Spray Coatings

- Thermal spray coatings
- Cold (gas) spraying

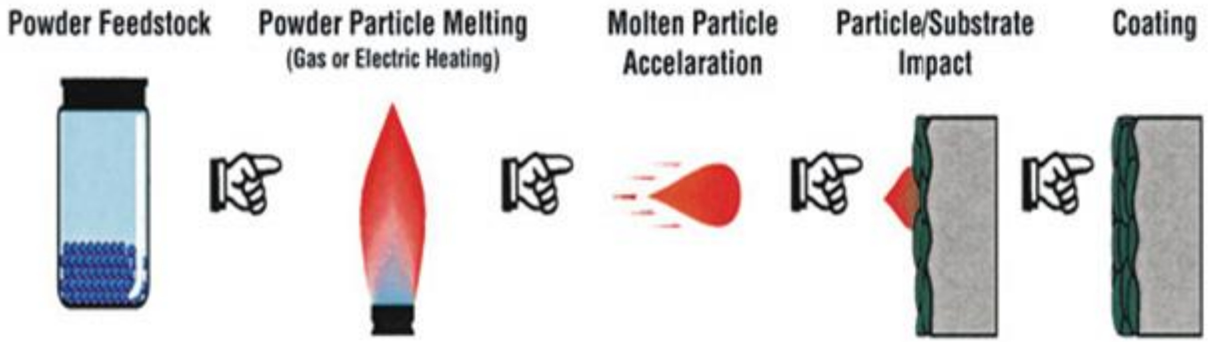
Prof. Dr. Kerem Altuğ GÜLER

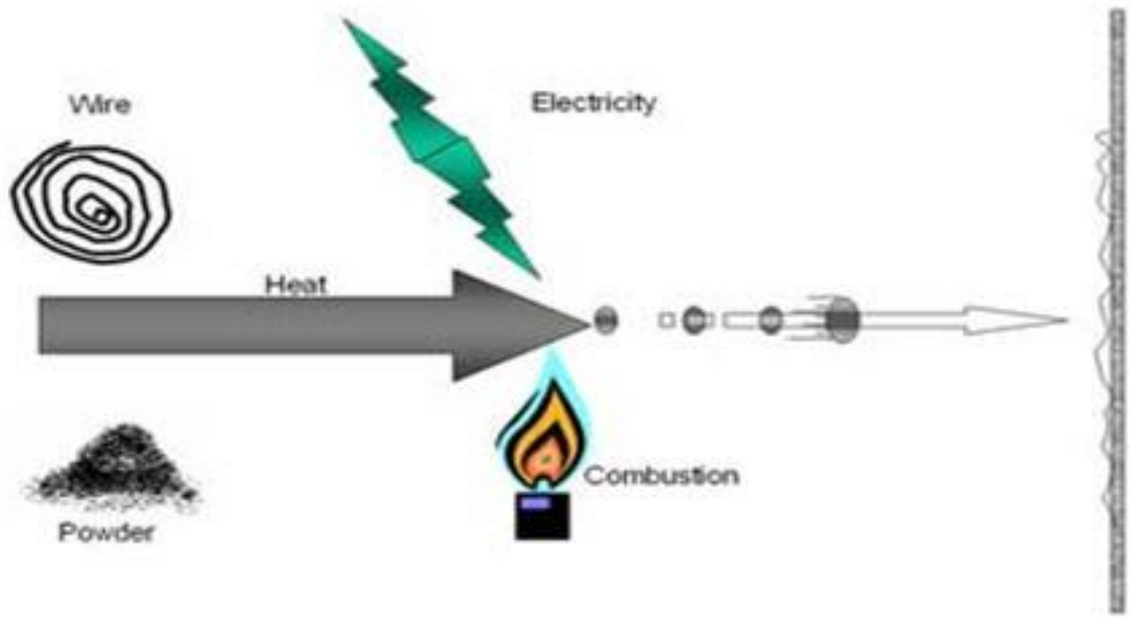
Thermal spray coatings

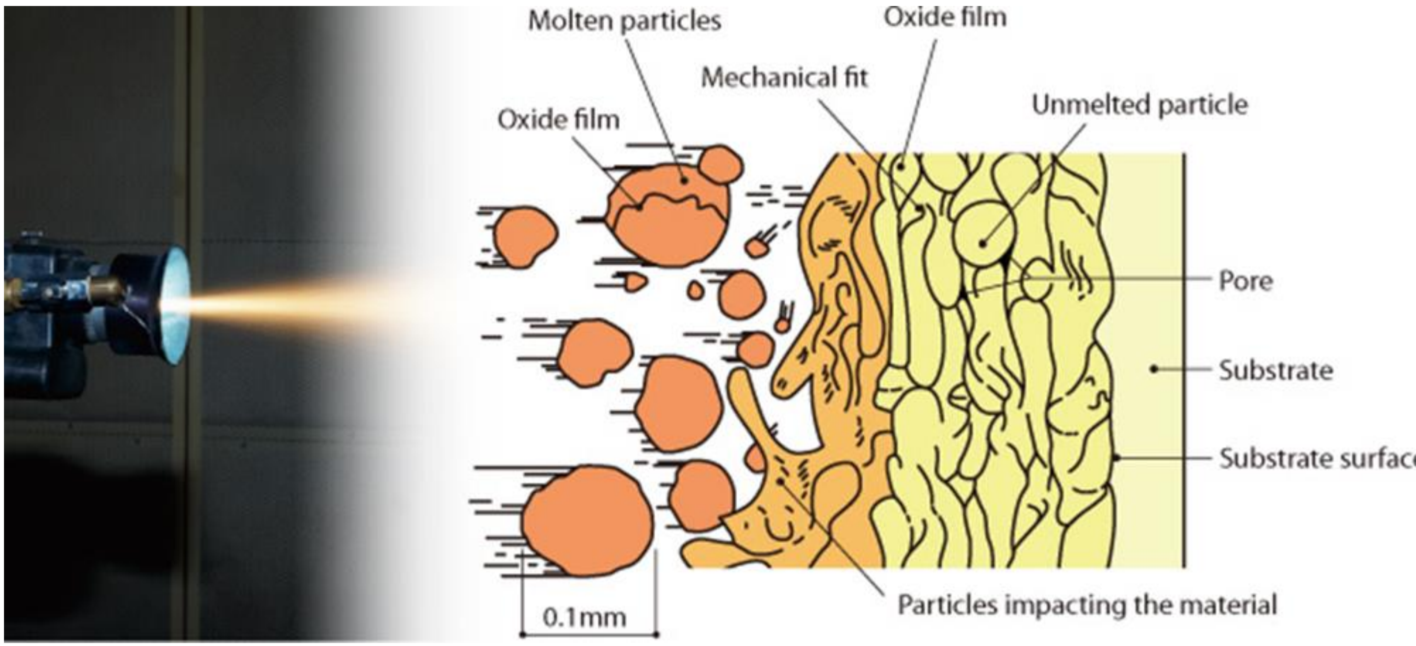
<u>Fundamentals of the technique:</u>

- Coating material in wire, rod or powder form is passed through a heat source to obtain molten or semi-molten material.
- This material is sprayed to base material (substrate) surface with high pressure gas or air blowing fan.
- Approximate thickness range is between 20 μm to several mm. Depending on the process and feedstock.

Thermal Spray Coating Process







Molten particles
Oxide film
Mechanical fit
Oxide film
Unmelted particle
Pore
Substrate
Substrate surface
Particles impacting the material
0.1mm

Bonding mechanisms of molten or semi-molten particles:

- Mechanical bonding occur between particle drops and base material or preceding particles.
- Local diffusion or alloying (metallurgical bonding) can occur between base material and coating.
- Bonding with Van der Waals forces can occur.

<u>These bonding types depend on:</u>

- Composition of the base material.
- Composition of the coating material.
- Melting process of the coating material.
- Surface roughness of the base material.
- Particle velocity, size and temperature.

<u>Thermal spray coatings are carried out in three stages:</u>

- Pre spraying treatments: Cleaning, masking, grinding (shot peening).
- Spraying process.
- Post spraying processes. (Surface finish treatments.)

Pre-spraying treatments

- Cleaning of the surface.
- Masking if necessary.
- Grinding of the surface with Al_2O_3 or SiC particles. (for improve mechanical bonding)
- Preheating of the base material

    - For remove humidity.

    - Improve binding conditions.

    - Decrease thermal expansion differences

between the base material and the coating.

Spraying processes

According to energy levels there are two process types.

Low energy processes:

- Flame spraying.
- Electric arc spraying.

High energy processes:

- Plasma spraying.
- Detonation gun spraying (D-gun).
- High velocity oxy-fuel deposition (HVOF).

Flame spraying

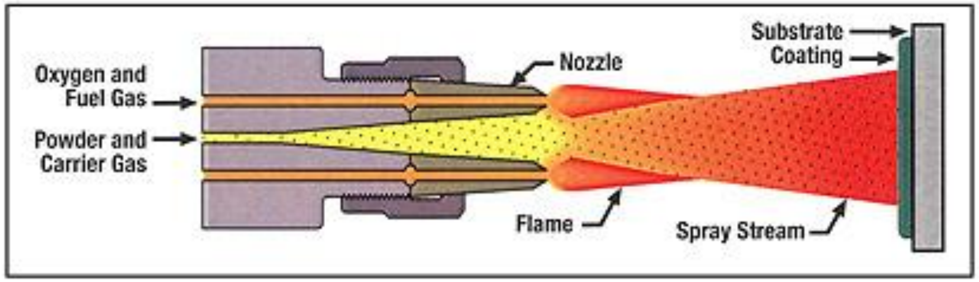
- Flammable gasses are used for coating material melting.
- Acetylene, propane and hydrogen are common gasses.
- Coating material can be in wire or powder form.
- Micro pulverized powder alloys vacuumed with oxygen and sprayed to surface with oxy-acetylene flame.
- Base material temperature does not increase above to 200 °C during spraying.
- Flame temperature is ~3300 °C
- Powder materials: Stainless steel, carbon steel, Ni-Cr alloys, Al alloys, bronzes, ceramics (Al_2O_3, Cr_2O_3, etc.)

Scope of application:

- Roller bearings.
- Compressor pistons.
- Cam shafts.
- Bushings.
- Sleeves.
- Hydraulic cylinder pistons.

*Coatings with flame spraying are occurred with low density (porous) and low adhesion strength.

Flame Spray Process



Characteristics

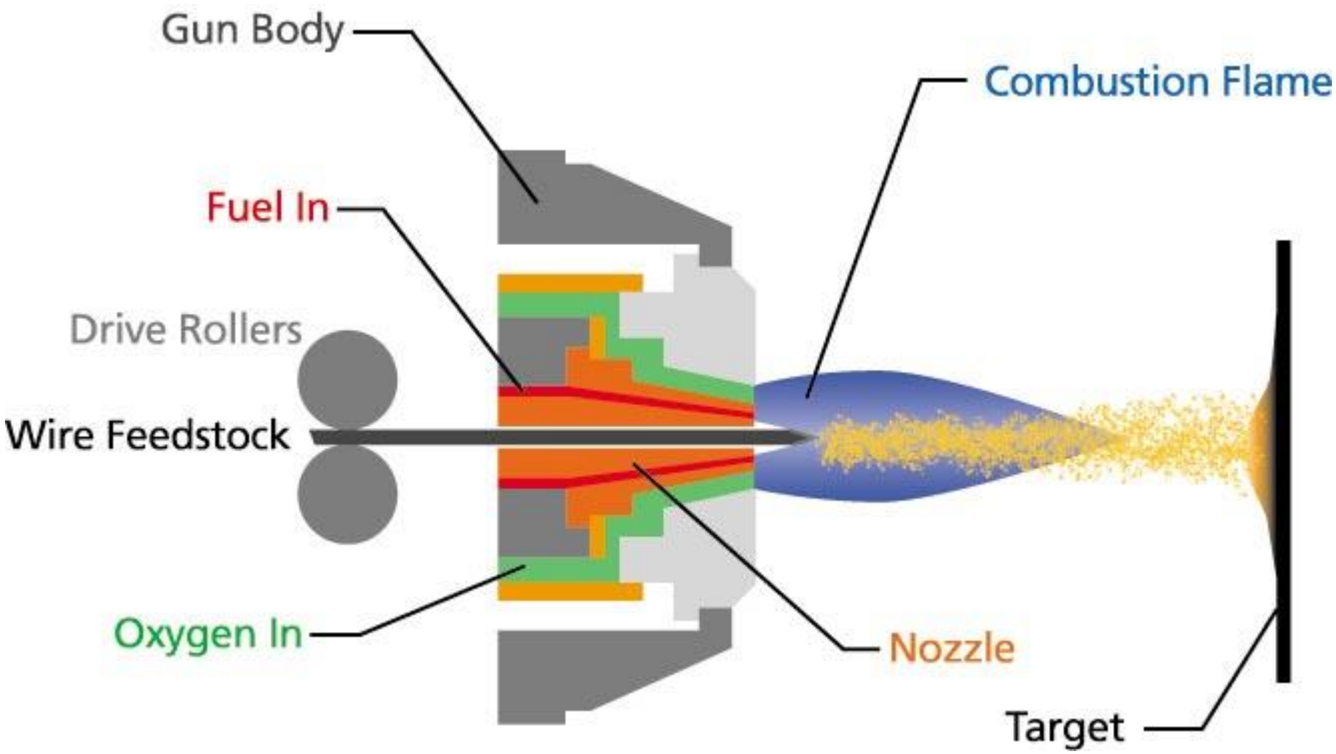
Flame Temperature:

Oxy-Acetylene, 5,600°F (3,100°C)

Oxy-Hydrogen, 4,900°F (2,700°C)

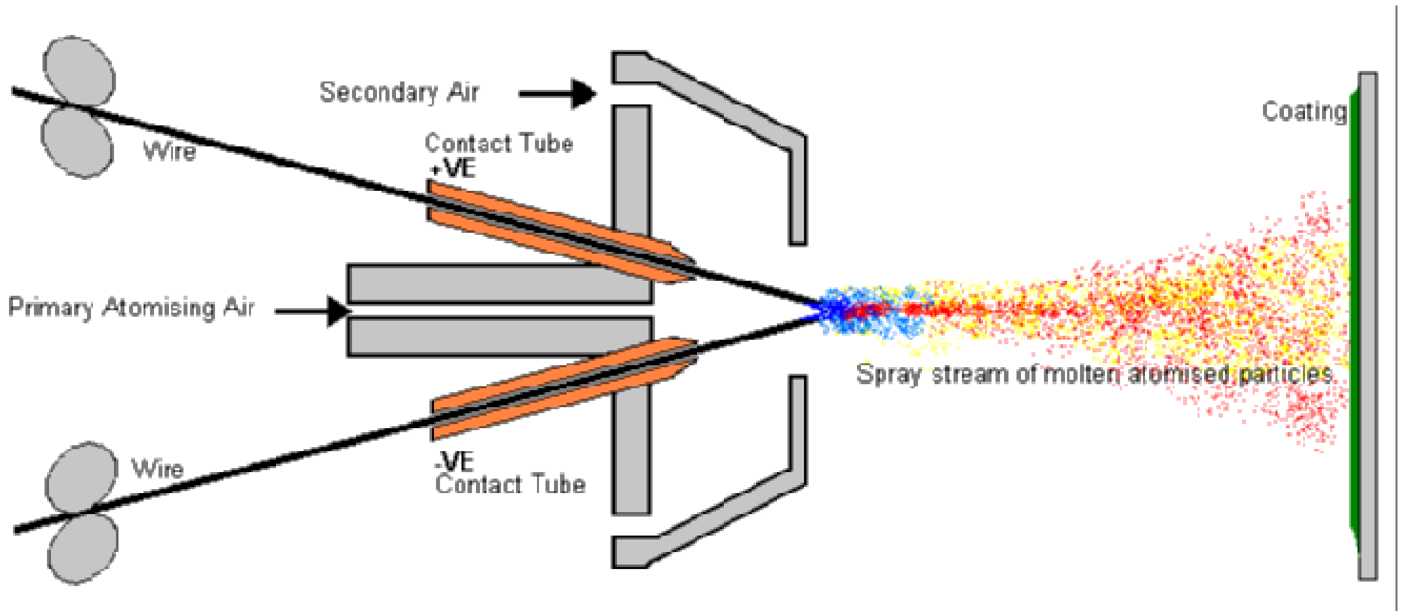
Particle Speed:

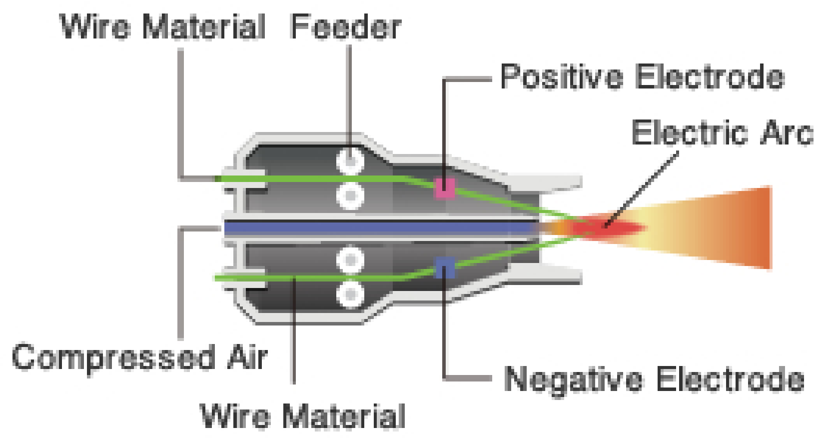
200 - 800 ft/s (60-240 m/s)

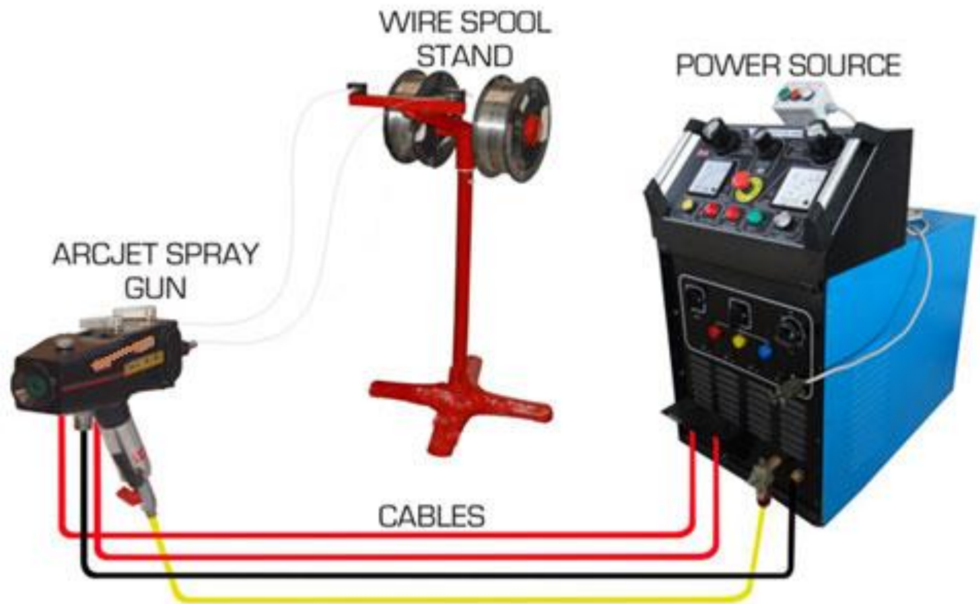


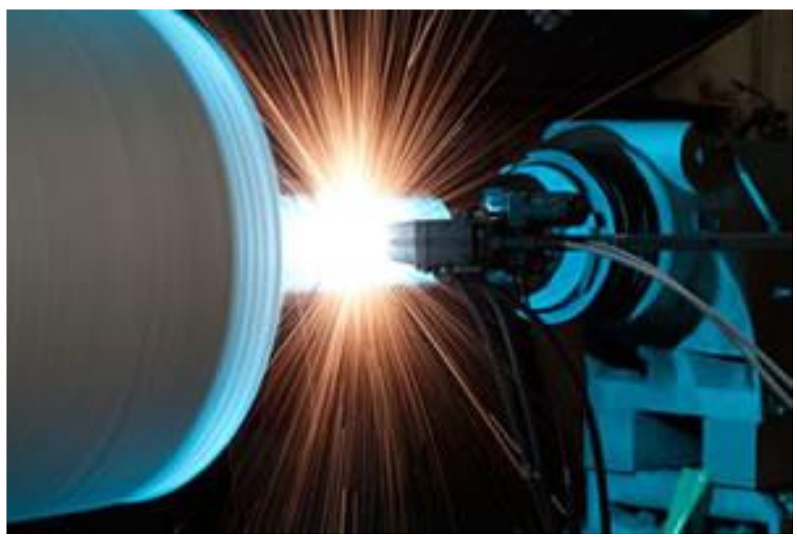
Electric arc spraying

- It is a suitable technique for spraying wire shaped metals.
- Wires drive to the gun with an electric motor.
- Electric arc occurs when wires are contacted passing through different polarized (positive and negative) nozzles.
- Molten metal is atomized with effect of the arc then sprayed to substrate with compressed gas or air flow.
- Used wire materials: Stainless steels, Mo, Cu, Zn, Al and bronze alloys.


Secondary Air
Contact Tube
+VE
Wire
Primary Atomising Air
Coating
Spray stream of molten atomised particles
Wire
-VE
Contact Tube


Wire Material
Feeder
Positive Electrode
Electric Arc
Compressed Air
Wire Material
Negative Electrode


WIRE SPOOL
STAND
POWER SOURCE
ARCJET SPRAY
GUN
CABLES



Scope of application:

- Very suitable for coating of large parts.
- Rollers used in steel, paper, paint and plastic industries.
- Hydraulic pistons and shafts.

Advantages:

- Wide coating alloy usage.
- High spraying velocities.
- Composite coatings can be produced with using two different wires.

Disadvantages:

- Lower adhesion and lower density depositions then high velocity (energy) processes.

Plasma spraying

- Coating material spray to the substrate passing through a plasma.
- Plasma occurs with ionized gas which is effected by electric arc.
- Argon noble gas is generally used.
- Ar is forwarded between W cathode and water cooled Cu anode.

Plasma Spray Process

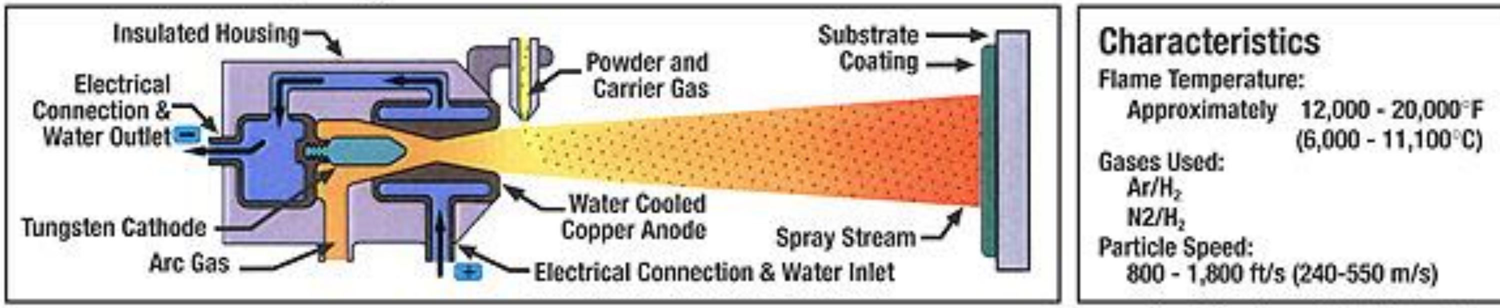
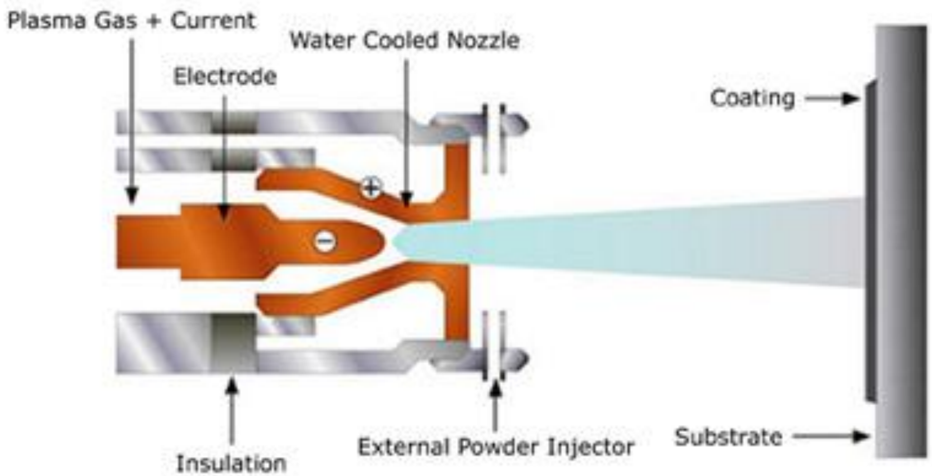
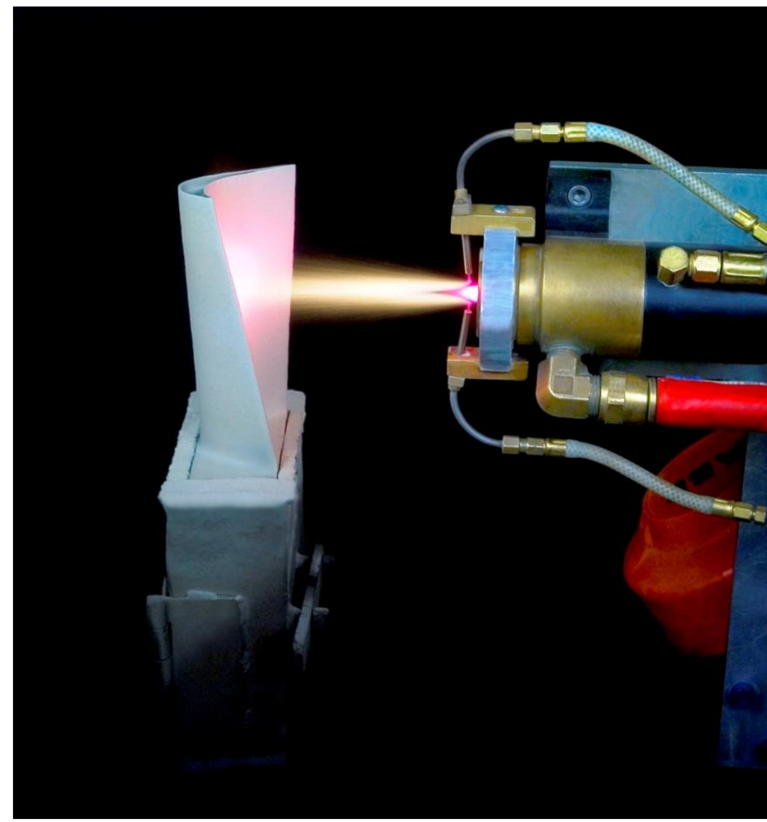


Photo Courtesy of Westaim Ambeon





- Because of concentrated in a very low volume arc temperature can reach very high degrees. (30.000 °C)
- Improve the thermal properties of Ar, H_2, He or N_2 can be added.
- 5-120 kW power provides 125-600 m/s powder velocities.
- Plasma coating can be carried out in air or vacuum atmospheres.
- Plasma coating in air atmosphere is used for:

  - High melting point refractory materials.

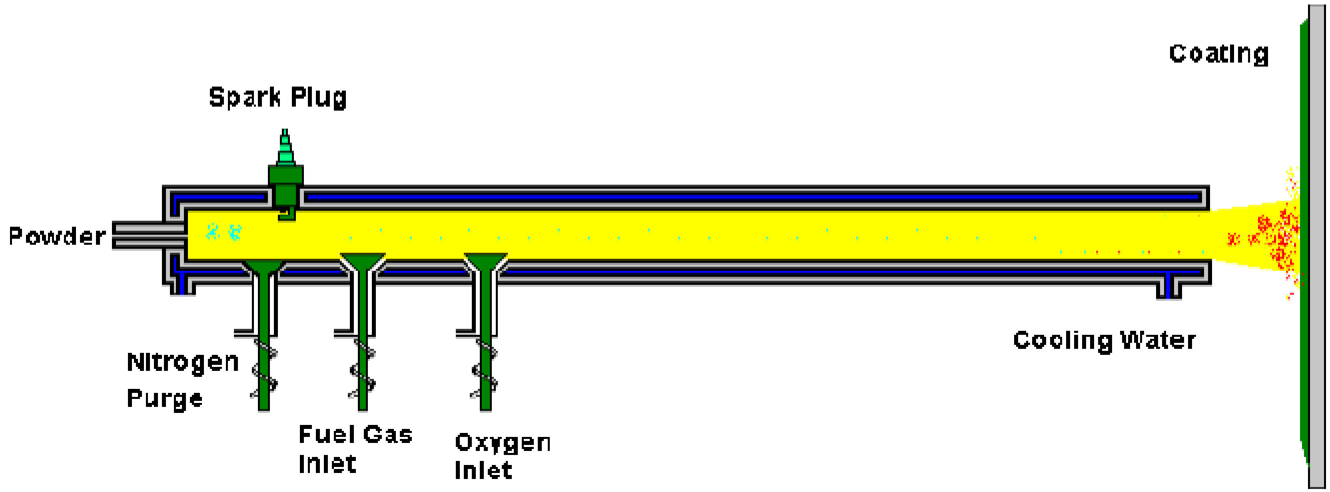
  - Ceramics, carbides.

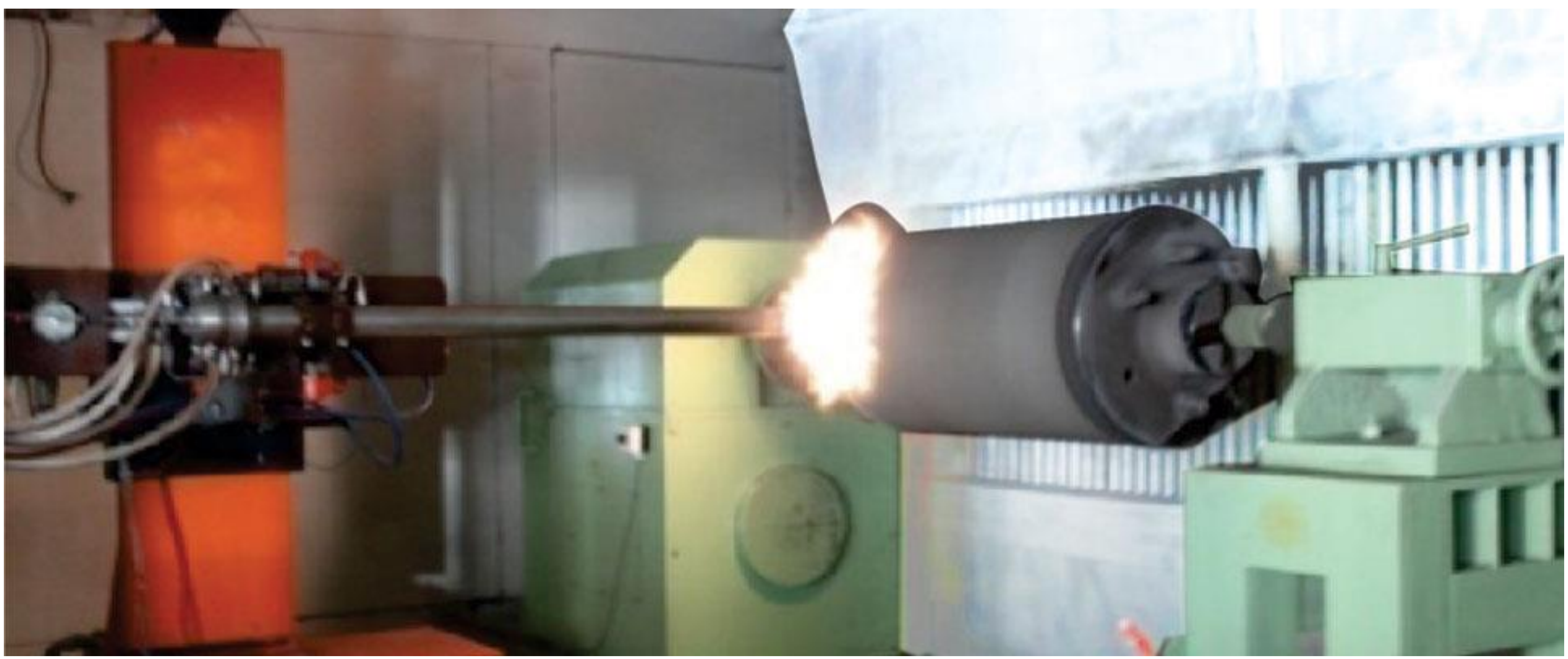
  - High temperature alloys.

- Aircraft engine components and textile machinery parts are coated with this technique.
- Because of high plasma temperature almost every material can be sprayed.
- Coating density is high and adhesion is good.
- Heat transfer to the substrate is very low.

Deposition with detonation gun (D-Gun)

- Oxy-acetylene gas mixture is used.
- Particle velocities can exceed 750 m/s.
- Detonation process repeats 5-10 times per second.
- Every detonation produce a coating with 25 mm diameter and a few micron thickness.
- Deposition of repeated coatings provides uniform thickness and structure.


Coating
Spark Plug
Powder
Cooling Water
Nitrogen
Purge
Fuel Gas
Inlet
Oxygen
Inlet

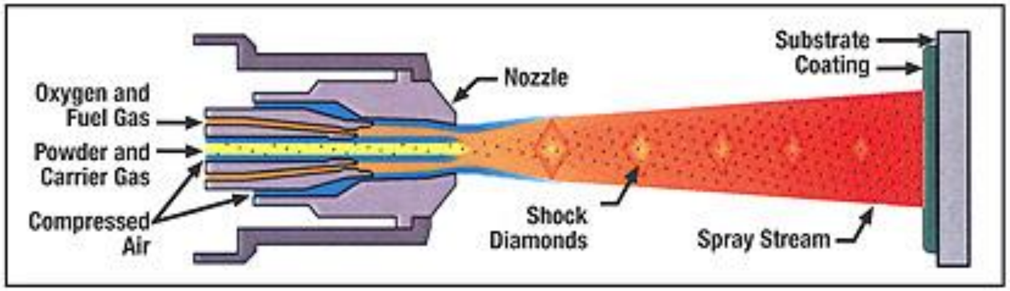


- All metallic, ceramic and cermet coatings can be deposited.
- There is an advanced technique called Super D-gun and powder velocities increase above 1000 m/s with changing fuel gas mixtures.
- More compact and denser coatings can be produced.

High velocity oxy-fuel spraying (HVOF)

- Fuel gas mixture: Hydrogen, propane, propylene, or acetylene and oxygen.
- The nozzle gas velocity is supersonic.
- HVOF produces high density coatings with good bonding properties.
- Heat transfer to the substrate is low.
- Depends on oxygen-fuel ratio, combustion products can be oxidized or carbonized. Thus, oxide or carbide coatings can be made.

High Velocity Oxy-Fuel Process



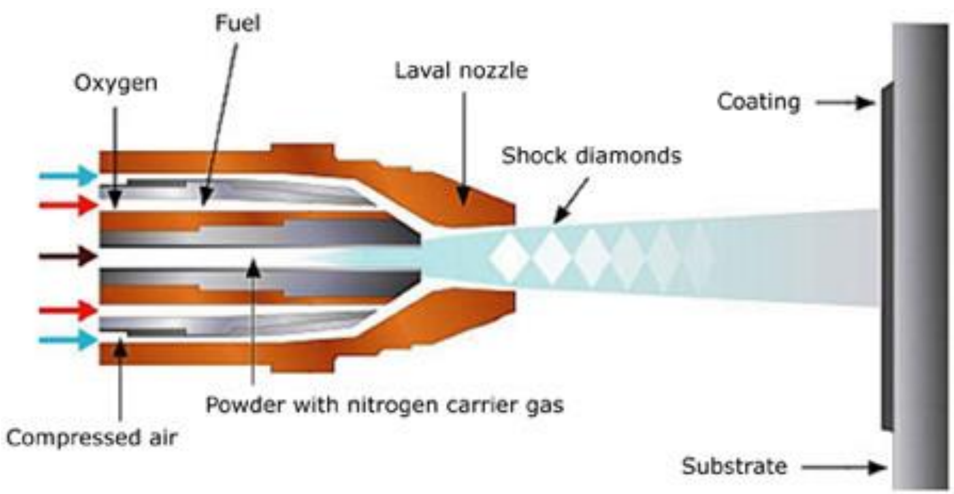
Characteristics

Flame Temperature:
Approximately 5,000°F (2,760°C)

Fuel Gases:
Propylene or Propane or Hydrogen

Particle Speed:
Up to 4,500 ft/s (1,400 m/s)

Photo Courtesy of Westaim Ambeon



Post spraying surface finish treatments

- Rough surfaces after coating are grinded.
- High porosity level (15-20 %) of flame spraying is reduced to 1 % with repeated melting process.

Properties of thermal spray coatings

Microstructure: Coating microstructure is not homogeneous. It has different physical and chemical properties. Phase transformations in coating materials can happen during spraying.

Bonding strength: It depends on:

- Coating parameters.
- Properties of coating material.
- Type of substrate (ferrous or non-ferrous)
- Conditions of substrate surface. (Cleaning and roughness degree and geometry.)

Bonding strength of WC cermet	**Spray technique**
61-83 MPa	Plasma, HVOF
172 MPa	D-Gun
310 MPa	Super D-Gun

- Coatings produced with D-gun and super D-gun have superior wear resistance.

Porosity: It is a characteristic property for thermal spray coatings.

Porosity %	**Spray technique**
5-15	Plasma
< 2	D-Gun
lower than D-Gun	HVOF

Industrial applications of thermal spray coatings

Paper and printing industry:

- Drying cylinder surface. Mo (electric arc), Mo-Ni (plasma)
- Polishing cylinders coated with WC-NiCr or WC-Co using HVOF technique.

Automotive industry:

- Crank shafts.
- Piston and piston rings. → Plasma spray technique is used for all these parts
- Fuel injection nozzles.
- Sensors.

Textile industry:

- Al_2O_3, Al_2O_3 + TiO_2 or Cr_2O_3 ceramic coating for improve wear resistance.

Glass and chemical industry:

- NiCrBSi coatings for glass shaping moulds.
- Al_2O_3 + TiO_2, Cr_2O_3 and $ZrSiO_4$ coatings for several systems and equipment.

Medicine and biomedical applications:

- Orthopaedic implant prostheses (dental screws, knee and hip prostheses) are coated with plasma spray technique.
- Also hydroxyapatite is successfully applied with this technique.

Iron and steel industry:

- Crushers, pulleys, grits, rollers, transfer cylinders, tuyeres.

Aerospace industry:

- Thermal barriers coatings for hot gas corrosion.

* Coating quality is usually assessed by measuring its:

- Porosity,
- Oxide content,
- Macro and micro hardness,
- Bond strength and
- Surface roughness.

* Generally, the coating quality increases with increasing particle velocities.

Cold (Gas) spraying (CS)

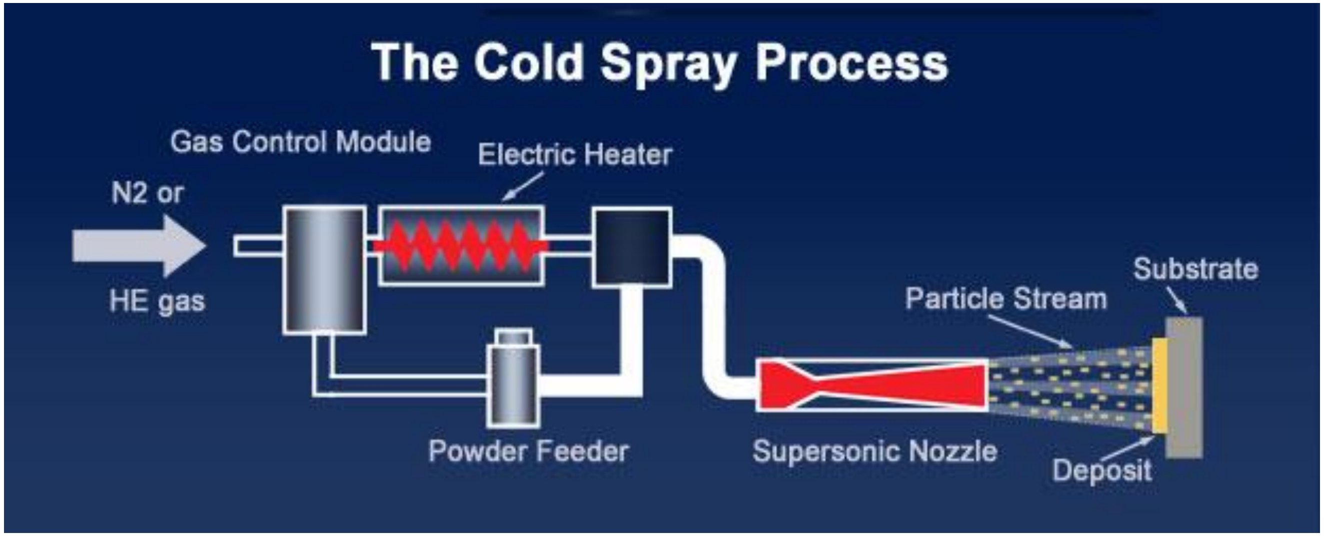
- Solid powders (1 to 50 μm in diameter) are accelerated in a supersonic gas jet to velocity up to 500-1000 m/s.
- During impact with the substrate, particles undergo plastic deformation and adhere to the surface.
- Metals, polymers, ceramics, composite materials and nanocrystalline powders can be deposited using cold spraying.
- <u>Unlike thermal spraying techniques the powders are not melted during the cold spraying processes.</u>

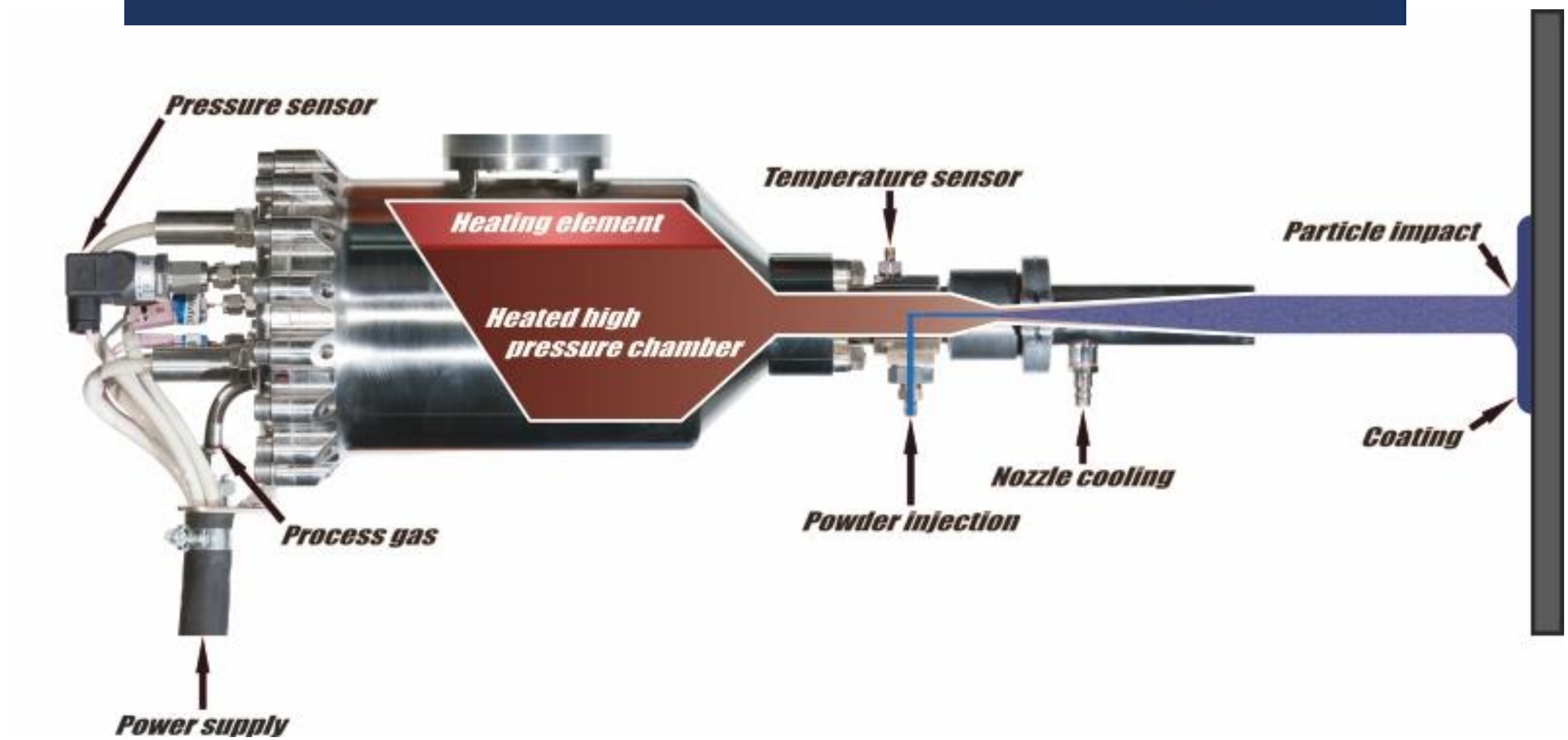
High pressure cold spray (HPCS):

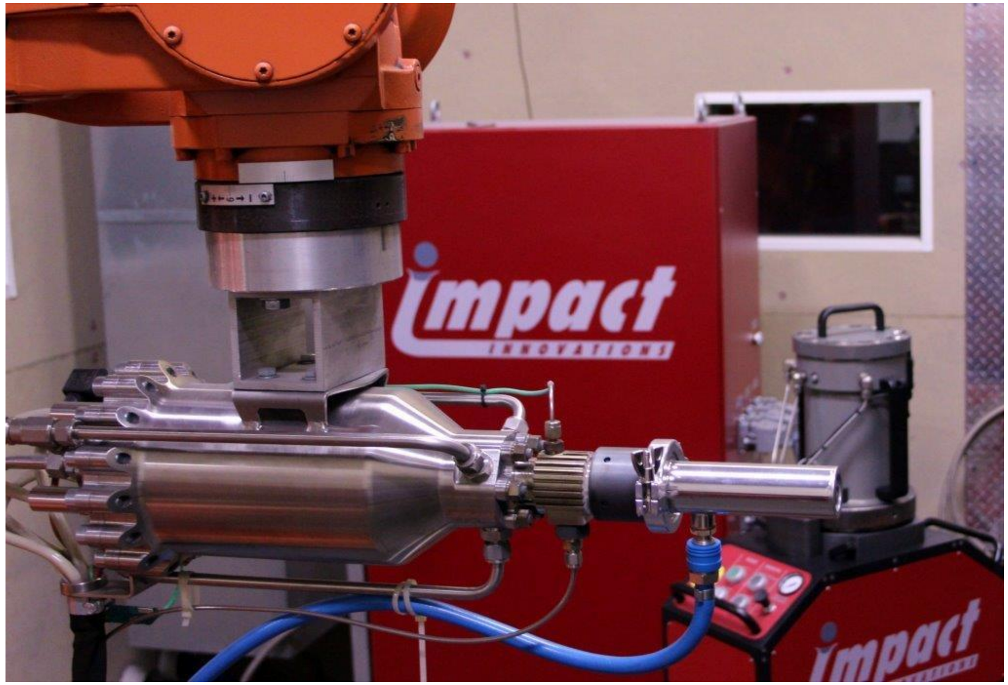
- Gas: N_2 or He
- Pressure: > 1.5 MPa
- Flow rate: > $2m^3$/min
- Heating power: 18 kW
- Application: Pure metal powders (5-50 µm)

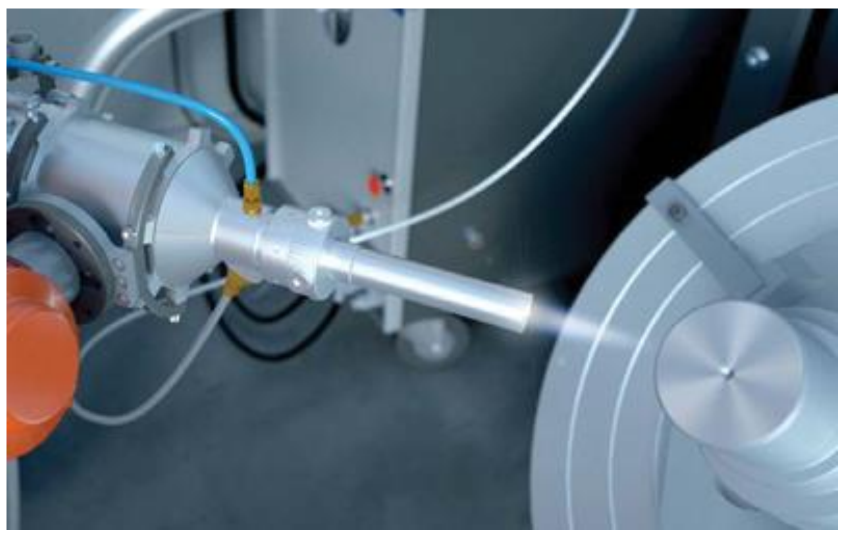
Low pressure cold spray (LPCS):

- Gas: compressed air
- Pressure 0.5-1.0 MPa
- Flow rate: 0.5-2 m^3/min
- Heating power: 3-5 kW
- Application: Mechanical mixture of metal and ceramic powders.


The Cold Spray Process
Gas Control Module
Electric Heater
N2 or
HE gas
Substrate
Particle Stream
Powder Feeder
Supersonic Nozzle
Deposit


Pressure sensor
Temperature sensor
Heating element
Particle impact
Heated high
pressure chamber
Coating
Nozzle cooling
Powder injection
Process gas
Power supply


impact
INNOVATIONS
impact



Video links

- https://www.youtube.com/watch?v=ah9kLdUFDQY
- https://www.youtube.com/watch?v=mvlEi3LvxD4&t=60s
- https://www.youtube.com/watch?v=Askv3es2QvA
- https://www.youtube.com/watch?v=mWWFy_WUtnY
- https://www.youtube.com/watch?v=b5VE7njZMek
- https://www.youtube.com/watch?v=pvm4R2wBjvA
- https://www.youtube.com/watch?v=AZbKEpF5AUY
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- https://www.youtube.com/watch?v=73ZaknMhQ5s
- https://www.youtube.com/watch?v=t71hCuE6B2c
- https://www.youtube.com/watch?v=8HiDgcwasCw