive for the manufacturing of large parts, which are challenging for today's powder bed fusion-based 3D printing processes due to equipment size limitations or protective atmosphere necessity, especially when depositing reactive materials such as Ti-6-4.

In **Cold Spray Additive Manufacturing** (CSAM) up to now Ti-6Al-4V was considered as one of the most challenging materials, due to the high critical velocities of the materials to overcome during the deposition process, which resulted porosities in the cold spray deposits of3%and higher. The recently developedCSAM process utilizing theunique combination of cold spray hardware, process parameters & post treatment procedure achieved porosity levels <0,5% and final mechanical properties exceeding the requirementsgiven by the ASTM F3001, ISO 5832-3 and AMS 4930 standards.

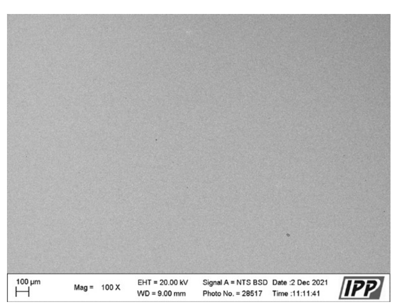
Mechanical properties according to ISO6892-1 in Post Treated State 1			
Property	Yield strength Rp0.2 (MPa)	Ultimate tensile strengthRm (MPa)	Elongation at break A_5 (%)
Direction X	895.3	929.2	19.9
Direction Y	909.8	941.5	19.8
Direction Z	868.5	948.6	18.8
ASTM F3001	795	860	10

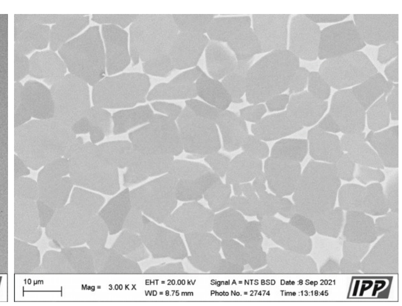
In contrast to other additive manufacturing technologies, powder particles are not melted during the Cold Spray process. The bonding occurs due to plastic deformation. Since Cold Spray does not require high temperatures, unlike other common technologies such as laser, electron beam or wire-arc based processes, it enables deposit components without the necessity of using any protective atmosphere with almost no dimensional limitation and in the absence of thermal residual stresses. The Ti-6-4 material efficiency from powder to deposit is more than 98%.

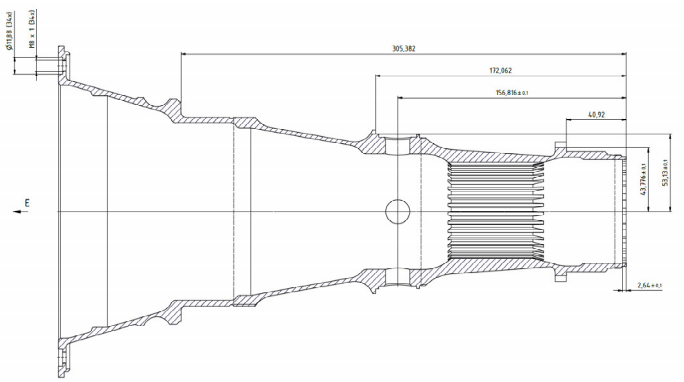
Impact Innovations GmbH decided to demonstrate its new CSAM process by building a Ti-6Al-4V freestanding turbojet aircraft engine fan shaft. The fan shaft is 380mm long and has in its widest place 223mm diameter. It was deposited in about 2h at deposition rate of 2,7kg/h. the net weight of the fan shaft after final machining is 3,2kg.

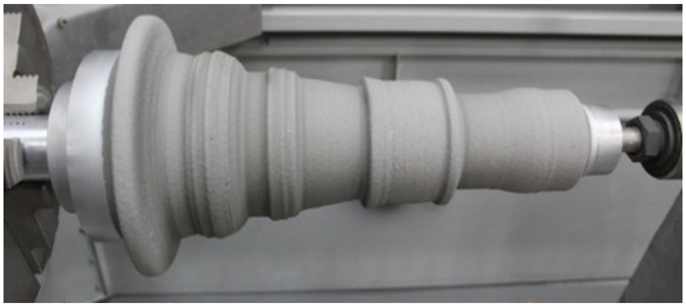
The fan shaft was deposited onto a pre-machined Al alloy mandrel, which was removed after the Ti-6Al-4V deposition by chemical dissolution. Subsequently the fan shaft demonstrator underwent dedicated post treatment processes to achieve the desired mechanical properties followed by turning to the final outer design and creating the additional features by other conventional subtractive manufacturing processes.

The Ti-6Al-4V alloy is typically used in marine and defence applications, for manufacturing aerospace structural parts, gas turbine components and biomedical implants and prostheses.

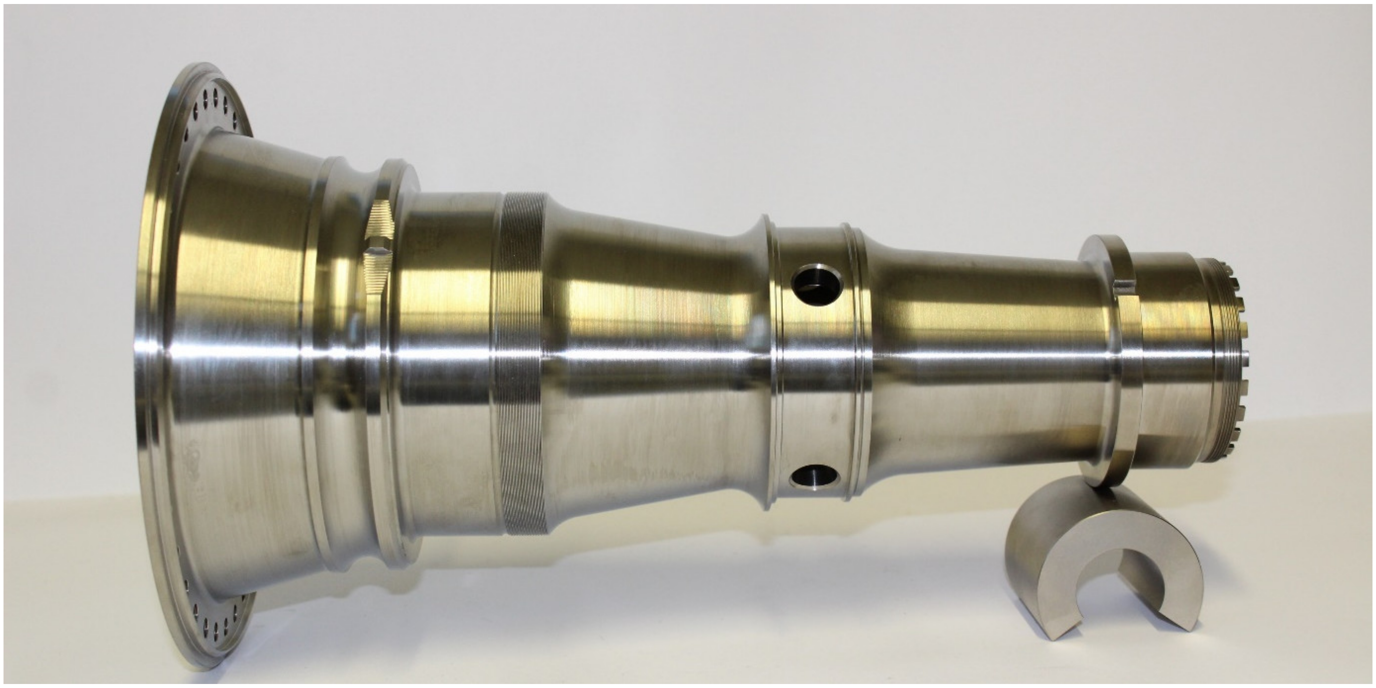








3,2kg net weight = ~2h deposition time



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Micro-mechanical characterisation of thermal spray coatings

By ***Ashwini Kumar Mishra, Bikash Kumar, Deepesh Yadav, Saim Abbas, Nagamani Jaya Balila,*** *Micromechanics of Materials Group, Department of Metallurgical Engineering & Materials Sceince, Indian Institute of Technology Bombay, Powai, Mumbai 400076, India.*
Email: jayabalila@iitb.ac.in

Introduction

The Micromechanics of Materials (MMM) Group at the Department of Metallurgical Engineering & Materials Sceince, IIT Bombay is involved in extensive micromechanical characterisation of thermal spray coatings including residual stress assessment and modeling, elastic property measurement, and fracture and interface strength determination of thermal spray coatings, mainly deposited by air plasma spray (APS) and high velocity oxy fuel (HVOF) techniques. Varied materials systems including thermal barriers, wear resistant coatings and bond coats have been explored in the group. The work started with the visit of Prof Sanjay, Sampath, Stony Brook Uiversity, New York, a pioneer in this area, to our lab in 2019. Following his visit, we set up multi-nodal collaborations with his group, the Center for Thermal Spray, Stony Brook University, companies like Pratt & Whitney, MECPL, Jodhpur, Associated Plasmatron, Mumbai, national labs like Naval Materials Research Labs and so on. In this article, we describe some of the selected capabilities of the MMM group in the area of microstructure and micromechanical charactersiation of thermal spray coatings. These works are being mainly carried out by PhD students and post-doctoral researchers.

Residual stress estimation of thermal spray coating system using thermo-mechanical finite element modeling

Residual stressesinvariably develop in thermal spray coatings during deposition and in service, due to their thermal, elastic and plastic incompatibility with the substrate. Accurate estimation of in-process residual stresses helps design deposition schedules better to achieve thicker coatings, while post thermal-cycling estimation will help predict their lifetime in service. There are in-situ based measurement tools, but they are not common and are an expensive method to determine residual stresses. Finite element modeling offers a less expensive alternative, which following the process of validation can be used to replace actual measurements. In the present work, a finite element-based heat transfer model is proposed (Fig 1-2) to track the thermal characteristics and residual stress enablingcapture of the quality, integrity and performance of the deposit for industrial significance.

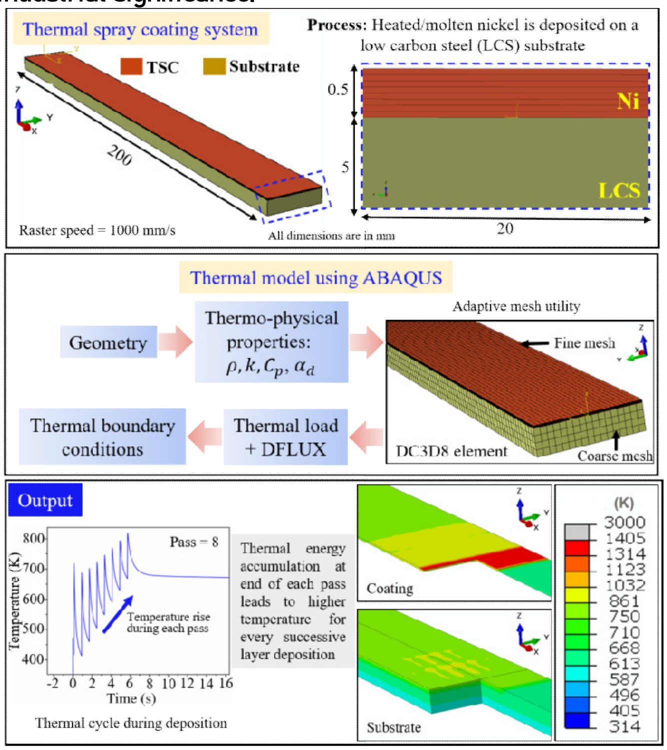

Figure 1: Overview of the heat transfer model used to characterize the temperature field evolving during thermal spray coating process. The variation of temperature with respect to time comprises the thermal cycle. The thermal cycle extracted from the model is composed of 8 spikes representing 8 passes. The 3-D contour plot shows the temperature distribution over the coating and substrate with the color-coded magnitude legend

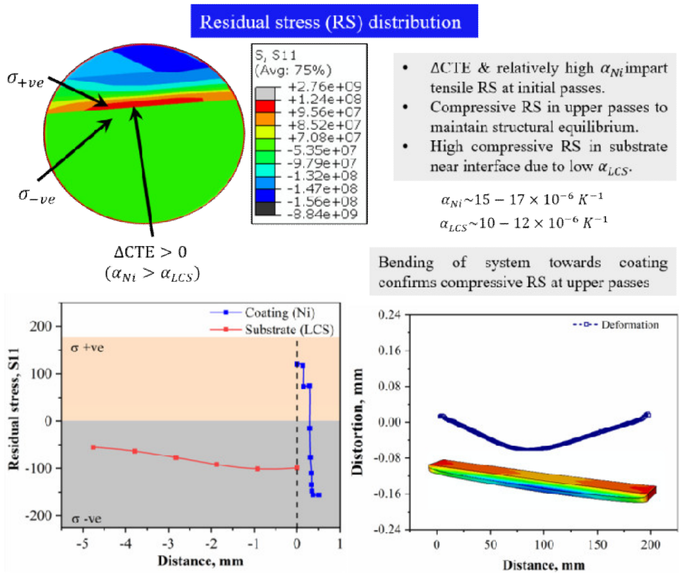

Figure 2: Overview of the stress field developed after cooling of the deposition. The deposition near the interface experiences stress reversaldue to ΔCTE ΔCTE – difference in thermal expansion coefficient between coating and substrate.

Elastic property measurements of thermal spray coatings

Elastic modulus measurements of coatings through the slopes of the load-displacement curves requires precise measurements of displacements during loading, which can be done through non-contact extensometers coupled with digital image correlation (DIC) in a universal testing machine (UTM). Four point bending of the entire coating-substrate system replaces the need to make free-standing coatings for such measurements, which are challenging especially for porous, thin coatings. In the case of a homogenous rectangular beam, the neutral axis coincides with the centroid of the cross-section during symmetrical bending. But, in the case of a coated system with a coating of different elastic modulus, the beam isno longer homogenous,leading to a shift of the neutral axis from the centroid of the cross-section. Therefore, the in-plane elastic modulus can be determinedusing the shift of the neutral axis. In 4-point bending with coating in compression, the elastic modulus of the coating can be calculated using (Fig 3 a-b) [C. C. Chiu, J Am. Ceram. Soc. 73 (1990) 1999, C. C. Chiu& E. D. Case, Mater. Sci. Eng. A 132 (1991) 39]:

$$E_c = E_s R_{sb} \left(\frac{K R_{sb} + 2K - R_{sb}}{2R_{sb} - K + 1} \right) \quad (1)$$

where, subscripts c & s represent the coating and substrate respectively, E is the elastic modulus, $R = h_s/h_c$, h isthe thickness, $K = -\varepsilon_s/\varepsilon_c$, ε is the longitudinal strain.The E_c of the alumina coating was determined to be 166 GPa using this experiment.

The alumina coating was deposited on a steel substrate using the Air Plasma Spray process at MECPL, Jodhpur.

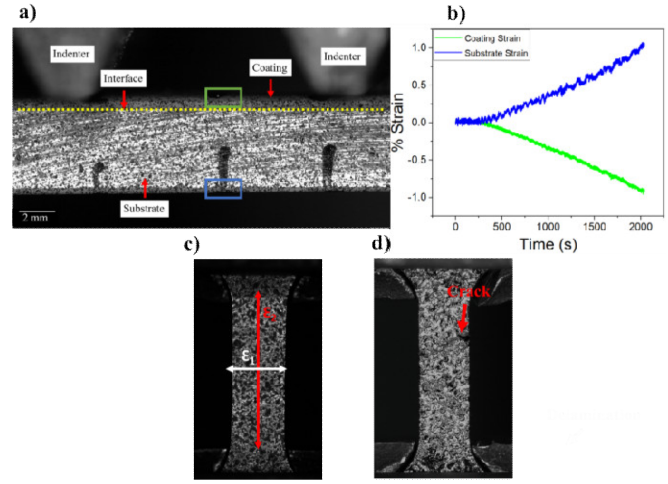

Figure 3:a)-b) The variation in the coating and substrate strains with time when subjected to 4-point bend test with coating under compression (The supports at the bottom were outside the camera frame) c) Tension test set up for elastic modulus measurement of free-standing coating d) Failure of coating in tension test. The speckle particles sprayed on the specimen surface are used to map the full field strain using DIC.

In addition, for thick coatings, elastic modulus and Poisson's ratio can also be directly determined using free-standing coatings subjected to tension (Fig 3 c-d).

$$\nu = -\frac{\varepsilon_1}{\varepsilon_2} \quad (2)$$

where, ν is the Poisson's ratio, ε_1 and ε_2 are the lateral and longitudinal strains.

The elastic properties can be correlated to the porosity in the coating (Fig 4), which invariably leads to lower stiffness compared to the dense counterpart. Porosity in turn can be controlled using process parameters.

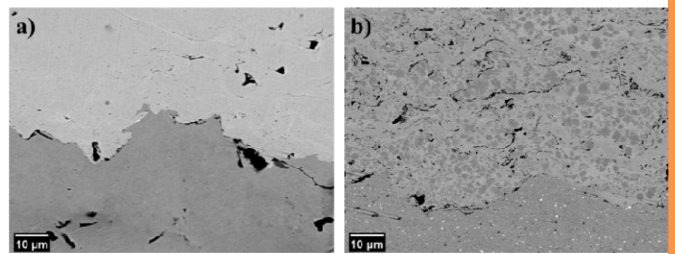

Figure 4: a) Ni and b) NiCrAlY coatings synthesized by HVOF process.

Evaluation of damage evolution in thermal spray coatings

The damage evolution in the thermal spray coatings in terms of adhesive & cohesive strengths can be measured by tension based shear lag test (Fig 5a). If the coatings is weaker and more brittle than the interface, coating crack

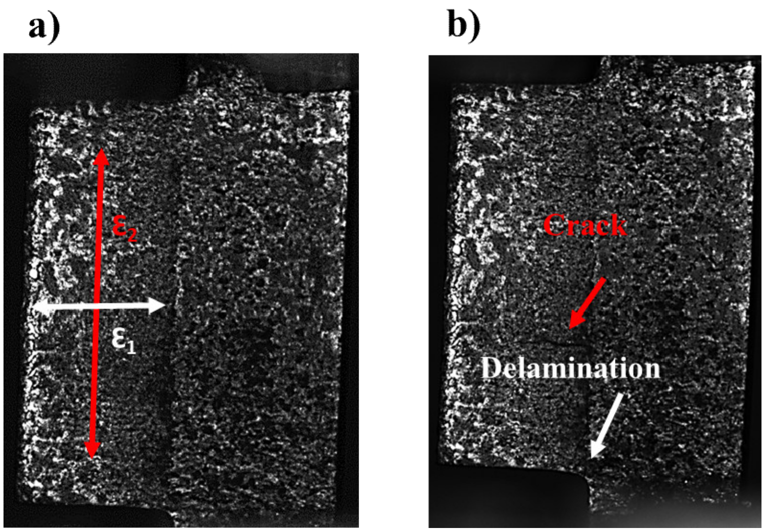

Figure 5: a) Shear lag test set up for cohesive and adhesive measurement b) Failure of coating by cracking and delamination

occurs first followed by delamination. Fracture strengths can be determined quantitatively using DIC coupled with FEM (Fig 5b). Fracture strength of Ni, Ni-5Al and NiCrAlY bond coats have been determined using this technique.

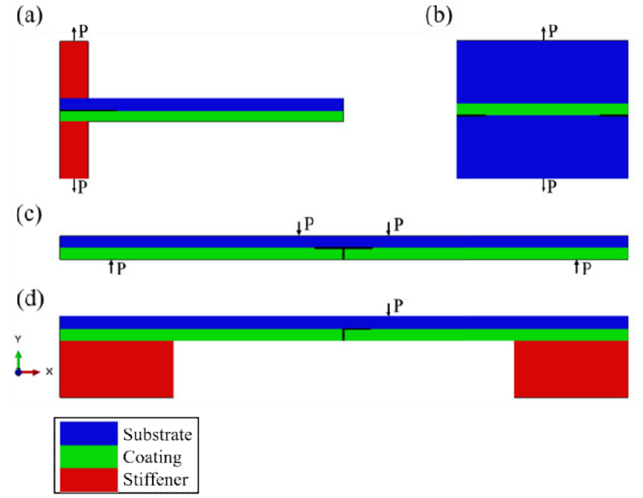

Figure 6: Schematic of a) double cantilever bending b) modified tensile adhesion c) 4-point bending and d) modified clamped beam bending tests

Interface fracture energy measurement of thermal spray coatings

Interface fracture energy measurementsare required to quantify the decohesion/delamination properties of coatings. Interface fracture energy is directly related to decohesion. Higher interface fracture energy signifies better adhesion strength. High adhesion strength is required in coatings to prevent delamination during thermo-mechanical loading in service. We are developing new techniques for interface fracture energy measurem-ent to overcome the challenges of conventional methods. Fig 6 shows four such techniques that can be used. The double cantilever bending and modified tensile adhesion depend on the adhesive property of the glue used as well as the properties of the stiffener. 4-point bending requires symmteric crack propagation on both sides of the beam. Modified clamped beam bending relieves both these problems.FEM is used to determine the energy release rates for interface crack growth and the failure load is input to determine the critical interfacial fracture energy.

Using these methods above, interface fracture energy measurements have been carried out on Yttria Stabilized Zirconia and Alumina coatings on metallic substrates.

For more information, please refer to the following publications/conference proceedings:

References

1. K. Mishra, S. Sampath, G. M. Smith, and N. J. Balila, “Experimental Measurements of Interface Fracture Toughness Using Double Cantilever Bending,” in Prakash R., Suresh Kumar R., Nagesha A., Sasikala G., Bhaduri A. (eds) Structural Integrity Assessment. Lecture Notes in Mechanical Engineering. Springer, Singapore, 2020, pp. 511–522.
2. K. Mishra, A. Pagare, S. V Shinde, S. Sampath, and B. N. Jaya, “Modified Clamped Beam Bend Method for Determination of Interfacial Fracture Energy of Thermally Sprayed Yttria Stabilised Zirconia Over Steel,” 2022. (Under Review)

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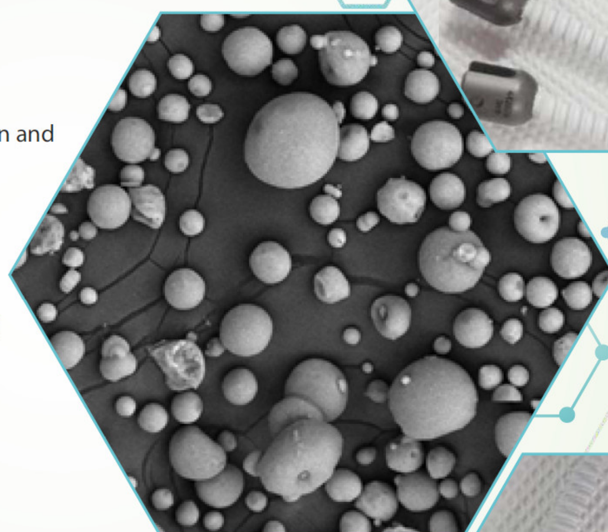
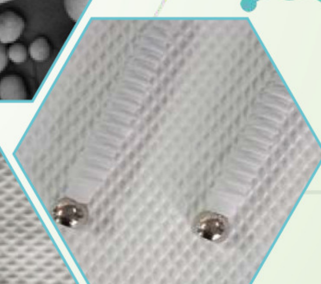
Hydroxyapatite powder details

- **Product name:** Hydroxyapatite powder, submicron particle (DLS), ≥ 99% (trace metal basis), synthetic
- **Chemical formula:** $Ca_5(PO_4)_3(OH)/Ca_{10}(PO_4)_6(OH)_2$
- **Formula weight:** 502.31 g/mol
- **CAS number:** 12167-74-7
- **Appearance:** Milky white free flowing powder
- **Manufacturing route:** Wet chemical precipitation
- **Major applications:** Biomedical graft, scaffold fabrication and implant coating applications



Physical and Chemical Properties
(conforms to specifications)

- **Phase purity:** X-Ray Diffraction
- **Chemical composition (Ca/P ratio):** 1.66 – 1.71 (ICP-MS)
- **Purity by XRF analysis, wt %:** ≥ 99%
- **Trace analysis (ICP):** 99% (min), per determination of trace metallic impurities
- **Melting point:** 1670 °C
- **Decomposition temp:** 1400 °C
- **Crystallite size:** 15 nm – 20 nm
- **Density (Helium gas pycnometry):** 3.15 – 3.20 g/cc
- **Average particle size:** 40-200 microns
- **Particle morphology:** Spherical, Spray dried/Granulated
- **Proposed sterilisation mode:** Gamma, EtO
- **Preferred coating route:** Atmospheric plasma spray
- **International standards:** ISO 13779-3, 6 ISO 13485 and ASTM-F1185-035



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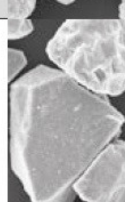
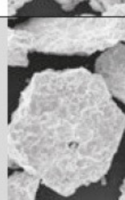
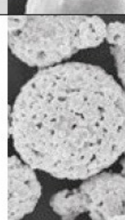
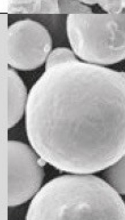
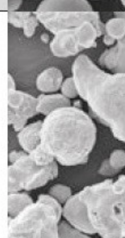
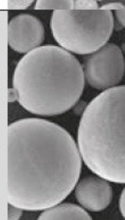
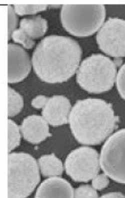
Thermal Spray Powder Types, Manufacturing Process & Characteristics

Powder type	Fused and crushed	Sintered and crushed	Agglomerated and sintered	Gas atomized	Water atomized	Spheroidized	Blended
							
Process	Fusing in arc furnaces, followed by cooling and crushing	Sintering of raw materials, crushing	Spray drying of a suspension consisting of fine powders and organic binder and subsequent sintering	Atomizing molten metal or alloy with high pressure gas (Ar, N_2) stream into a chamber	Atomizing with water into a chamber and subsequent drying	Feeding of agglomerates into a plasma flame to produce spherical particles	Mixing of 2 or more powders
Characteristics	Blocky, irregular, dense	Blocky, irregular, relatively dense	Spherical, porous, constituents homogenously distributed	Spherical, dense, high purity, low oxygen content	Irregular, dense, increased oxygen content compared to gas atomized	Spherical, porous or hollow, partly open (shells)	Different morphologies, segregation possible
Examples	Al_2O_3; Cr_2O_3; ZrO_2-Y_2O_3	WC-CoCr	WC-CoCr; Cr_3C_2-NiCr; ZrO_2-Y_2O_3	MCrAlY; Ni-, Co-base alloys; NiAl	NiCr; NiAl	ZrO_2-Y_2O_3	NiSF+WC-Co; Mo + NiSF; Cr_3C_2-NiCr; AlSi-Polys

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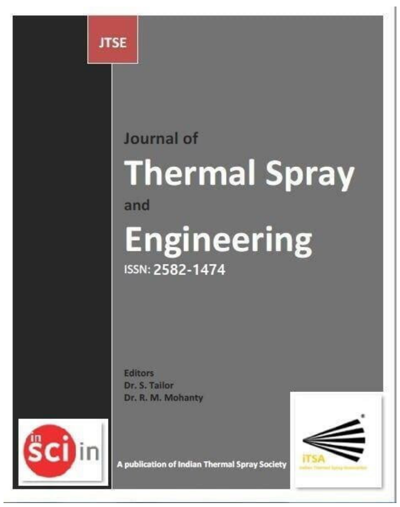

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