On the study side: The Cold Spray

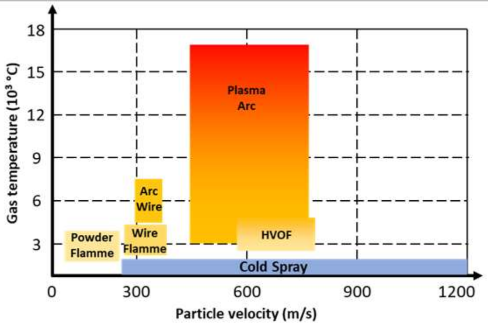
Tooling in industry is generally exposed to extreme environments in terms of heat, corrosion, mechanical stress, etc. In order to extend the life of these tools, it may be interesting to use protective layers that can be implemented by Cold Spray deposition, to envisage repairs or even additive manufacturing, using this same technology.

In this issue, this thermal spray equipment used by ICAR-CM2T will be discussed along with all the aspects surrounding it. Cold Spray is a coating technique involving the projection of small cold particles (5-40 µm) at high speed (300-1500 m/s) onto a substrate, using a supersonic gas (He, N_2, Ar, Air). The deposit is then formed by particles that have impacted the substrate in the solid state.

Principle

The principle of Cold Spray is based on keeping the particles in a solid state during their projection. Their densification results from their very high impact velocity (largely supersonic) and their ability to deform plastically. It is the spray gas that is heated, which increases the speed of the particles by reducing their viscosity, without reaching melting temperatures.

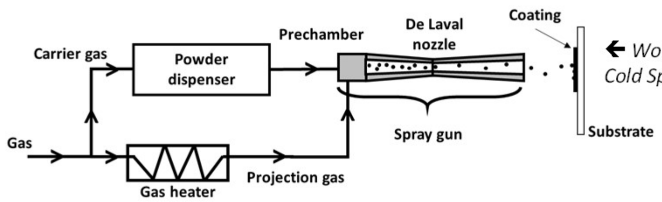
Cold Spray focuses on ***kinetic energy*** *rather than* ***thermal energy****.*



The Cold Spray process as part of the overall thermal spraying process (according to Techniques de l'ingénieur)

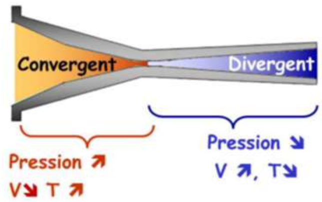
How it works

The spray powder, which comes from the powder dispenser, is fed by the carrier gas to a convergent-divergent nozzle (Laval nozzle). The nozzle will accelerate the spray gas, which has been previously heated and compressed, to supersonic speed. Once propelled out of the nozzle, by the spray gun, the particles collide with the substrate, which is located at a some distance from the nozzle. The coating then results from the stacking of the particles which are plastically deformed on impact. The lower layers, which are close to the surface of the substrate, will be the densest due to the hammering effect of the particles as they are deposited.



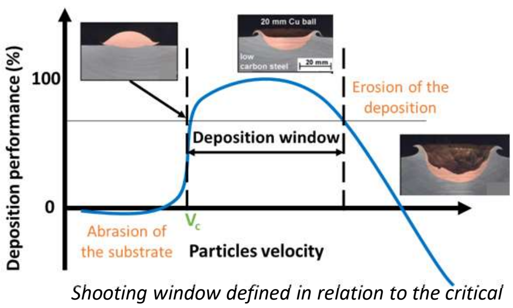
← Working principle of the High Pressure Cold Spray

The core of the process: the Laval nozzle →



Critical speed and shooting window

In order to obtain a dense coating, the particles must reach a velocity higher than a so-called critical velocity "v_c" during the impact. This speed depends on the nature of the powder, its morphology and also its size. The finer the particles, the higher the velocity. If the speed is lower than this v_c, the particles will erode the substrate by abrasion, without adhesion. A second erosion phenomenon is encountered when the speed is much higher than the v_c (overspeed).



Shooting window defined in relation to the critical particle velocity

Projection parameters to be optimized

Cold Spray is not an easy process, many parameters influence the adhesion of the particles to the substrate and the increase in coating thickness. It is therefore important to control each of these parameters in order to avoid any surprises during the spraying tests. The particle velocity is the main parameter to control, as seen in the previous paragraph. It can be adjusted with the temperature, pressure and type of gas used, but also with the nozzle geometry. The distance and angle of projection also influence the adhesion of the particles to the substrate and to each other; a 90° angle of projection is often preferred. Furthermore, the properties of the powder (composition, particle size, morphology, pre-treatment, etc.) and those of the substrate (nature, hardness, surface preparation, etc.) play an important role.

What materials can be projected and on which substrates?

The list of materials that can be deposited by Cold Spray is very large and includes metals (Al, Cu, Zn, Ni, Ta, Ti, Cr, Nb, Zr, Ag, Sn, ...), alloys (copper, MCrAlY's, Hastelloy, Inconel, austenitic stainless steel, steel, etc.), composites (WC/Co, WC/NiCr, Al/SiC, Cu/W, Al/Al_2O_3, etc.) or even polymers (PA, PEEK).

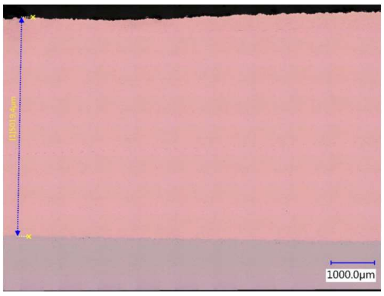
The substrates that can be used are also numerous and quite different from one another, including metals (steel, cast iron, etc.) and alloys, solid and composite polymers, certain ceramics (Al_2O_3, ZrO_2, etc.) and glass.

ICAR-CM2T – Ingénierie Matière - 4 Rue Lavoisier - 54300 MONCEL LES LUNEVILLE
Tél. : 33 (0)3 83 76 39 39 - Fax : 33 (0)3 83 76 39 40

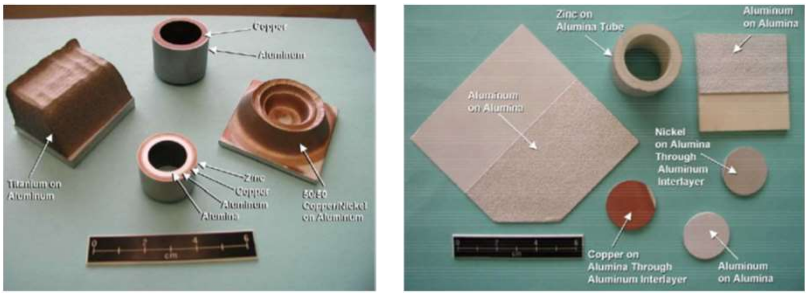
ICAR-CM2T
Ingénierie Matière

e-Newsletter no.45 – September 2021

www.icar-cm2t.com
info@icar-cm2t.com



Dense copper deposit with a thickness >5 mm and a spraying efficiency >99%



Examples of substrate/deposition combinations (Source: Key Tech)

Advantages of Cold Spray

The Cold Spray coating process has many advantages due to its unique operation, the main ones are:

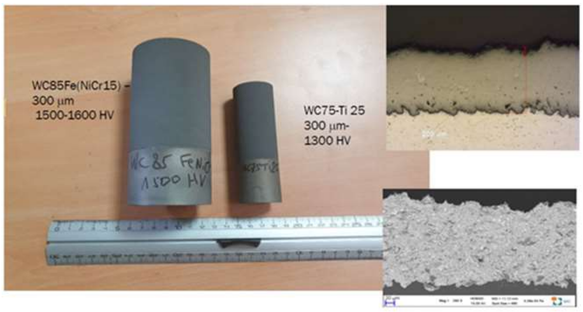
- Low substrate temperature (80 to 150°C): possibility of coating heat sensitive materials without changing the structure of the material.
- Adjustable spray width: depending on the nozzle geometry.
- A wide range of coating thicknesses for some materials: from a few tens of micrometers to several tens of millimeters (possibility of using Cold Spray in additive manufacturing).
- No melting or oxidation of the particles in flight: possibility of depositing materials sensitive to oxidation (Zr, Ti, Ta, Al).
- High spraying yields (>80% for some materials (Cu, Ti, Zr, stainless steel, etc.)) with a very low porosity rate (<1%).
- High coating hardness: linked to particle strain hardening.

Cold Spray applications

Cold Spray is used in many applications which can be divided into three categories: surface treatment, part repair and additive manufacturing.

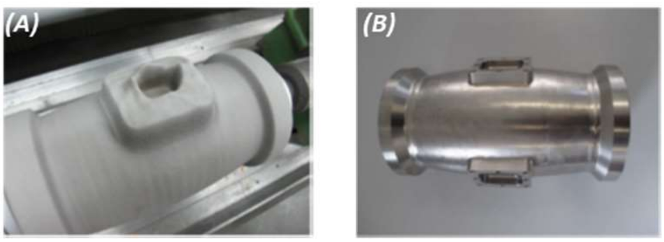
The surface treatments concern first of all the anti-corrosion which consists in depositing a coating on a substrate in order to protect it from corrosion in its environment. The powders most frequently used for this application are aluminum and alloys, stainless steels, nickel and alloys, tantalum or zirconium. Surface treatments are also used to metalize dielectric substrates (composites, polymers, ...) in order to make them conductive, or to metalize conductive substrates to improve their conduction. In both cases the coatings are mainly copper of a few tenths thickness. Surface coatings can also be used to improve heat conduction or heat exchange, in which case copper or aluminum is sprayed between 100µm and a few millimeters. Other surface functionalities can be implemented such as anti-wear coatings with carbide coatings or even bactericidal coatings by spraying hydroxyapatite alloyed with silver or brass. In addition, post-treatments can be carried out to chemically adjust the deposited layer. Furthermore, brazing deposits and the creation of brazing interfaces can be carried out for the elaboration of ceramic/metal assemblies.

Cold Spray can also be used for **part repair**. Indeed, the spraying process has the advantage of offering little heating and deformation of the part. It is also possible to carry out important repairs, up to several kilograms. In addition, the mechanical properties of the repaired areas are comparable to those of the base metal. Cold Spray repair allows parts to be returned to their original condition from a dimensional and geometric point of view. This repair can also improve the life of parts in service or even allow the addition of functionality (flange, fastener, pin, stiffener, ...). The repaired parts can be heat treated if necessary and remanufactured.



Deposition of carbides for anti-wear application (credit: ICAR-CM2T)

Finally, **additive manufacturing** is the new application that is being democratized with the use of Cold Spray. Its use allows the elaboration of very thick deposits (several centimeters) or even the possibility of assembling different materials between them, with a very precise and localized projection of the powder. The main advantages of the use of Cold Spray compared to selective laser fusion are the productivity (a few kilograms per hour) and the mechanical properties of the deposits, which are similar to those of the material produced in a conventional way after heat treatment. However, this technology still faces certain limitations, such as the development of complex shapes and the need to rework the parts.
The use of Cold Spray for additive manufacturing implies an increased optimization of the powders (hardness, morphology, microstructure, ...), the use of new specific nozzles.



Cold Spray additive manufacturing (A) of a raw titanium preform and (B) finished part after heat treatment (credit: Impact innovation)

ICAR-CM2T – Ingénierie Matière - 4 Rue Lavoisier - 54300 MONCEL LES LUNEVILLE
Tél. : 33 (0)3 83 76 39 39 - Fax : 33 (0)3 83 76 39 40

KUKA robot with Impact 5/11 spray gun and turners and positioners in the spray cabin

Cold Spray installation

The Cold Spray equipment, to which ICAR-CM2T has access, is an Impact 5/11 high pressure system (Impact Innovations GmbH) which allows to work at a maximum temperature of 1100°C and a pressure of 50 bars. The system is also associated with a control panel that allows to manage the shooting parameters.

The Cold Spray system is mounted on a KUKA KR 60-2 JET robot, which is installed on a frame and has six axes that allow it to move widely and coat large parts. Two turners and a dual-axis positioner can also be used to coat rotational parts.

ICAR-CM2T know-how in Cold Spray

ICAR-CM2T has experience in spraying many metallic and composite powders, acquired since 2003 :

- Ti and Ta6V dense and porous
- Nickel and cobalt bases (F. Raletz thesis): Inco 625 and 718, MCRAlY
- Cu and bronzes
- ZnAl (soldering and corrosion protection, EMI shielding)
- Al base (series 2000, 6000 and 7000)
- Composites (Al/SiC, Al/Al_2O_3, WC/FeNiCr, WC/Ti, Al/CNT, WC/Co, WC/NiCr, ...)
- Stainless steel (ferritic and austenitic (304, 316L)
- Zn, Sn, Ag, Ta, Zr
- Kovar, Invar 36 ...

Cold Spray Impact 5/11 installation (credit: Impact Innovations) ➔

🡐 *Impact 5/11 water cooled spray gun (credit: Impact Innovations)*

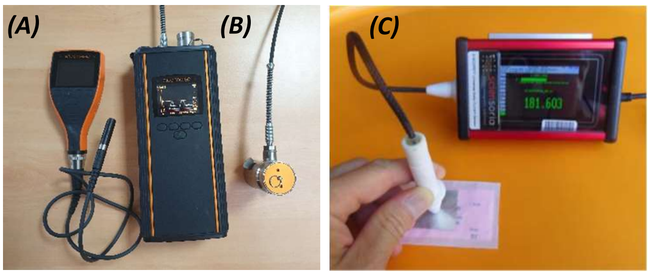
The experience around these different powders has been acquired during different R&D and resourcing projects, including the **Bebest** project which concerns the metal coating of polymers, glass and CFRP (carbon fiber reinforced polymers), polymer coatings on metal, additive manufacturing and process hybridization; the **Clean Sky CO3** project which concerns the metallization of thermoplastic and thermosetting polymers and CFRP for aeronautical applications (anti-dust, electrical conduction) or the **Costhedi** project which concerns the Cold Spray and nitriding hybridization to form TiAlN layers and coatings rich in MAX phases Other projects have also used Cold Spray, such as **Soprodsyse** (Cold Spray hybridization and MAO treatment), **Zircospray**, **Protector**, **Promapal** or **Nicolhass** (Cold Spray solder deposition).
ICAR-CM2T has also developed Cold Spray through industrial collaborations in different fields of application: electrical and thermal conductions (Busbars and contacts), automotive (engine cylinder coating, anti-corrosion), aeronautics (repair of aluminium and magnesium alloy parts, repair of turbine blades and EMI shielding), anti-corrosion (aqueous and high temperature environments), chemistry and pharmacy, and tribology (anti-wear and friction).

Inspection and characterization of coatings

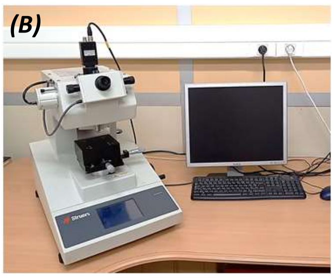
Once the coating has been done by Cold Spray, it is important to check the quality of the deposit and its thickness and the integrity of the interface. To ensure this, various characterization methods are available at ICAR-CM2T.

The adhesion level between the coating and the substrate is measured by a portable Elcometer 510 traction device. It allows to determine the breaking load of the coating after sticking a pin to its surface. The higher the breaking load, the better the coating adheres to the substrate.

In the context of a treatment to metalize a surface and make it conductive, it is important to evaluate the electrical conduction of the coating. It is then measured by a Sciensoria device that uses Foucault currents.



Portable devices for measuring thickness (A), adhesion (B) and electrical conduction (C) of coatings



Olympus optical microscope (A) and Duramin microdurometer (Struers) (B)

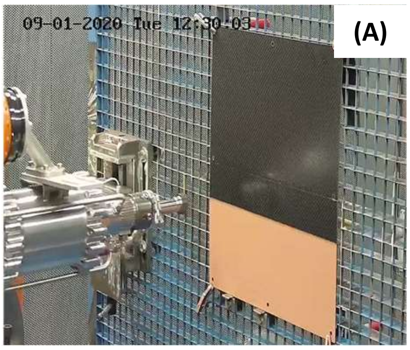
Coating thicknesses can be measured by an Elcometer 456 coating thickness gauge. This device uses the electromagnetic induction principle for non-magnetic coatings and the Foucault current method for non-conductive coatings applied to non-ferrous metal substrates. Thickness measurements can also be measured more precisely by observation with an optical microscope (Olympus) after a polishing step of a section of the coating/substrate couple. The microscope observation also allows to appreciate the quality of the coating from a microstructural point of view and the absence of porosity.

The last aspect of characterization concerns mechanical measurements, and in particular microhardness by Vickers indentation which can be carried out on the coatings or even at the interfaces in order to appreciate the toughness.

ICAR-CM2T – Ingénierie Matière - 4 Rue Lavoisier - 54300 MONCEL LES LUNEVILLE
Tél. : 33 (0)3 83 76 39 39 - Fax : 33 (0)3 83 76 39 40

Examples of ICAR-CM2T realizations

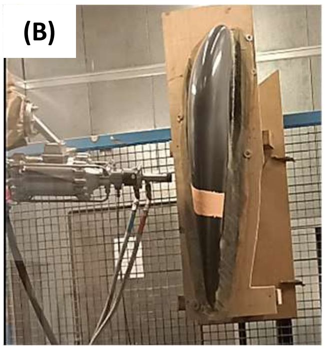
Internal coating Al2024 and pure Cu on stainless steel tube diameter 95 mm

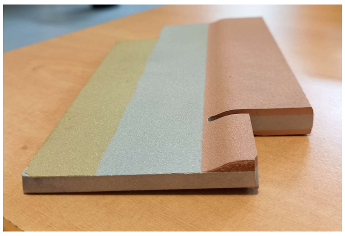


(A)

Pure copper deposition on a carbon/epoxy CFRP plate (600x600mm) (A) and on a carbon/epoxy CFRP demonstrator (B) (Clean Sky CO3 project [1])

(B)





🡐 Thick coatings of brass and copper on an aluminum substrate

Thick copper coating on a steel substrate 🡒

🡐 Nozzle for vertical walls

[1] Delloro, F., Chebbi, A., Perrin, H., Ezo'o, G., Bastien, A., Ascani, J., & Tazibt, A. (2021, June). Cold Spray of Metallic Coatings on Polymer Based Composites for the Lightning Strike Protection of Airplane Structures. In ITSC2021 (pp. 87-95). ASM International. https://doi.org/10.31399/asm.cp.itsc2021p0087

If you are interested in feasibility studies or Cold Spray deposits or if you want to know more... CONTACT US...

Bibliography :

This selection of publications is the result of the Technological Watch carried out by the Documentation Department of the SFC (French Ceramics Society). For more information on these scientific, technical or competitive monitoring products: monthly monitoring bulletin, specific targeted monitoring, access to the "CeramBase" monitoring database, contact the SFC at: ***soc.fr.ceram@ceramique.fr***

SFC

•KIMURA T., ISHIHARA S., NISHIDA K, et AL.
The influence of steel plates on refractory in cement rotary kilns
Journal of the Technical Association of Refractories, Japan, Vol. 41, n°02, 06/21, pp. 64-69, 10 fig., 4 tab., bibliographie (3 réf.), ANG.
The poor quality of waste materials that feed the rotary kilns can be varied and introduced in large quantities. The load on the refractory bricks is thus significant, causing considerable damage. This article presents the case of a kiln whose life is affected by steel plates placed at certain joints. The case of a kiln whose service life is improved by the use of mortar is presented in comparison.
Mots clé : ROTARY KILN. CEMENT. MORTAR. METALLIC PLATES. SERVICE LIFE.

Next training sessions (in french)

- ***Le 5 octobre 2021 à Moncel-les-Lunéville : (STR4) Calcul thermique – (7h)***
- ***Du 2 au 4 novembre 2021 à la SFC (Les Ulis) pour le CTIF : Produits réfractaires dans l'industrie (17h)***

- ***Du 22 au 26 novembre 2021 à Moncel-les-Lunéville : (STR3) Tenue en service et traitement des réfractaires usagés – 1ère partie 18h, 2nde partie 14h***
- ***Du 23 au 25 mars 2022 à Moncel-les-Lunéville : (STR1) Généralités sur les Réfractaires – (18h)***

As usual, the possibility to provide on site dedicated training program,

DATADOCKÉ

ICAR-CM2T – Ingénierie Matière - 4 Rue Lavoisier - 54300 MONCEL LES LUNEVILLE
Tél. : 33 (0)3 83 76 39 39 - Fax : 33 (0)3 83 76 39 40