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VTS
Vereniging voor Thermische Spuittechnieken
Dutch association for thermal spray technology

Gas Dynamic Cold Spraying, een nieuw thermisch spuit proces.

Marcel van Wonderen (KLM)

2023

Levensduur

Levensduur van alle mechanische werktuigen, equipement en machines wordt beïnvloed door:

- Slijtage
- Corrosie
- Temperatuur
- combinatie van bovenste 3

Op industriële schaal leidt dat tot enorme economische kosten, maar bovendien verlies van grondstoffen.

Daarom speelt de reparatie en onderhoudsindustrie een grote rol in de circulaire economie.

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Bescherming nodig tegen vele soorten slijtage.

Abrasieve slijtage

Lagerpassing slijtage

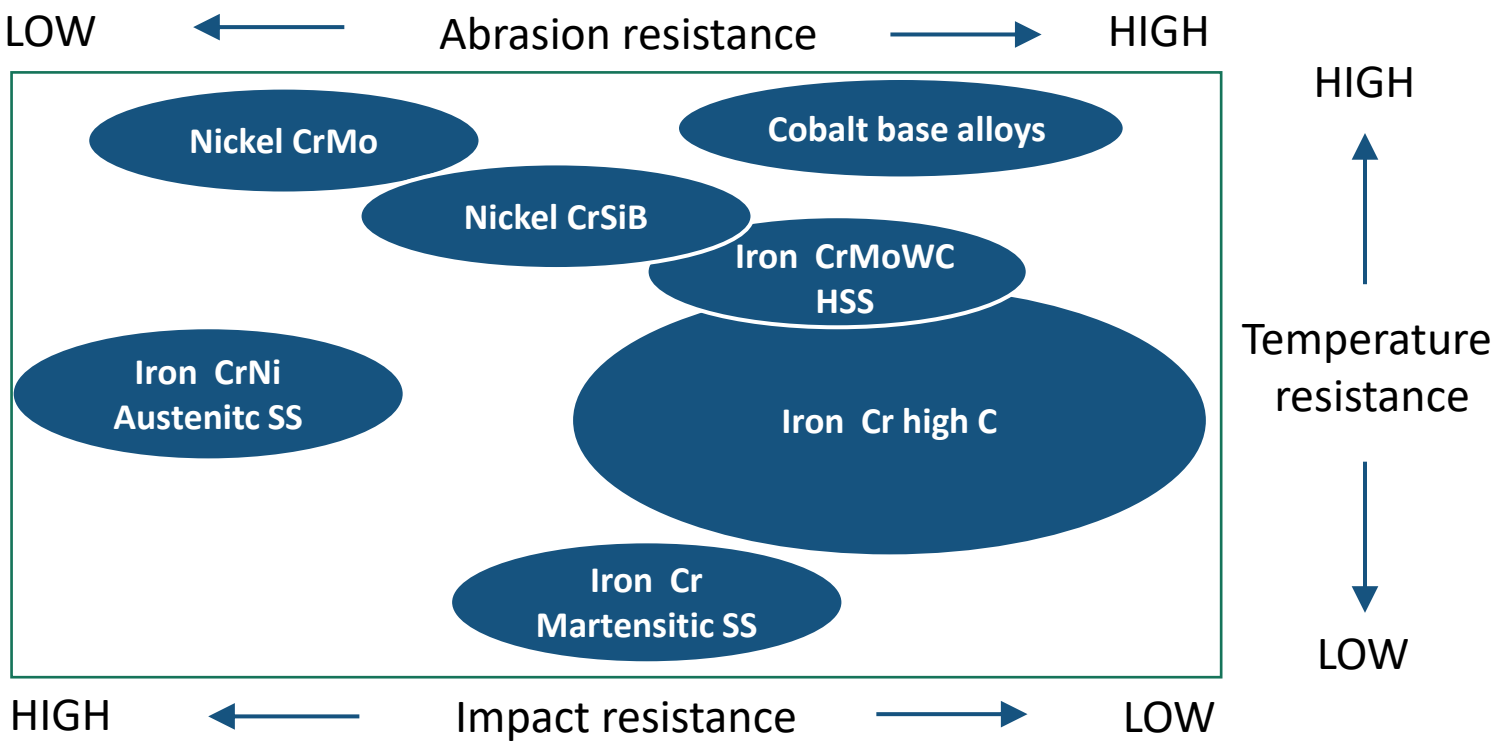
Erosie

Chemische aantasting

Fretting (invreting)

Adhesieve slijtage

Materialen


LOW
Abrasion resistance
HIGH
HIGH
Nickel CrMo
Cobalt base alloys
Nickel CrSiB
Iron CrMoWC
HSS
Iron CrNi
Austenitc SS
Iron Cr high C
Temperature
resistance
Iron Cr
Martensitic SS
LOW
HIGH
Impact resistance
LOW

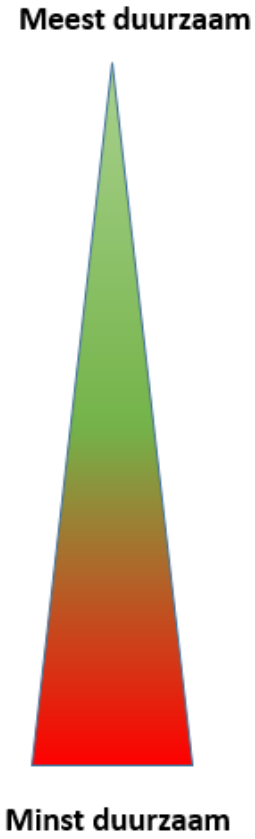
Inzet van coatings

Vele technieken/processen zijn bekend om onderdelen continu een extra “leven” te geven. Het toepassen van de ge-engineerde coatings speelt een sleutel rol hierin.

Coatings kunnen voor diverse doelmatigheden worden ingezet:

- Langere levensduur
- Verbetering van prestatie of rendement
- Lagere onderhoudskosten
- Lagere productiekosten
- Lagere CO2-footprint

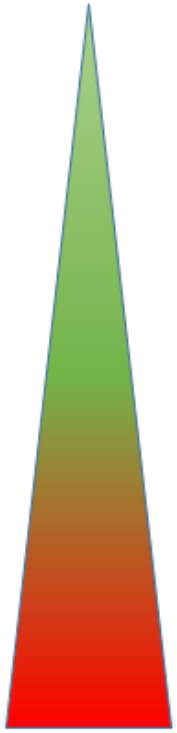
Niveau’s van circulariteit (10 R’s)



Refuse: Weigeren/voorkomen van gebruik
Reduce: Gebruik minder grondstoffen
Redesign: Herontwerp met oog op circulariteit
Re-use: Product hergebruik (2e hands)
Repair: Onderhoud en reparatie
Refurbish: Product opknappen
Remanufacture: Nieuw product van 2e hands
Re-purpose: Hergebruik product naar anders
Recycle: Verwerking en hergebruik materialen
Recover: Energie terugwinning

Niveau’s van circulariteit (10 R’s)

Meest duurzaam



Minst duurzaam

Refuse	Weigeren/voorkomen gebruik
Reduce	Gebruik van minder grondstoffen
Redesign	Herontwerp met het oog op circulariteit
Re-use	Product hergebruik door andere gebruiker
Repair	Onderhoud en reparatie voor gebruik in oude functie
Refurbish	Product opknappen of moderniseren
Remanufacture	Gebruikte onderdelen gebruiken in nieuw product
Re-purpose	Hergebruik in nieuw product met andere functie
Recycle	Verwerking en hergebruik van materialen
Recover	Verbranden met energie terugwinning

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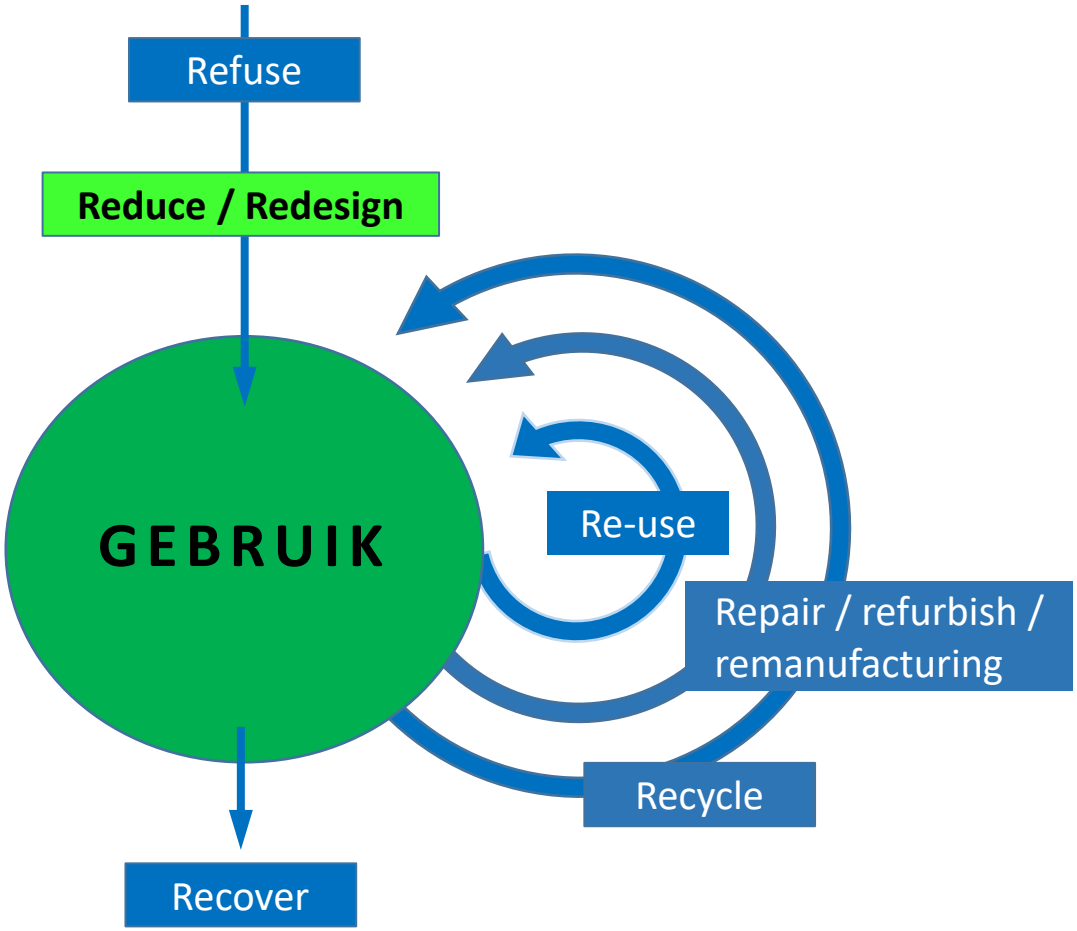
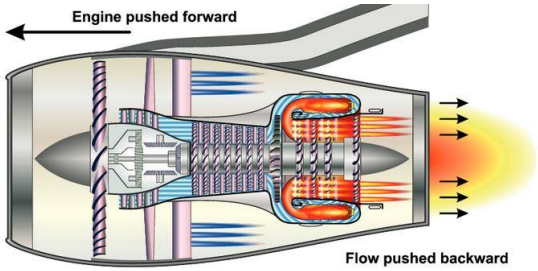
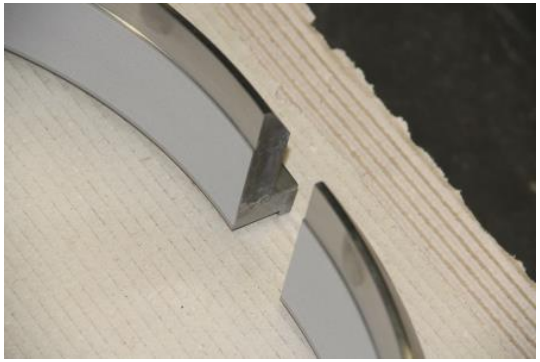
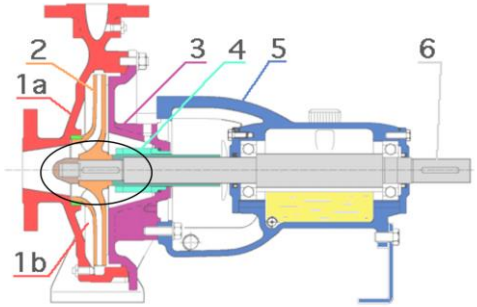
Circulariteit door reduce en redesign









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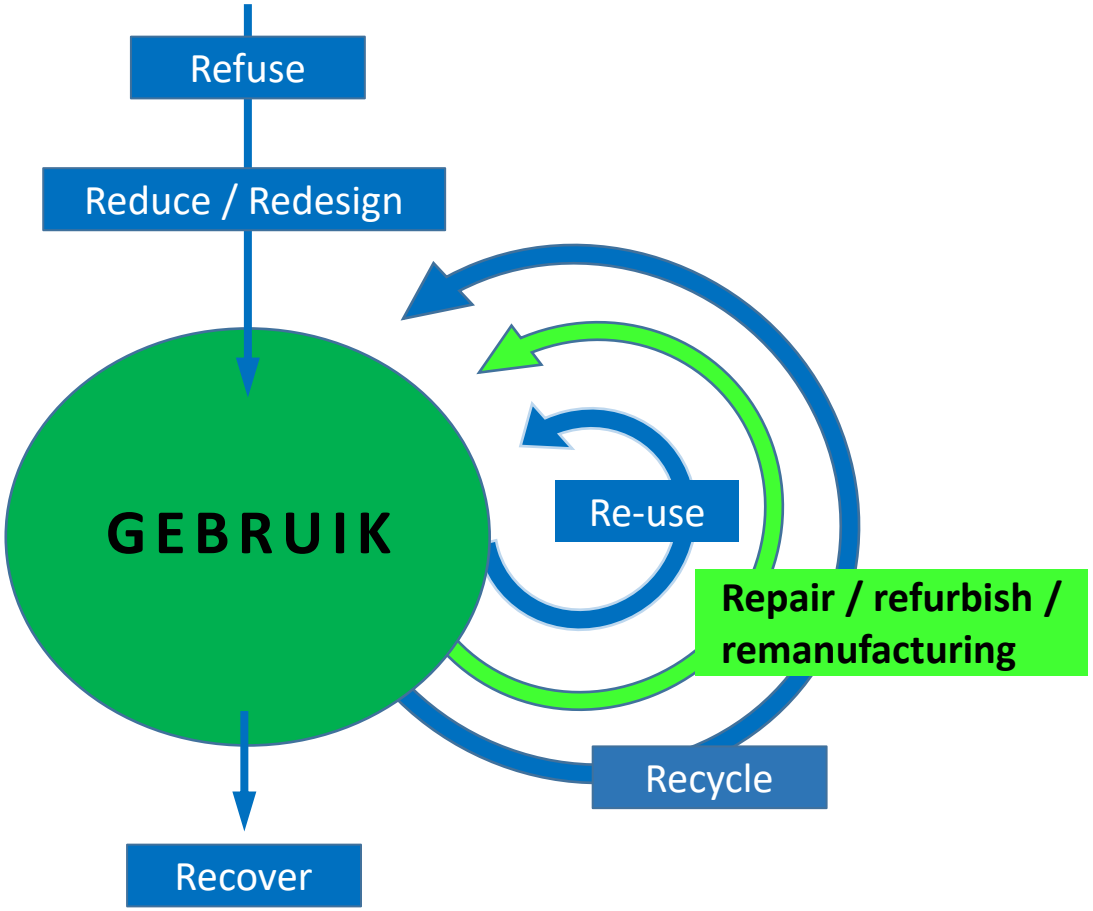
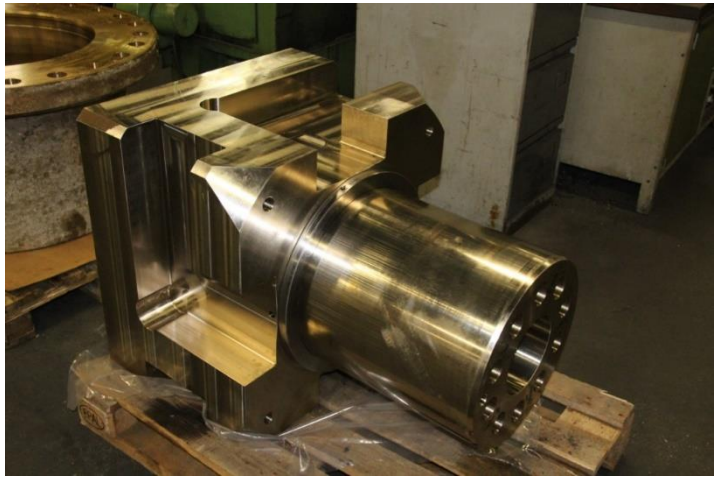
Voorbeeld chemische reactor installatie

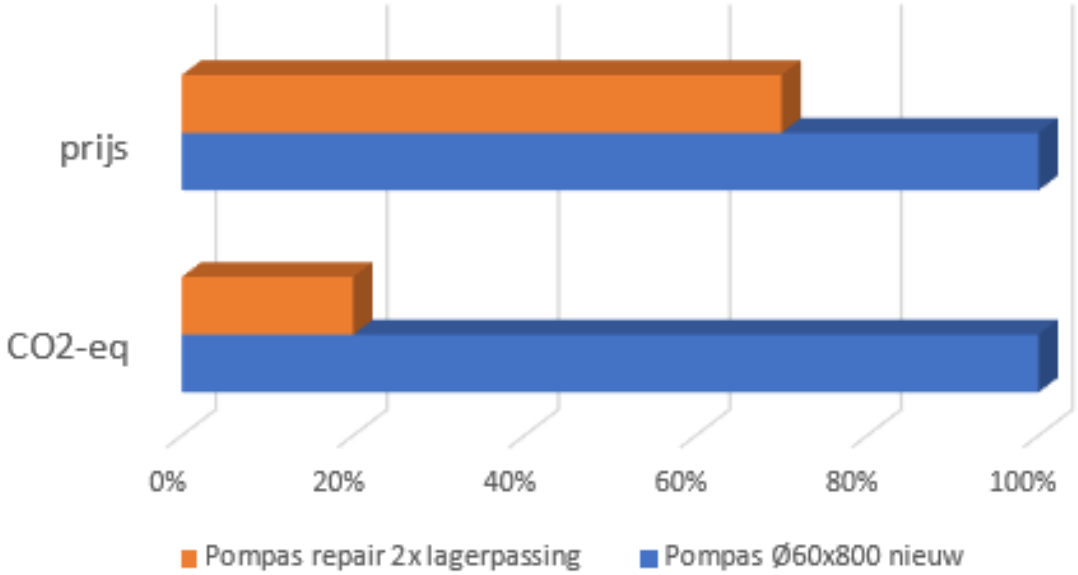
	met originele onderdelen	met juiste slijtvaste coating
Vervanging installatie	Elke 6 maand	Elke 30 maand
Stilstand per vervanging	2-3 weken	2-3 weken
Uptime per jaar	46-48 weken	51 weken

Circulariteit door repair / refurbish of remanufacturing





Kosten pompas in € vs CO2-equivalenten



Coatings ?

Bekende organische en anorganische coating processen/technieken:

- Galvano (verchromen, vernikkelen, verzilveren, anodiseren, fosfateren, etc.)
- Opdampen (Vapor Deposition (PVD, EB-PVD, CVD, sputteren, etc.)
- Thermisch Spuiten (vlamspuiten, plasma spuiten, HVOF, electrisch draadspuiten, etc.)
- Cladden (LASER-cladden, coëxtruderen, explosielassen, magnetisch pulslassen, etc.)
- PTA (plasma transfer arc)
- Verfspuiten
- etc.

Principe van thermisch spuiten

Schematisch het thermisch spuitproces

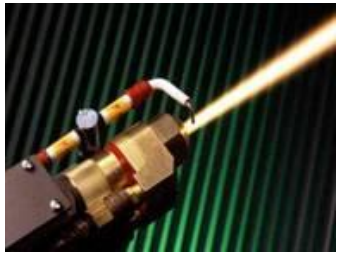
- Spuitmateriaal wordt in meer of mindere mate aangesmolten door de brander/spuitkop --> druppeltjes van 1 - 200 micron
- Spuitmateriaal (druppeltjes) legt ‘vliegend’ een bepaalde afstand af tussen spuitkop en substraat
- Er vindt geen opmenging plaats met het substraat
- Het substraat smelt niet, wordt ca. 100-150°C warm. Daardoor vele substraatmaterialen mogelijk. Ook kunststoffen.
- **Thermisch spuiten is een KOUD proces !!!**

Thermische Spuitprocessen

Poeder

Plasma

HVOF



Powder
Flame spray

Coldspray

Draad

Electric Arc

Wire
Flame spray

DIN EN ISO 14917: classificatie thermisch spuitprocessen

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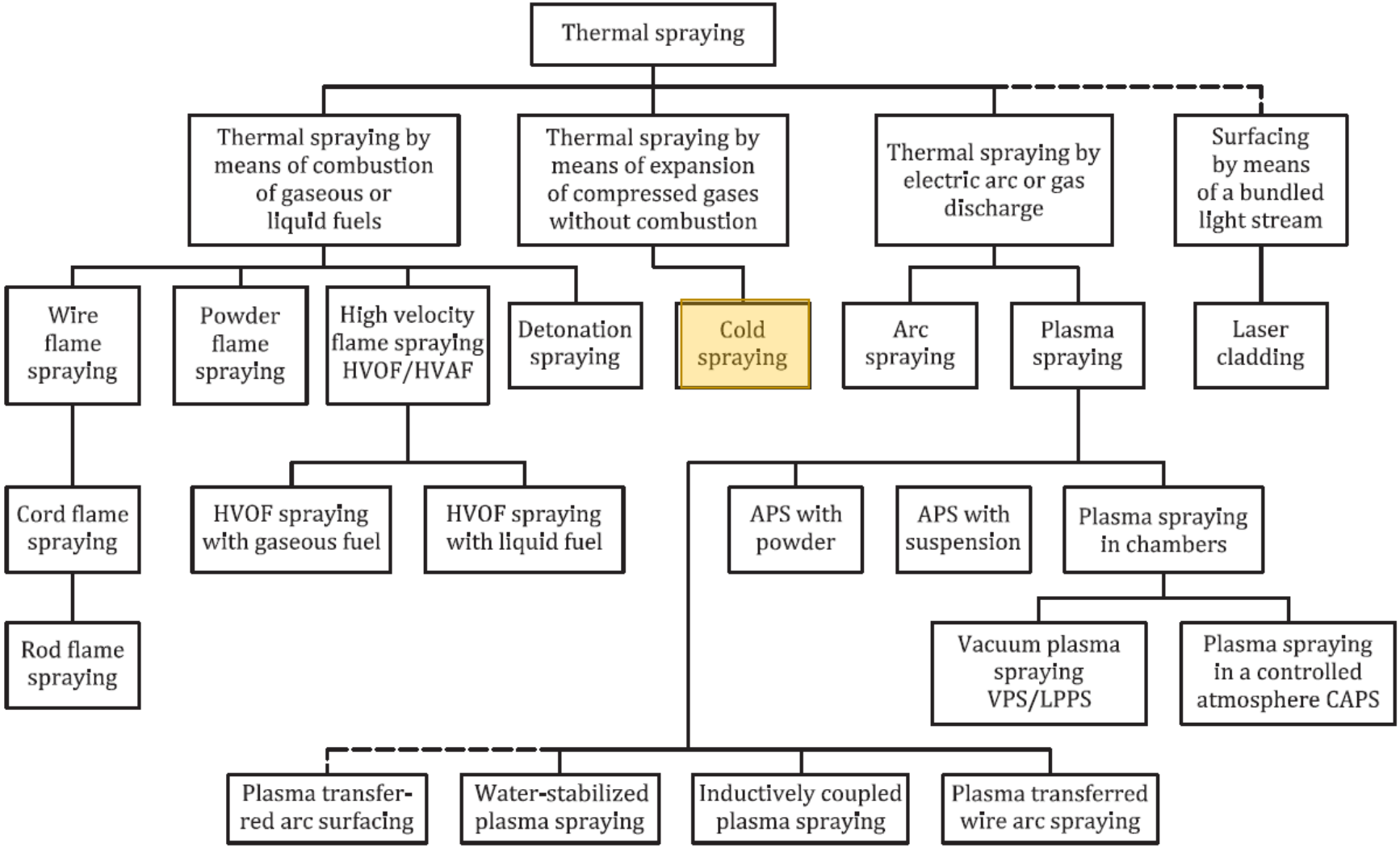
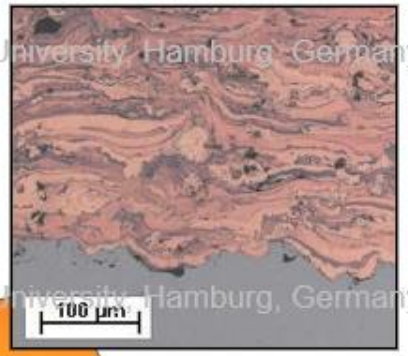


Thermal Spray / Cold Spray: Benefits

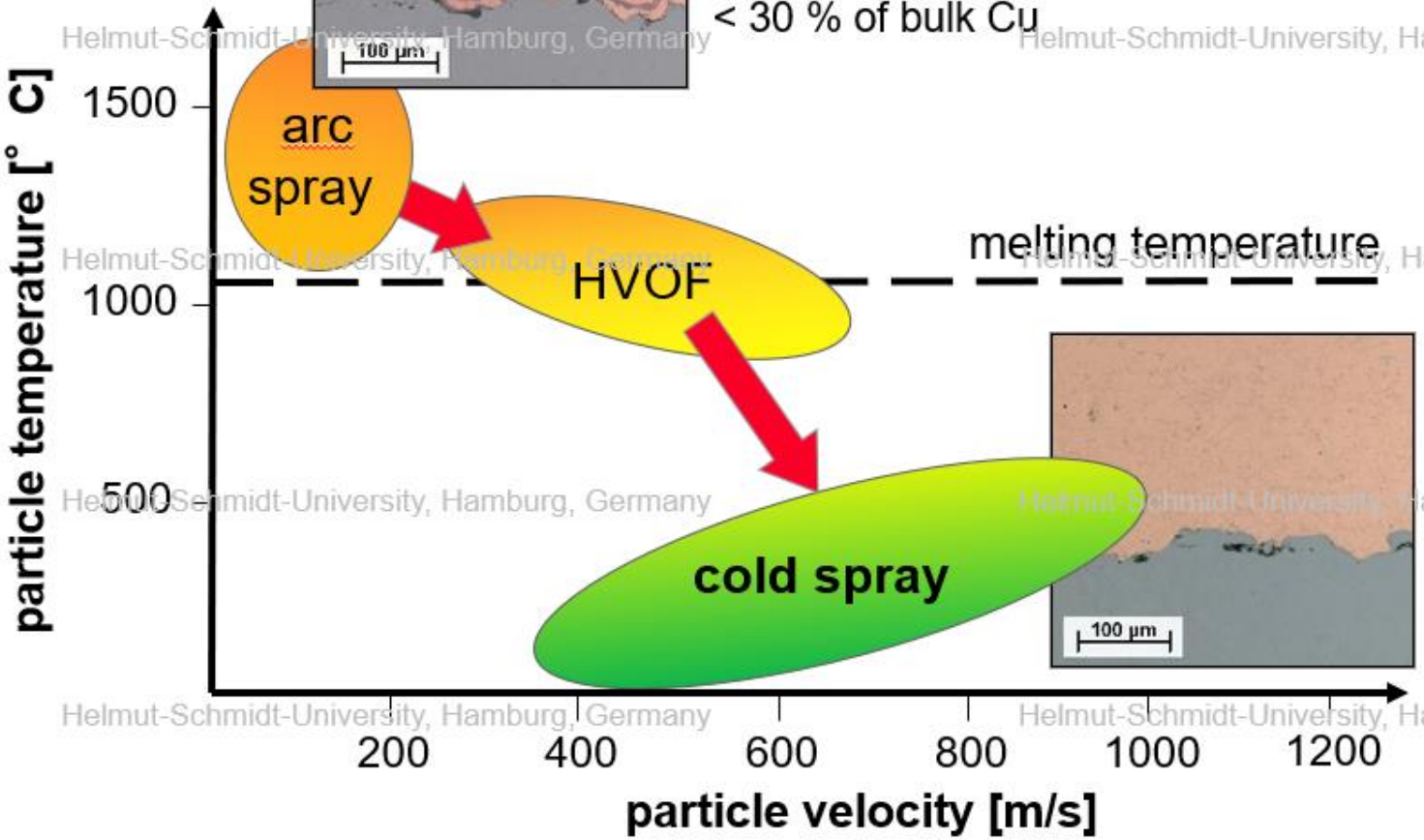
HELMUT SCHMIDT UNIVERSITÄT



O–content:
1.5 wt.-%

el. conductivity:
< 30 % of bulk Cu

bulk Cu



O–content:
< 0.05 wt.-%

el. conductivity:
> 90 % of bulk Cu

Helmut-Schmidt-University, Hamburg, Germany

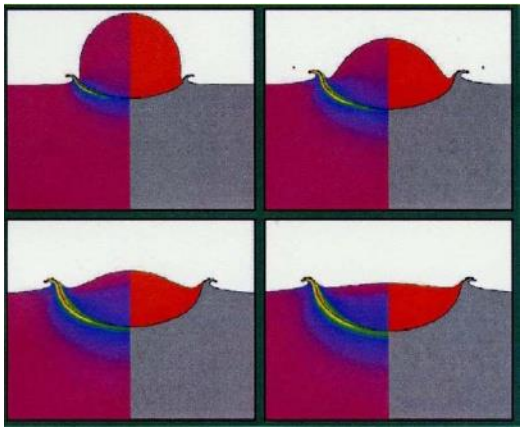
Gas Dynamisch Koud Spuiten

Meerdere Engelse termen:

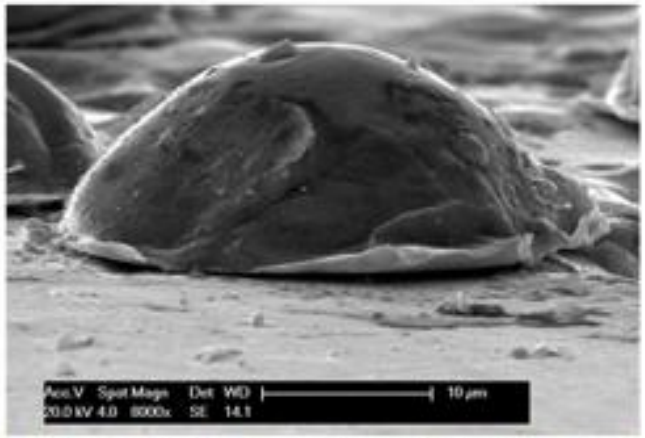
- Gas Dynamic Cold Spraying (GDCS)
- Cold Gas Spray (CGS)
- Cold Spraying (CS) (meest gebruikte verkorte naam voor GDCS)
- Kinetic Fusion process (KF)
- Kinetic Metallization (KM)
- Supersonic deeltjes Deposition (SPD)
- Cold Spray Additive Manufacturing (CSAM)

Gas Dynamisch Koud Spuiten

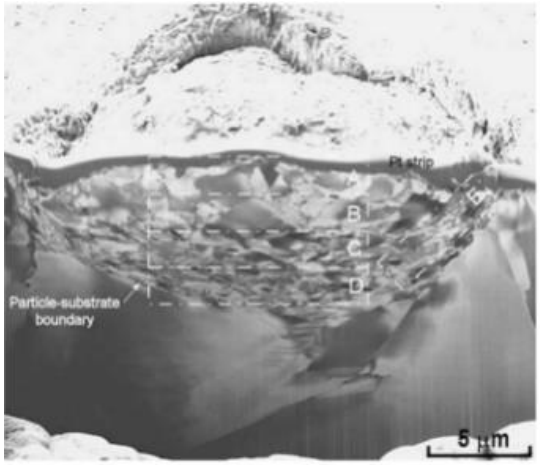
Hechtings kenmerken:



- De hechting is metallurgisch
- Vrijwel geen opwarming van het oppervlak door deeltjes deformatie and hete gassen



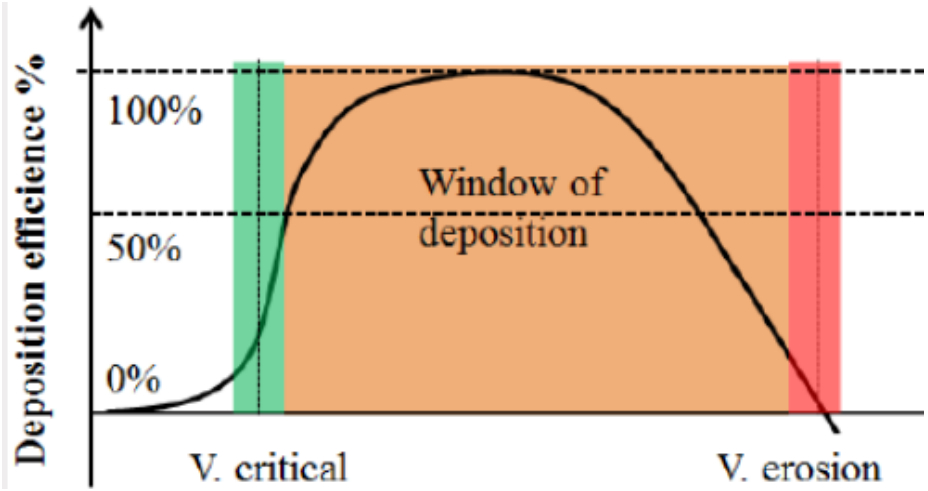
A cold sprayed Ti particle onto steel substrate showing jet formation

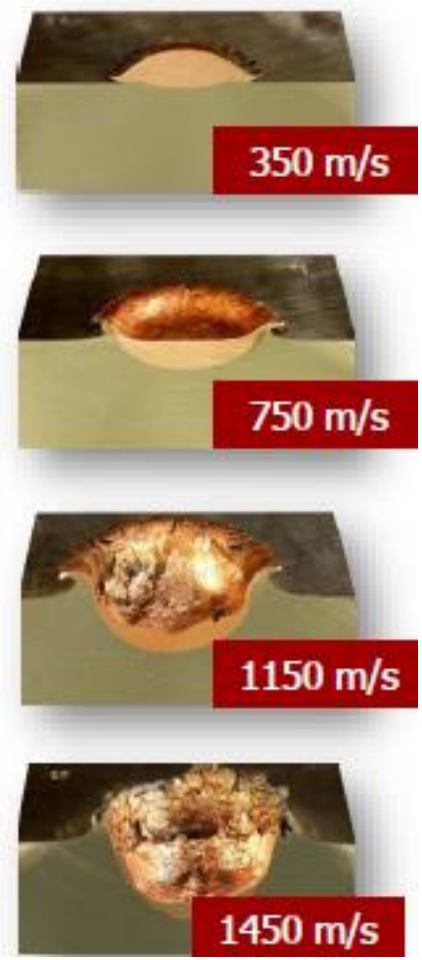


Gas Dynamisch Koud Spuiten

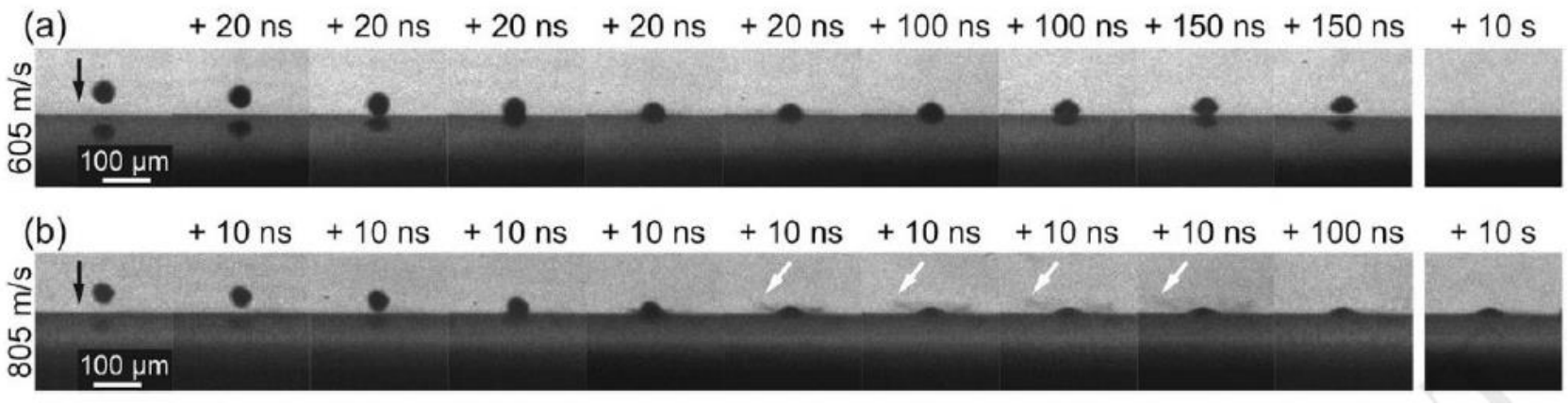
Hechtings voorwaarden:

- Invloed van snelheid bij opmenging
- Bestaan van kritische snelheid en erosie snelheid

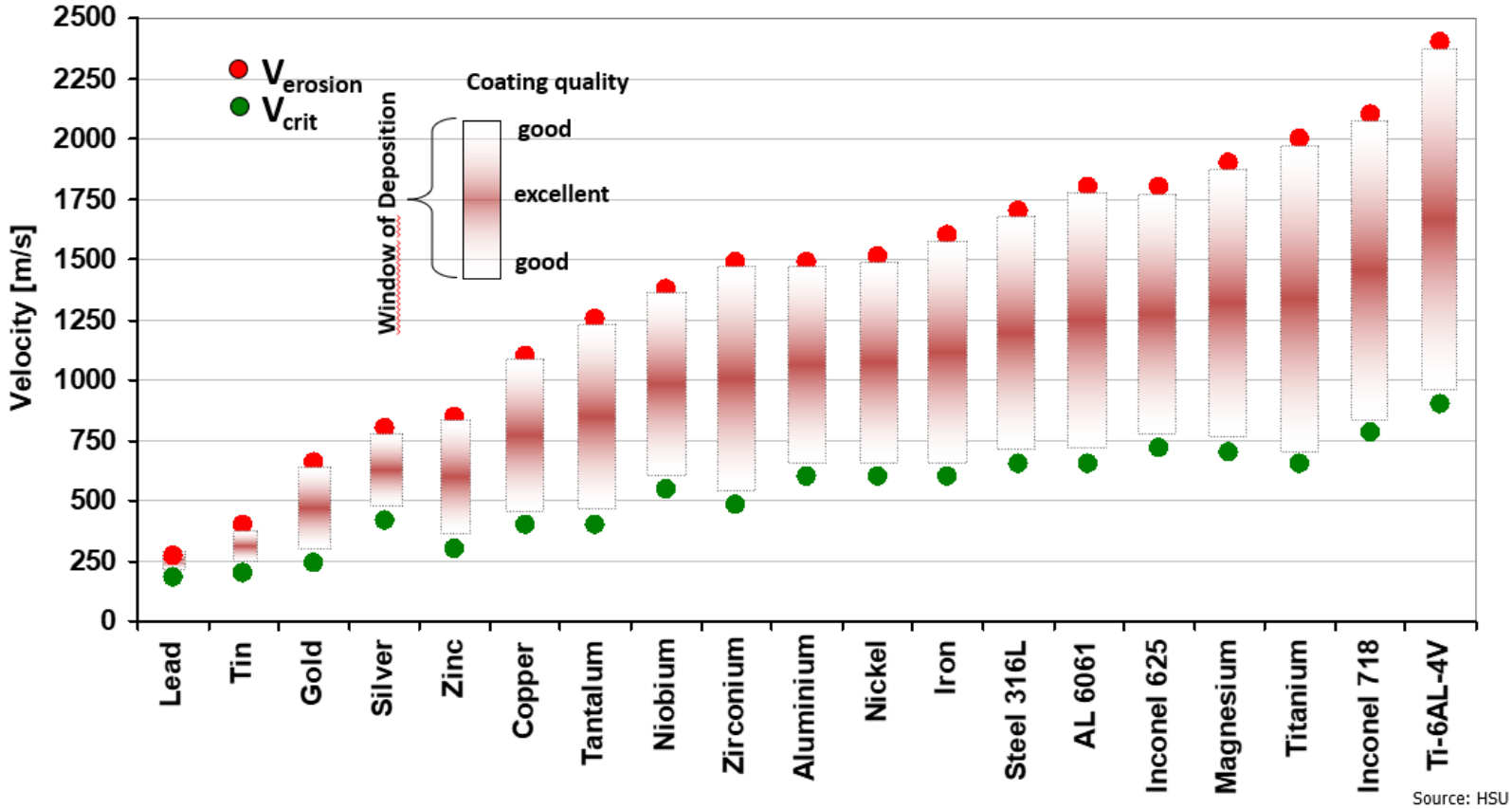




Deeltjes met te lage snelheid en de juiste snelheid



Gas Dynamisch Koud Spuiten

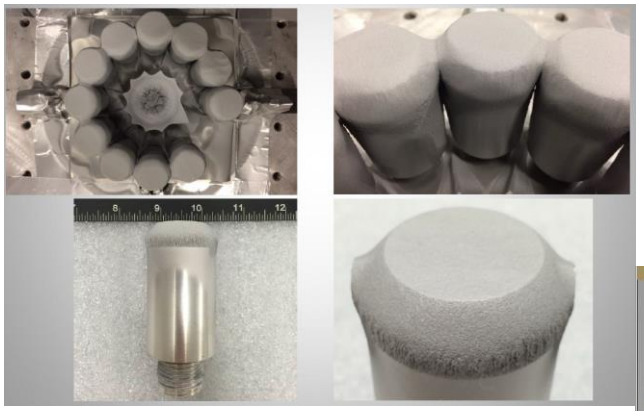


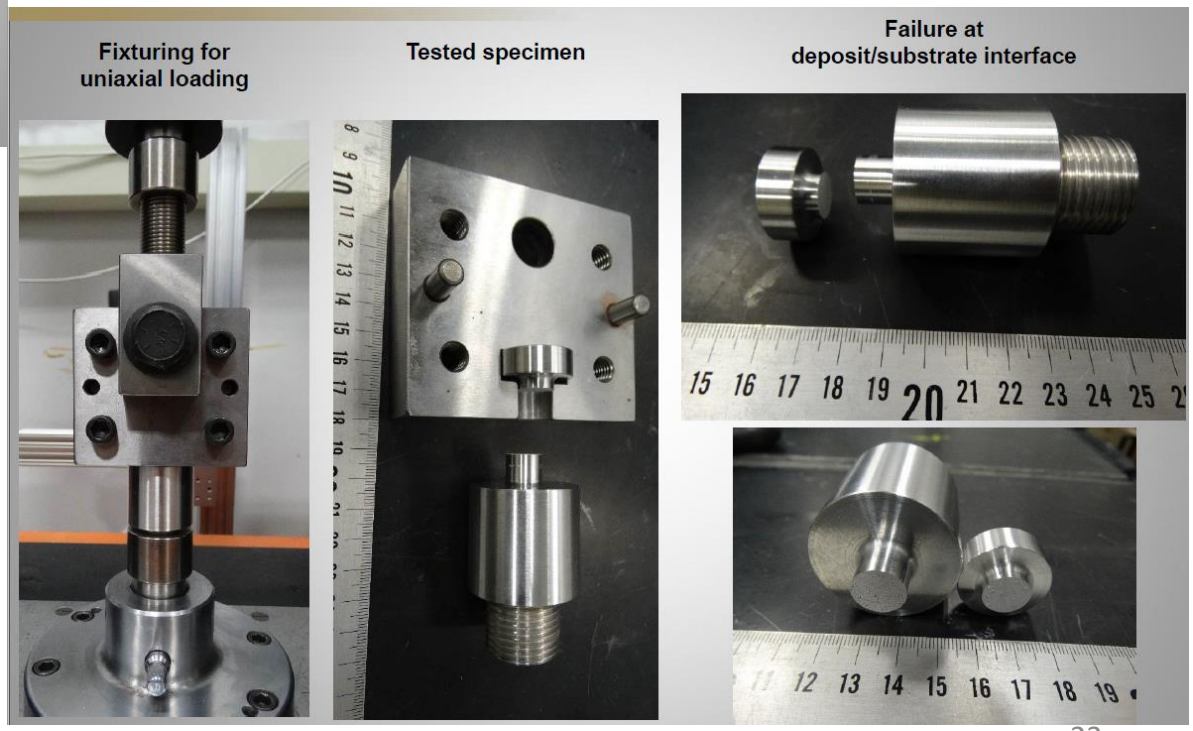
Gas Dynamisch Koud Spuiten

Voorbeelden van hechtingswaarden:

• Vlam spuiten:	bij 200 µm laagdikte - 10 - 30 MPa
• Plasma/Electric Arc spuiten:	bij 300 µm laagdikte - 20 - 50 MPa
• High Enthalpy Plasma / LPPS:	bij 300 µm laagdikte - 60 - 80 MPa
• HVOF/HVAF:	bij 300 µm laagdikte - 80 - 100 MPa
• Galvanisch Hard Chroom:	bij 50 µm laagdikte - 250 MPa
	bij 100 µm laagdikte - 70 MPa
	bij 200 µm laagdikte - 40 MPa
	bij 400 µm laagdikte - 30 MPa
• Cold Spray:	**bij 500 µm laagdikte - 200 - 600 MPa**

Gas Dynamisch Koud Spuiten





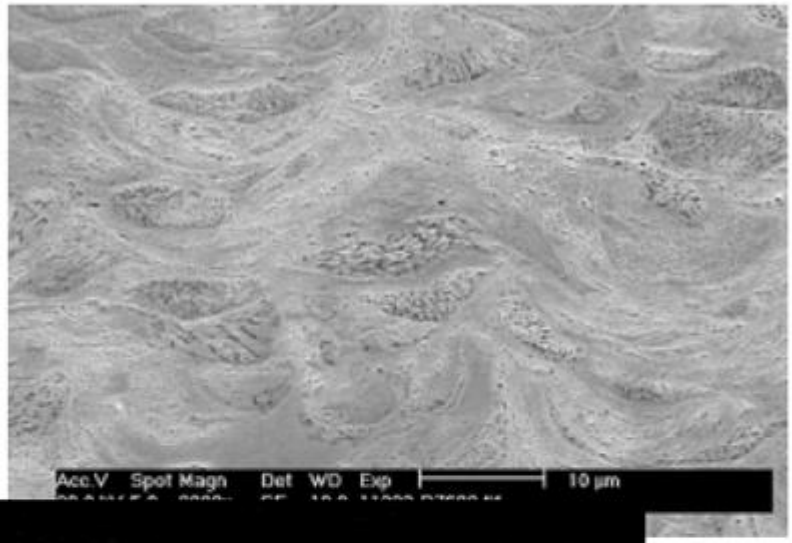
Gas Dynamisch Koud Spuiten

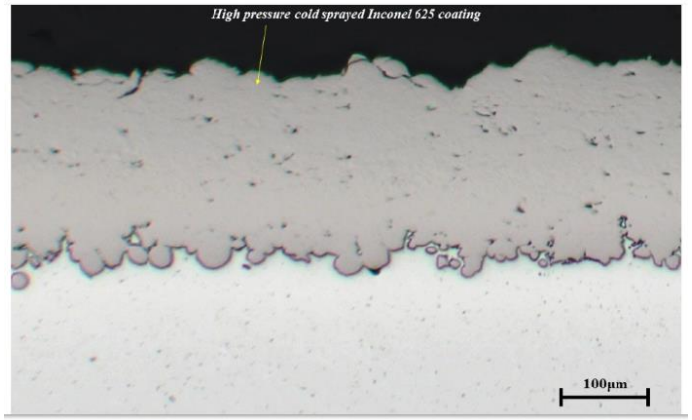
• Cold Spraying Cu (adhesive):	400 MPa
• Cold Spraying Al alloy A357 (adhesive):	170 MPa
• Cold Spraying Al 2024 (cohesive):	650 MPa
• Cold Spraying Ta (adhesive)	290 MPa
• Cold Spraying Ti (adhesive)	125 MPa
• Cold Spraying Inc 625 (cohesive):	600 MPa
• Cold Spraying Inc 718 (cohesive):	800 MPa
• Cold Spraying Inc 718 (cohesive incl. heat treatment):	1240 MPa

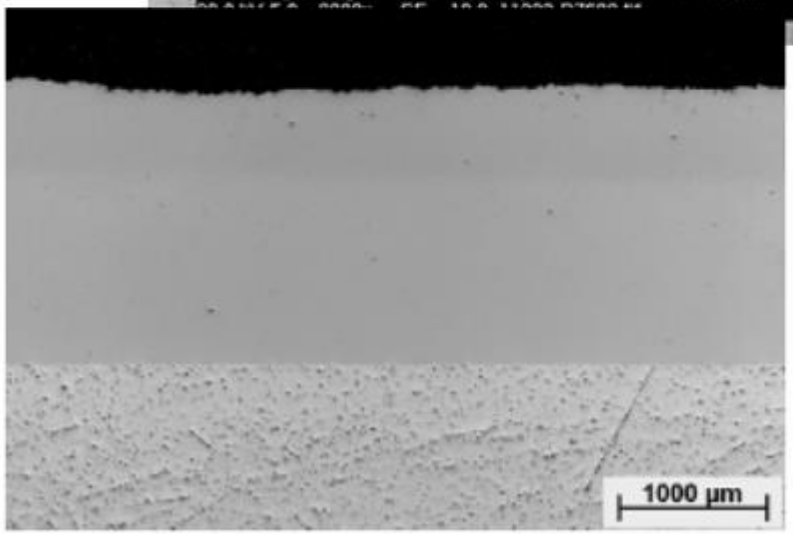
Gas Dynamisch Koud Spuiten

Voorbeeld metallurgische foto's van CS coating:

- Zeer dichte coating
- Geen geoxideerde deeltjes
- Geen micro-cracks

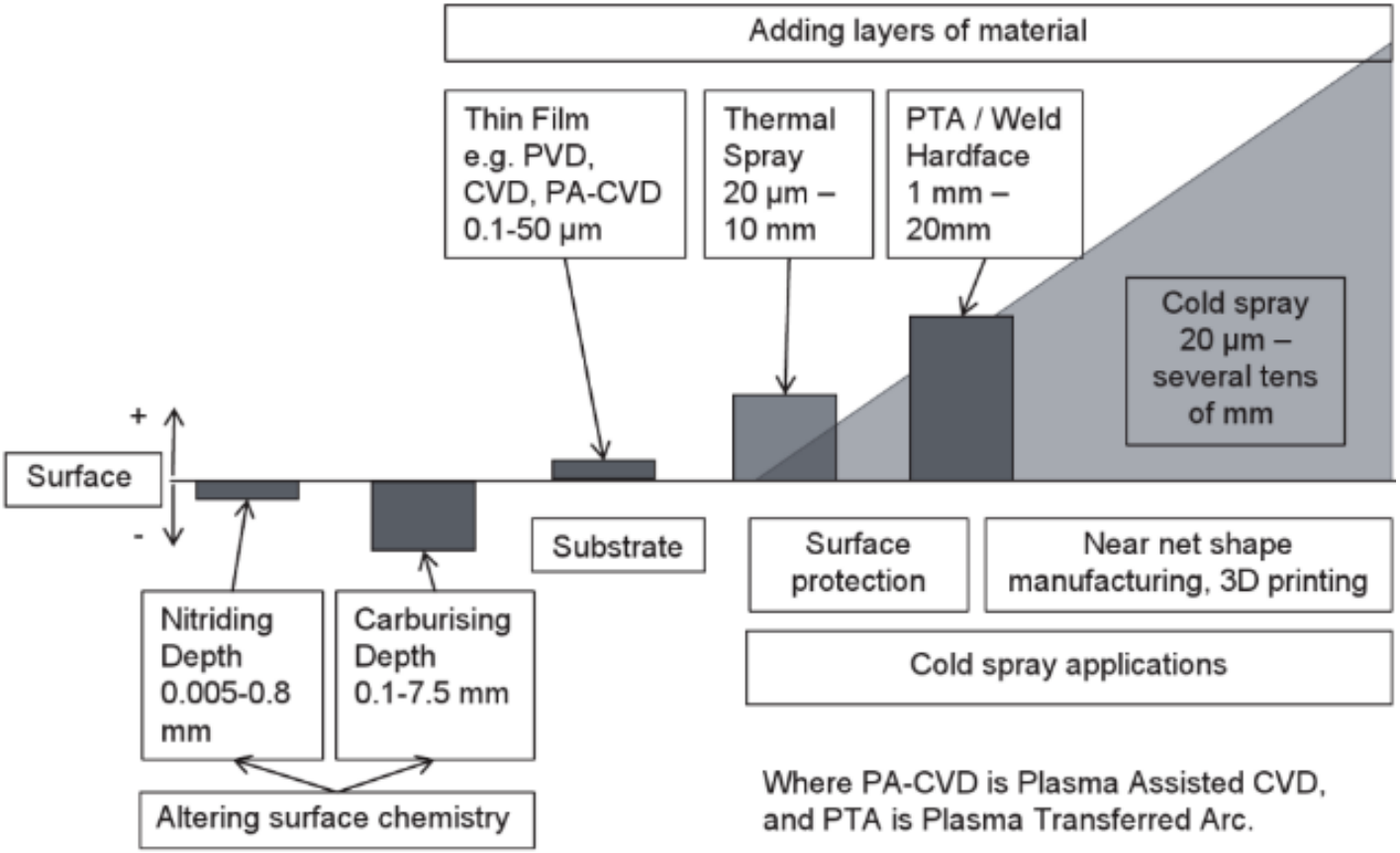






Gas Dynamisch Koud Spuiten

Coating laagdiktes van verschillende processen



Gas Dynamisch Koud Spuiten

Toepassingsrichtingen:

- Alternatief voor / aanvulling op: Thermisch Spuiten / Cladden
- Alternatief voor ARBO en Milieu kritische processen (b.v. verchromen)
- Volledig nieuwe applicaties (die tot voor kort niet mogelijk waren)
- Structurele reparaties of verbeteringen (sterkte terugbrengen)
- Maken van losstaande onderdelen (Additive manufacturing / 3D printing / Free Standing Bodies)

Gas Dynamisch Koud Spuiten

Coating eigenschappen en voordelen:

- Geen opmenging tussen basismateriaal en spuitmateriaal
- Geen smeltbad, dus geen stolling en geen spanningen
- Geen oxidevorming in de laag, dus geen beschermgassen nodig
- Coatings met hoge temperatuur en elektrische geleiding mogelijk
- Homogene en dichte lagen zonder poriën.

Gas Dynamisch Koud Spuiten

Verspuitbare commerciele materialen:

Lage druk/temperatuur systemen:
- Aluminum and Aluminum Alloys
- Zinc
- Copper
- Nickel
- Steel

Midden druk/temperatuur systemen:
- Inconel
- MCrAlY
- Nickel & Nickel Alloys
- Stainless Steel
- Titanium & Titanium Alloys

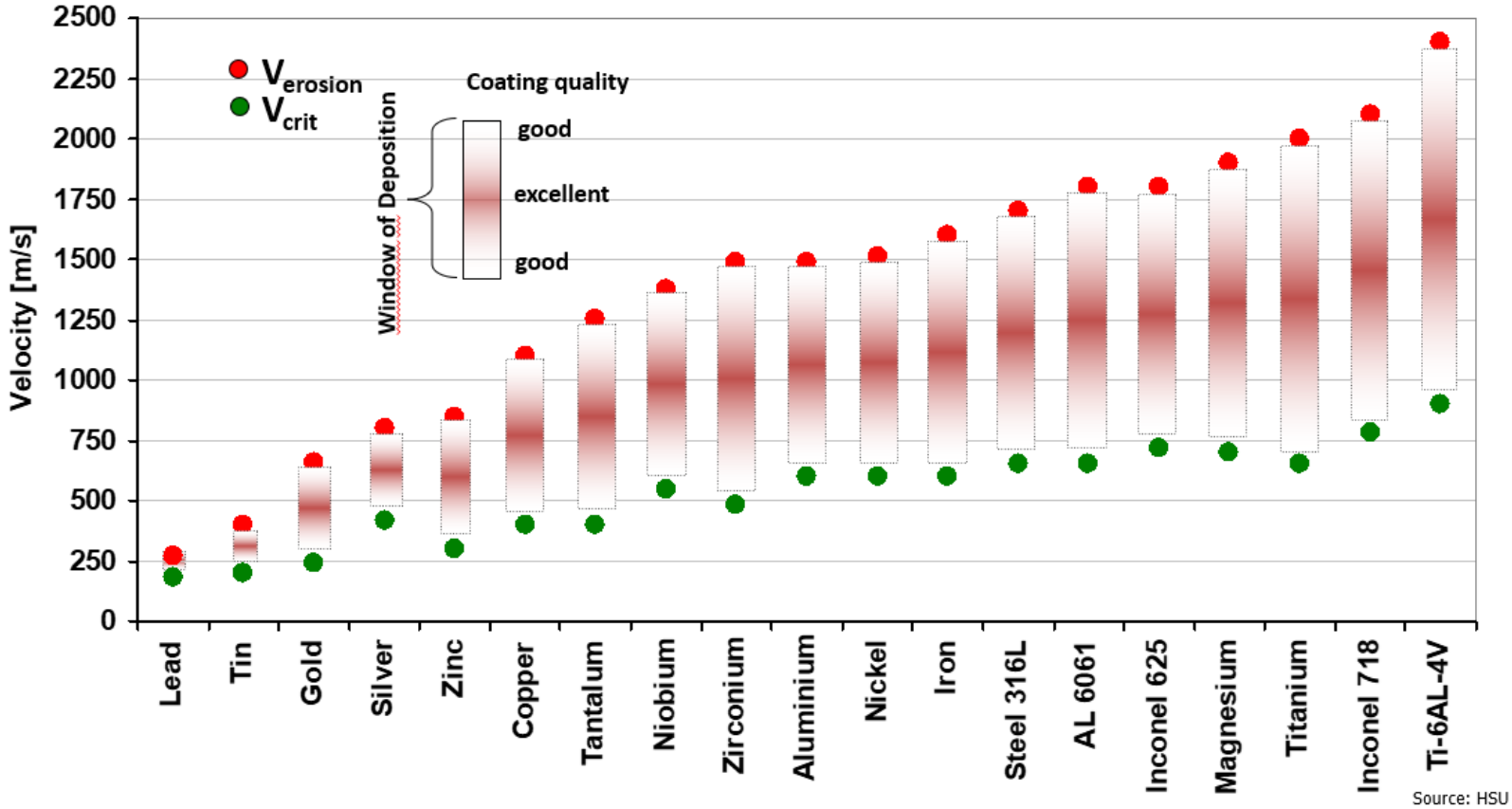
Hoge druk/temperatuur systemen:
- Bronze
- Cobalt
- Chrome
- Tantalum
- Niobium
- Carbide-Metal mixtures
- Ceramic-Metal Mixtures

Gas Dynamisch Koud Spuiten

Verschillende soorten materialen

- Metals
- MMC's (Metal Matrix Composites)
- MMMC's (Metal-Metal Matrix Composites)
- Ceramics
- Polymers
- Nanostructured powders
- Oxidation sensitive materials
- Phase sensitive materials
- Temperature sensitive materials
- Amorphous materials (metallic glass / glassy metals)

Gas Dynamisch Koud Spuiten



Gas Dynamisch Koud Spuiten

- LPCS:
  - Gas drukken: 5 – 10 bar (70 – 140 psi)
  - Gas temperaturen: tot 630 °C (* en 1000°C)
  - Deeltjes snelheden: tot 500 m/s (* en tot 1000 m/s)

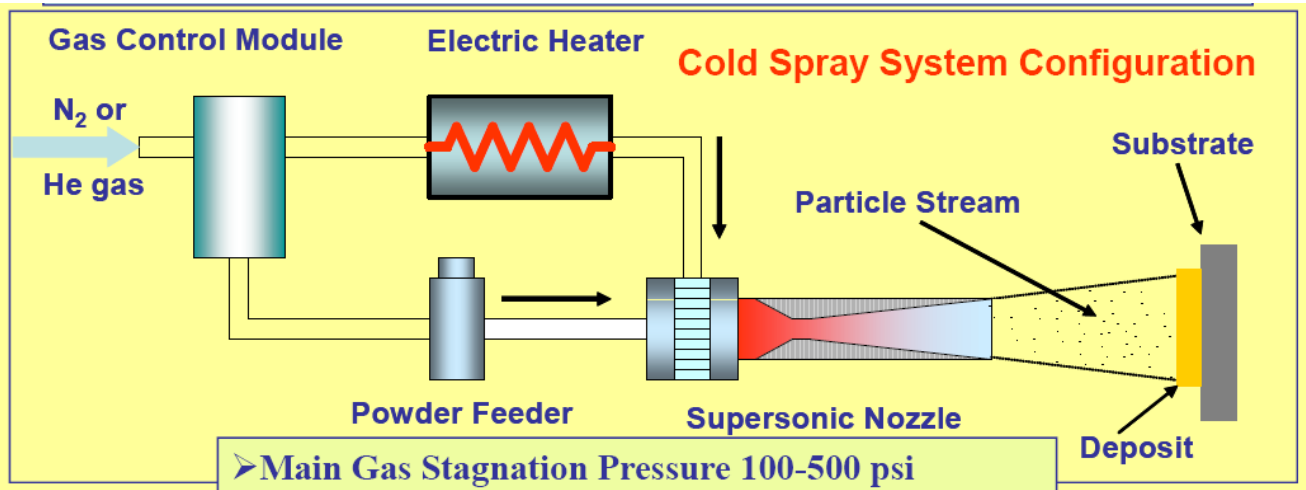
- MPCS:
  - Gas drukken: 7 – 35 bar (100 – 500 psi)
  - Gas temperaturen: tot 750 °C
  - Deeltjes snelheden: tot 900 m/s

- HPCS:
  - Gas drukken: 35 – 80 bar (500 – 1140 psi)
  - Gas temperaturen: tot 1100 °C
  - Deeltjes snelheden: tot 1200 m/s

(*) met Sonic Nozzle by Kinetic Metallization

Gas Dynamisch Koud Spuiten

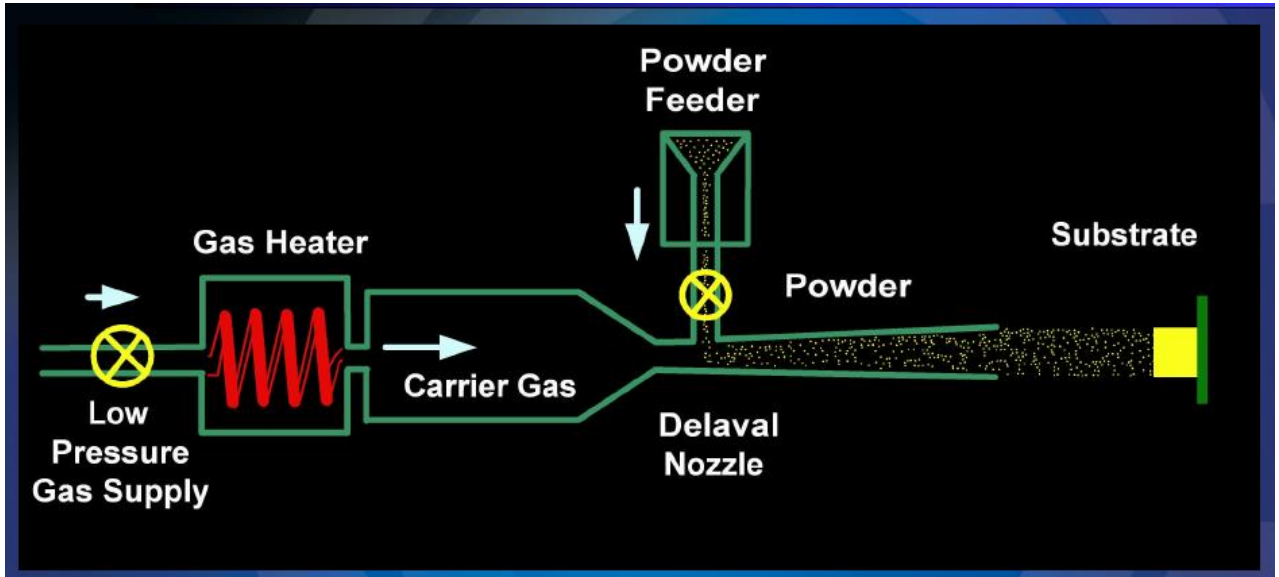
Principle (1):



- Main Gas Stagnation Pressure 100-500 psi
- Gas Temperature 0-500°C
- Main Gas Flow Rate 30-100 CFM
- Powder Feed Rate 1 to 10 pounds/hour
- Particle Velocity 300-1500 m/sec.
- Particle Size 1-100um diameter

Gas Dynamisch Koud Spuiten

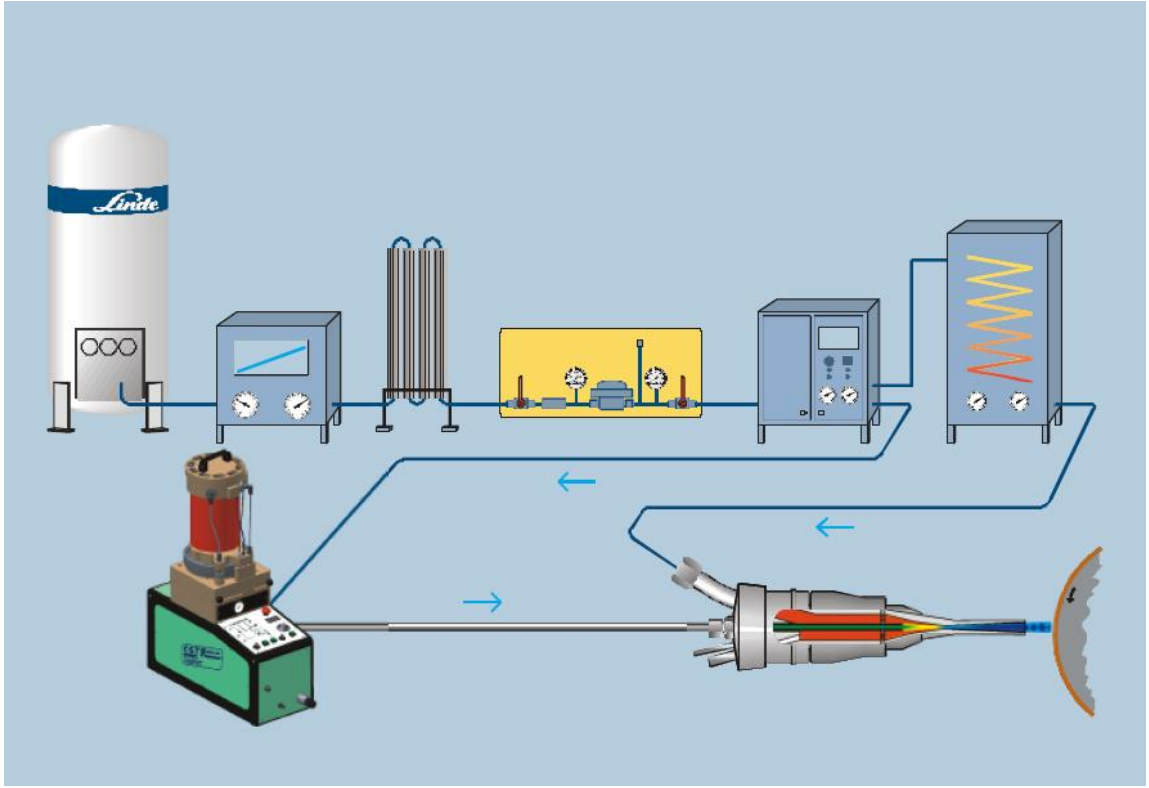
Principle (2):



Gas : Air , Nitrogen / pressure: 80 -150psi (5-10 bar)
Gas Temperature Ambient – 600°C (80- 1100 °F)
Particle Velocities 350 – 650 m/s

Gas Dynamisch Koud Spuiten

Equipment overview:



Gas Dynamisch Koud Spuiten

Plasma Giken
(Japan)

Gas Dynamisch Koud Spuiten

Impact
(Germany)

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VTS
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Dutch association for thermal spray technology

SST (Centerline)

(Canada)

http://supersonicspray.com/en/

Gas Dynamisch Koud Spuiten

Dymet
(Russia)

Gas Dynamisch Koud Spuiten

Dycomet/Titomic
(The Netherlands)

Gas Dynamisch Koud Spuiten

VRC
(USA)

Gas Dynamisch Koud Spuiten

LPCS:
- Dymet (Russia): 80 systems sold (prices: 25 – 35 k€)
- SST – Centerline: 100 systems sold (prices: 80 - 100 k€)

MPCS:
- SST – Centerline(Canada): 25 systems sold (prices: 125 – 150 k€)
- Titomic/Dycomet: 30 systems sold (prices: 150 – 400 k€)

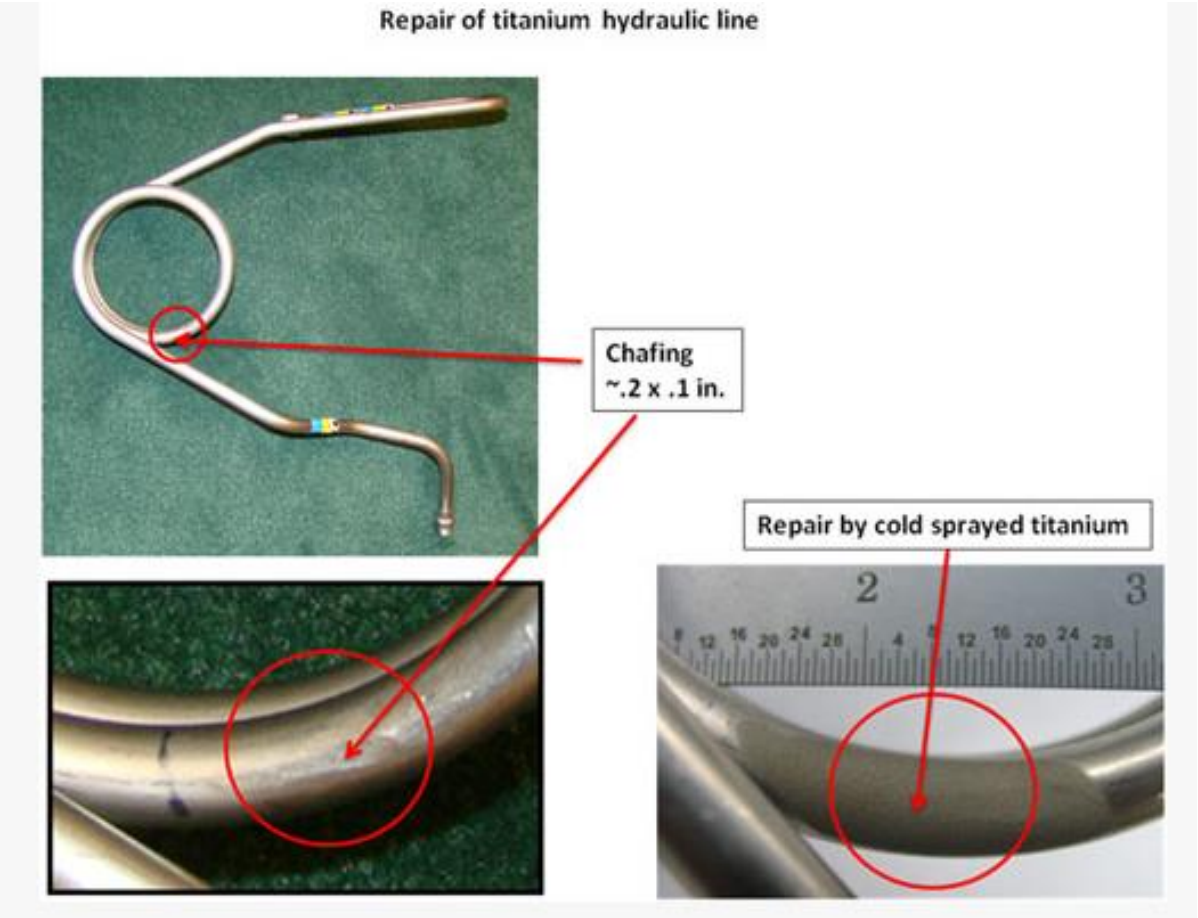
HPCS:
- Plasma Giken (Japan): 60 systems sold (prices 250 – 300 k€)

- Impact (Germany): 80 systems sold (prices: 290 – 320 k€)

- VRC (USA): 40 system sold (price: approx. 300 k€)

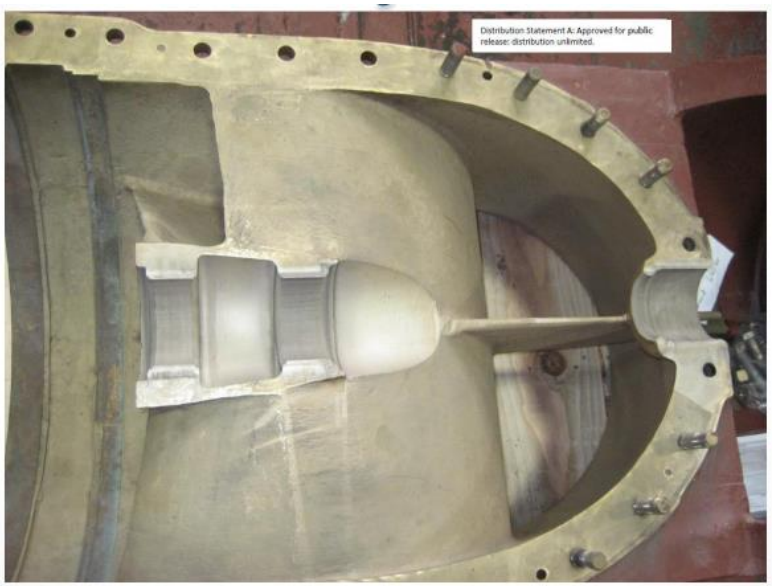
Gas Dynamisch Koud Spuiten

Applicatie voorbeelden

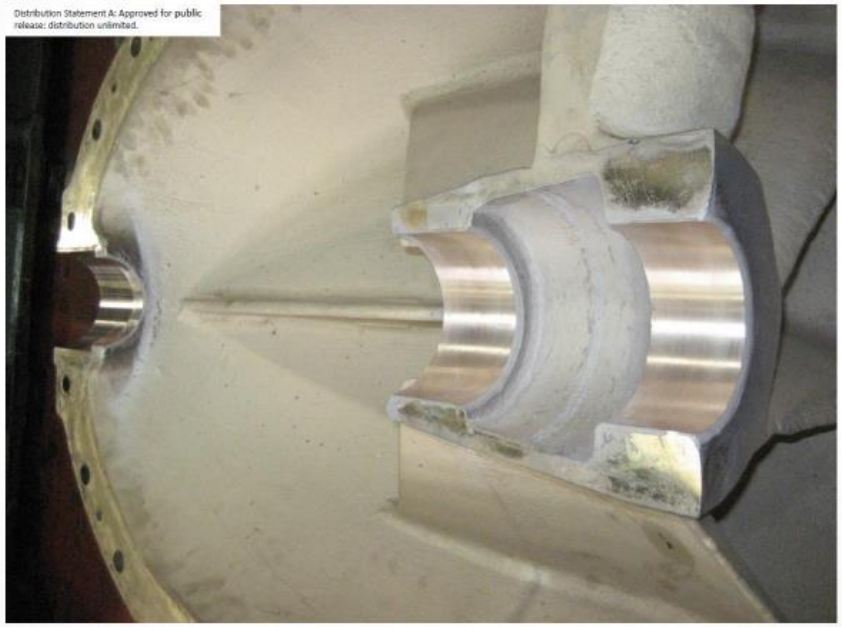


Gas Dynamisch Koud Spuiten

Applicatie voorbeeld



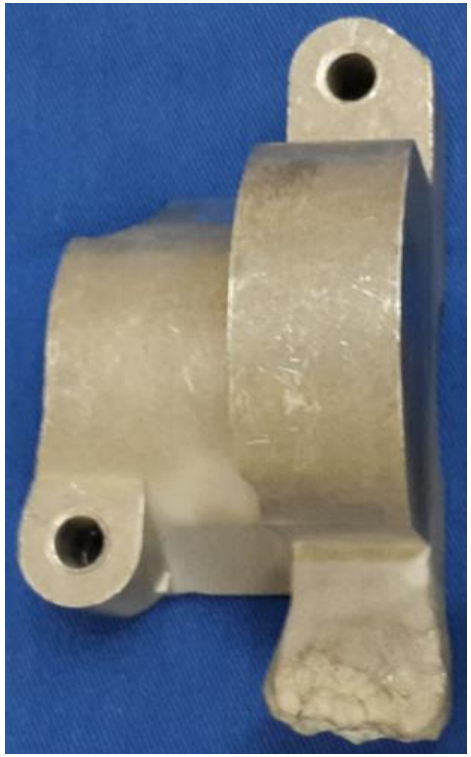
Case: As sprayed

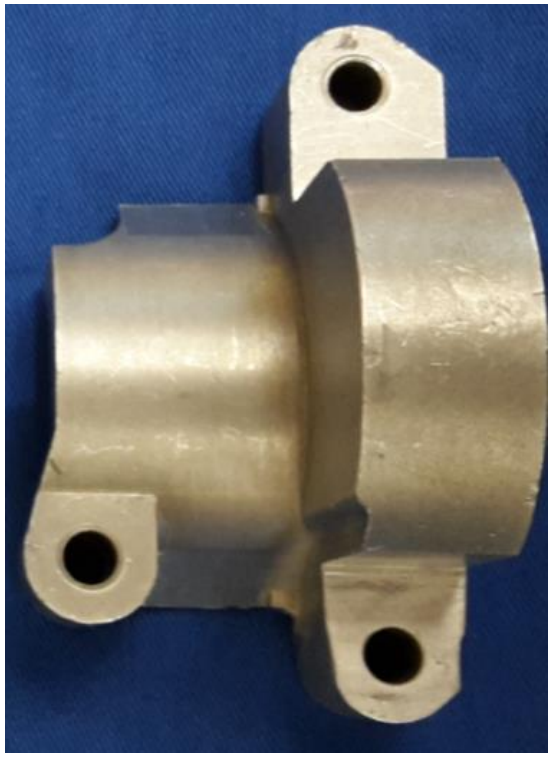


Cover: Finish machined

Gas Dynamisch Koud Spuiten

Applicatie voorbeeld “redesign”





Gas Dynamisch Koud Spuiten

Applicatie voorbeeld “redesign”

Gas Dynamisch Koud Spuiten

Voorbeeld toepassing mobiele CS systeem

Gas Dynamisch Koud Spuiten

Grootste CSAM (3D Cold Spray printer) in de wereld

(video: courtesy of Titomic, Australia)

Gas Dynamisch Koud Spuiten

Applicatie voorbeelden 3D printen

Gas Dynamisch Koud Spuiten

Applicatie voorbeelden 3D printen

Photos: Courtesy of Impact Innov

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Applicatie voorbeelden 3D printen

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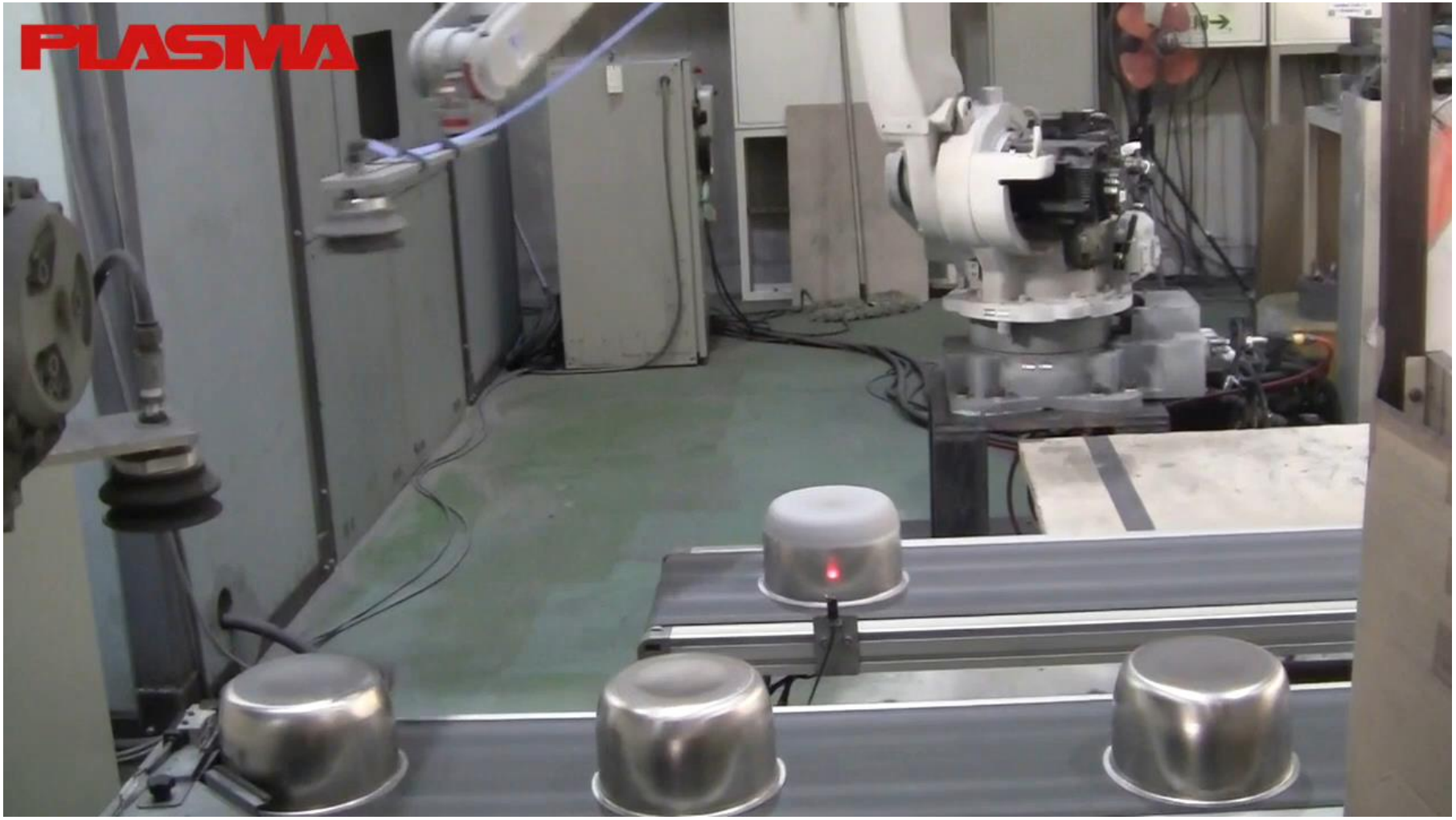
Dutch association for thermal spray technology



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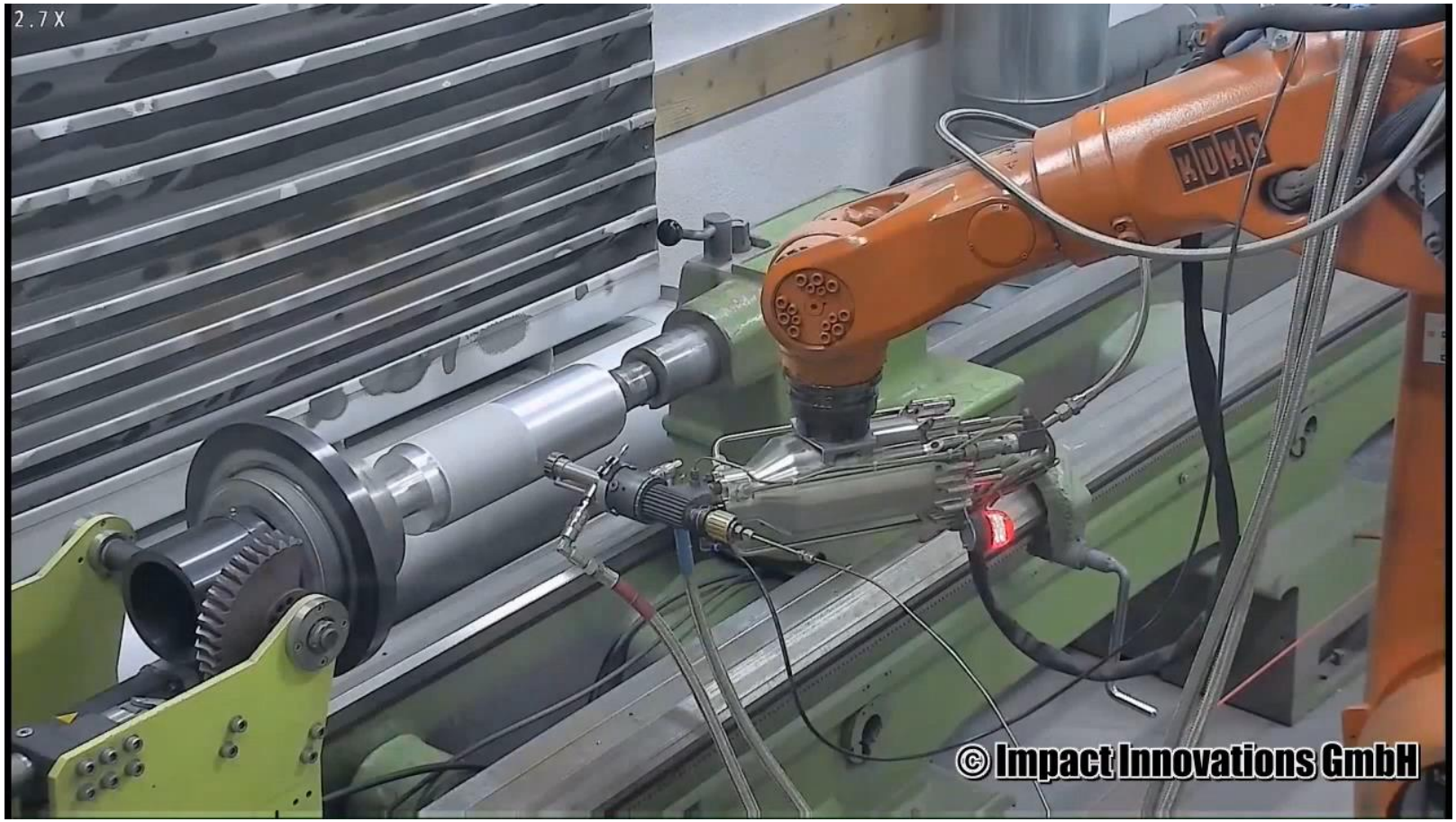
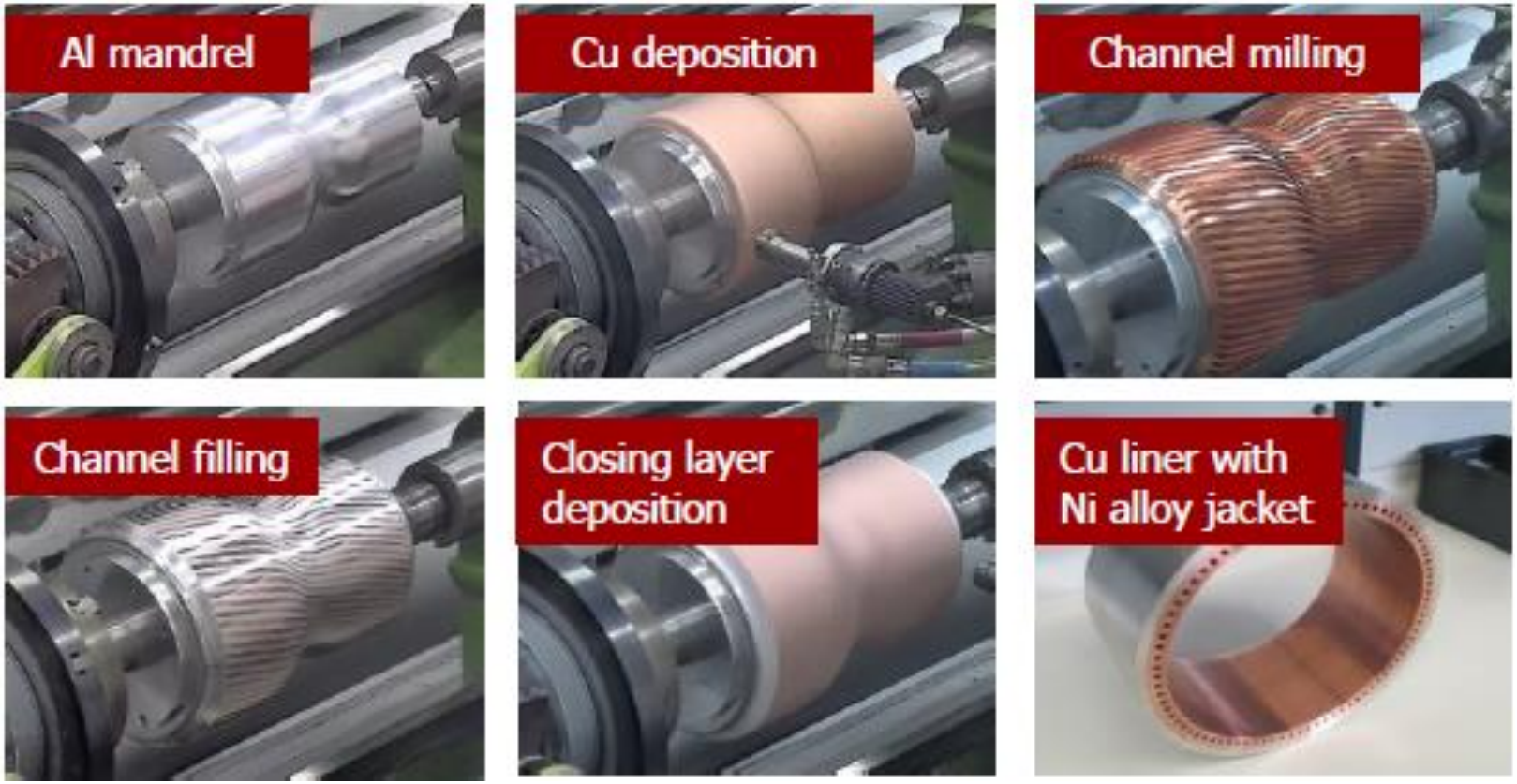
Applicatie voorbeelden "Multi Material Coating"



Gas Dynamisch Koud Spuiten

Applicatie voorbeelden 3D printen met Multi Materials



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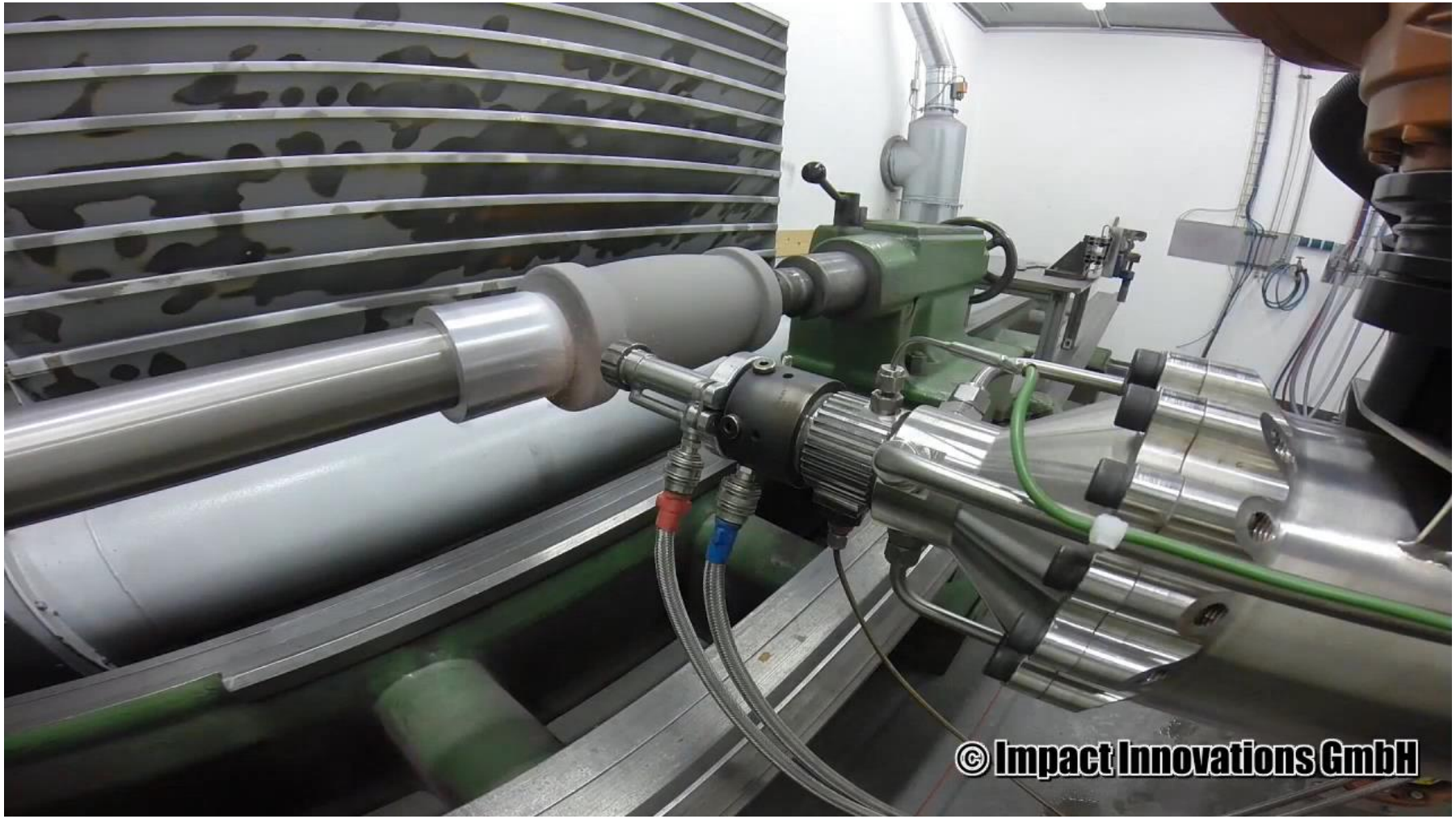
Applicatie voorbeelden 3D printen



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Applicatie voorbeelden 3D printen

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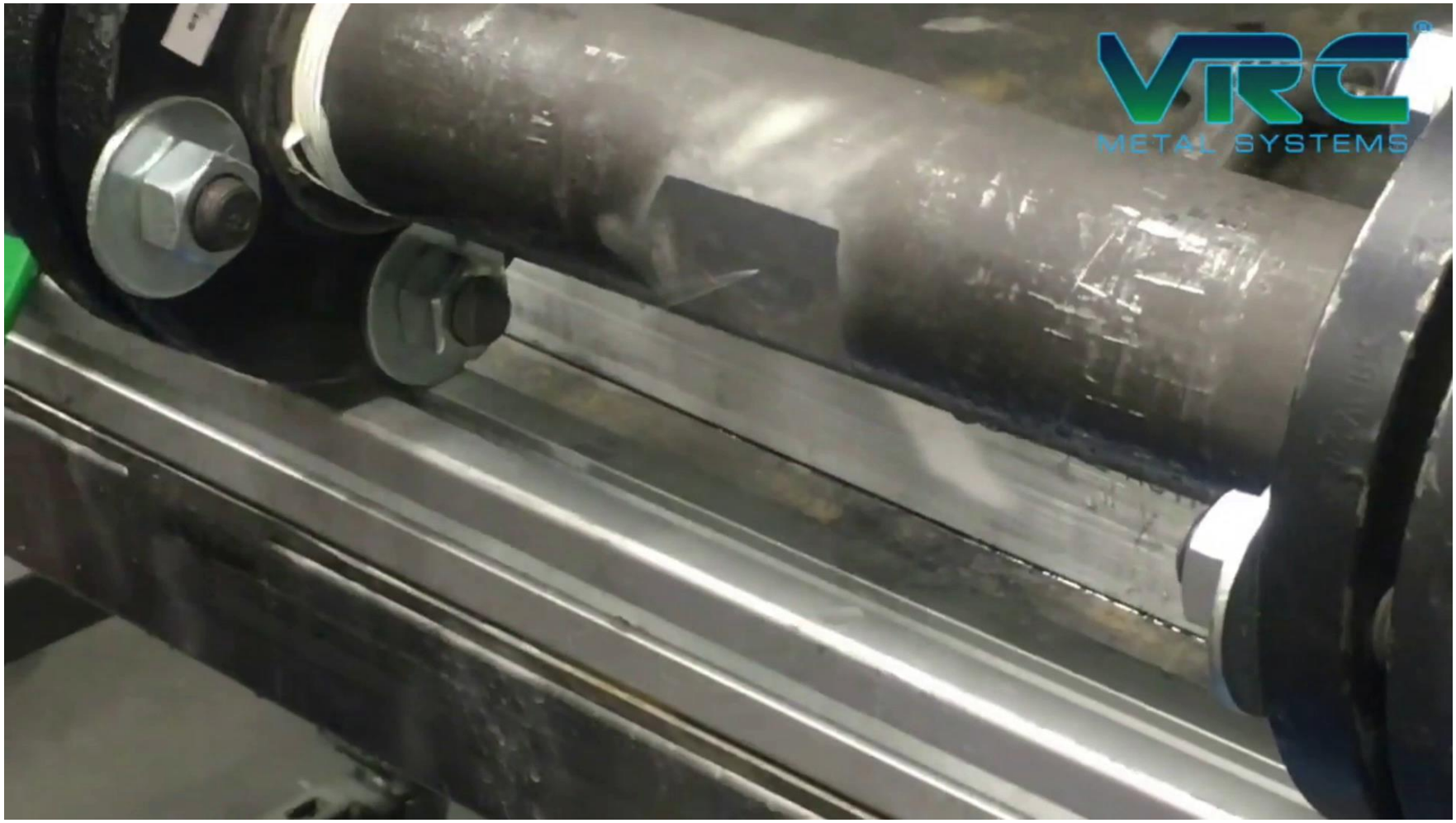

Gas Dynamisch Koud Spuiten

Cold Spray film voorbeelden op internet:

- https://www.youtube.com/watch?v=0KF2_GMaots Spraying Inconel
- https://www.youtube.com/watch?v=lQ8SOq1UIbw Spraying Copper
- https://www.youtube.com/watch?v=3xs4sjIu7HM Spraying Titanium
- https://www.youtube.com/watch?v=9krFI7AVWIY Spraying Aluminium
- https://www.youtube.com/watch?v=O7JyN-Ns0Zs Spraying Steel
- https://www.youtube.com/watch?v=dErRoEKuloo Impact Innovations
- https://www.youtube.com/watch?v=hFwqt276YWA Impact Innovations
- https://www.youtube.com/watch?v=DnVny_pioJ8 Impact Innovations
- https://www.youtube.com/watch?v=ZzhPXgrYdsA Centerline SST
- https://www.youtube.com/watch?v=ALPMZbXGw1g Dymet1
- https://www.youtube.com/watch?v=f7sNYm9uEUQ Dymet2
- https://www.youtube.com/watch?v=ghD7xeA_1_w Dycomet
- https://www.youtube.com/watch?v=NXGOZ5ns3Zo GE spraying a gear
- https://www.youtube.com/watch?v=QsR7MnFCM74&ab_channel=VRCMetalSystems

Gas Dynamisch Koud Spuiten

Institutes / Universities / Research Centers, involved with Cold Spraying:

GE Global Research Center, OH, USA
Army Research Lab, USA
University of Dayton, OH, USA
University of Wisconsin-Madison, USA
Rowan University, New Jersey, USA
University of Tampere, Finland
University of Barcelona, Spain
University of Dublin (Trinity College), Ireland
University of Nottingham, UK
University of Cambridge, UK
TWI, Cambridge, UK
Helmut Schmidt University, Hamburg, Germany
University of the Federal Armed Forces, Germany
Swinburne University of Technology, Australia
Charles Darwin University, NT, Australia
Scientific Industrial Research Organization, Australia
São Paulo State University, Brasil
University of LIMOGES, France
University of Technology of Belfort, France

National Research Council, Canada
University of Alberta, Canada
Concordia University, Montreal, Canada
Toyohashi University of Technology, Japan
Keio University, Tokyo, Japan
Tohoku University Sendai, Japan
Niigata University, Niigata, Japan
Xidian University, China
University of Science and Technology, Beijing, China
Xi'an Jiaotong University, China
Nanjing University, China
Gitam University, India
Guru Nanak Dev University, India
Belarus State Technical University, Minsk, Russia
St. Petersburg University, Russia
Wroclaw University of Science and Technology, Poland
Technical University Delft, The Netherlands
University of Johannesburg, South Africa

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Aerospace companies involved:

Pratt & Whitney
A United Technologies Company

Ohlinger Industries

DASSAULT AVIATION

Able AEROSPACE SERVICES
A Textron Company

WALCH

VAC AERO INTERNATIONAL INC.

BOEING

Honeywell

FLAME SPRAY

DELTA

NAVAIR

ACR

U.S. AIR FORCE

Hamilton Sundstrand
A United Technologies Company

Alabama LASER

ARL

CTC
Concurrent Technologies Corporation

ACCUWRIGHT

E23

MAINTENANCE IBERIA

GE Aviation

Rolls-Royce

AIRBUS GROUP

AIRBUS MILITARY

Avio Aero
A GE Aviation Business

Lufthansa Technik
More mobility for the world

Gas Dynamisch Koud Spuiten

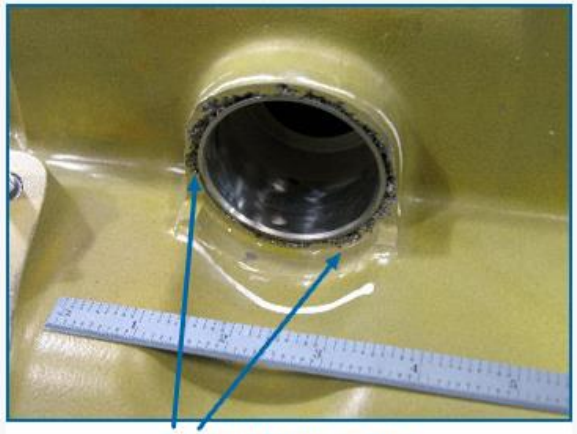
Hierna een bijlage met

allerlei praktijk applicaties

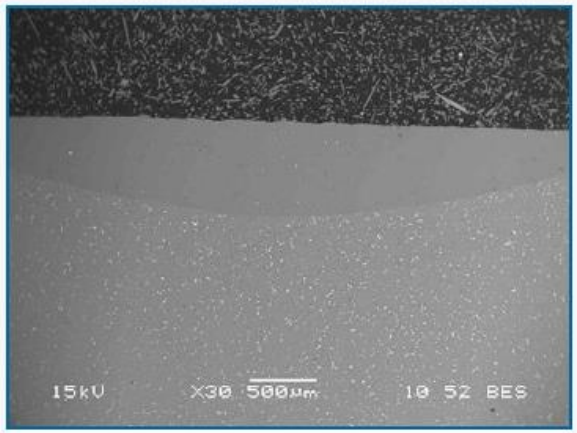
Gas Dynamisch Koud Spuiten

Gas Dynamisch Koud Spuiten

Repair of Magnesium Rotorcraft Components

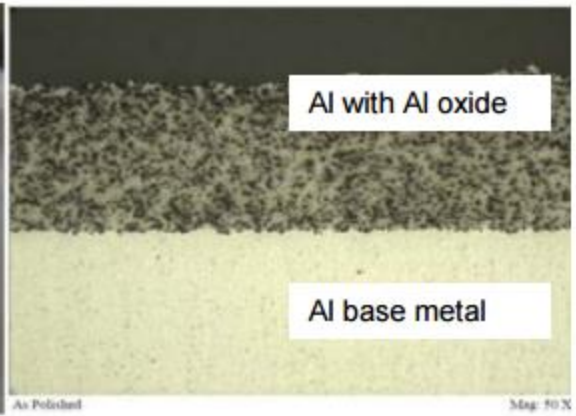


Wear and Corrosion Sites



Microstructure of Cold Spray Repair

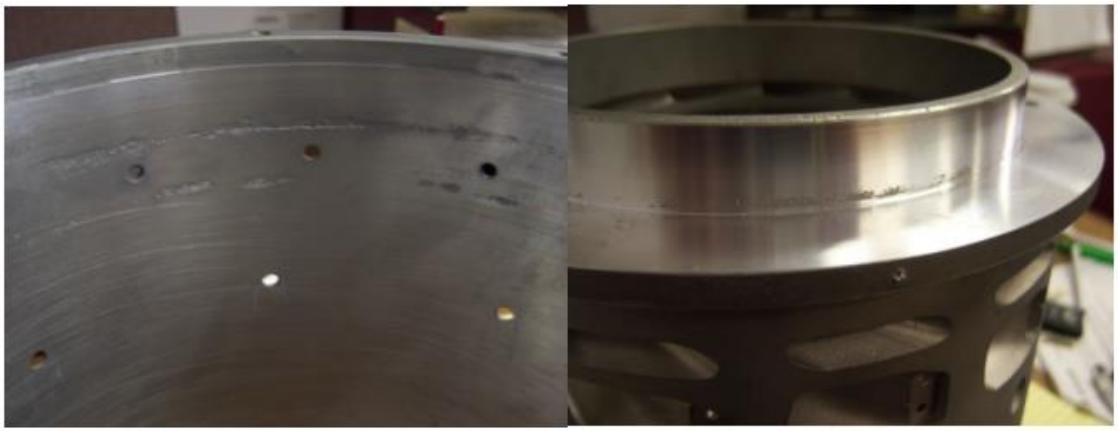
Gas Dynamisch Koud Spuiten



Gas Dynamisch Koud Spuiten

APU Generator Endcap-Boeing 777

IDG End Housing-Boeing 747/757/767



APU Generator Stator Housing-Boeing 747

Gas Dynamisch Koud Spuiten

IDG Stator Housing-747/757/767

APU Generator Endcap-Boeing 777

IDG Stator Housing-A320 classic

IDG Stator Housing-MD11/777

Gas Dynamisch Koud Spuiten

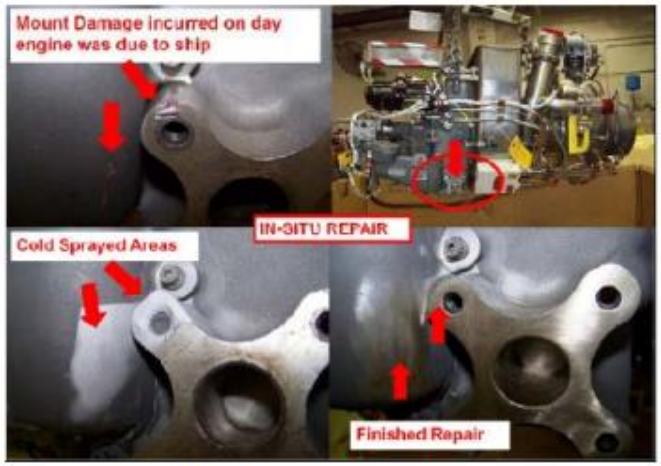
- Pneumatic Valve Housing
- Landing Gear Steering Colum
- Helicopter case housing

Gas Dynamisch Koud Spuiten

Fan shaft assembly

Fan rotor blade

Gas Dynamisch Koud Spuiten

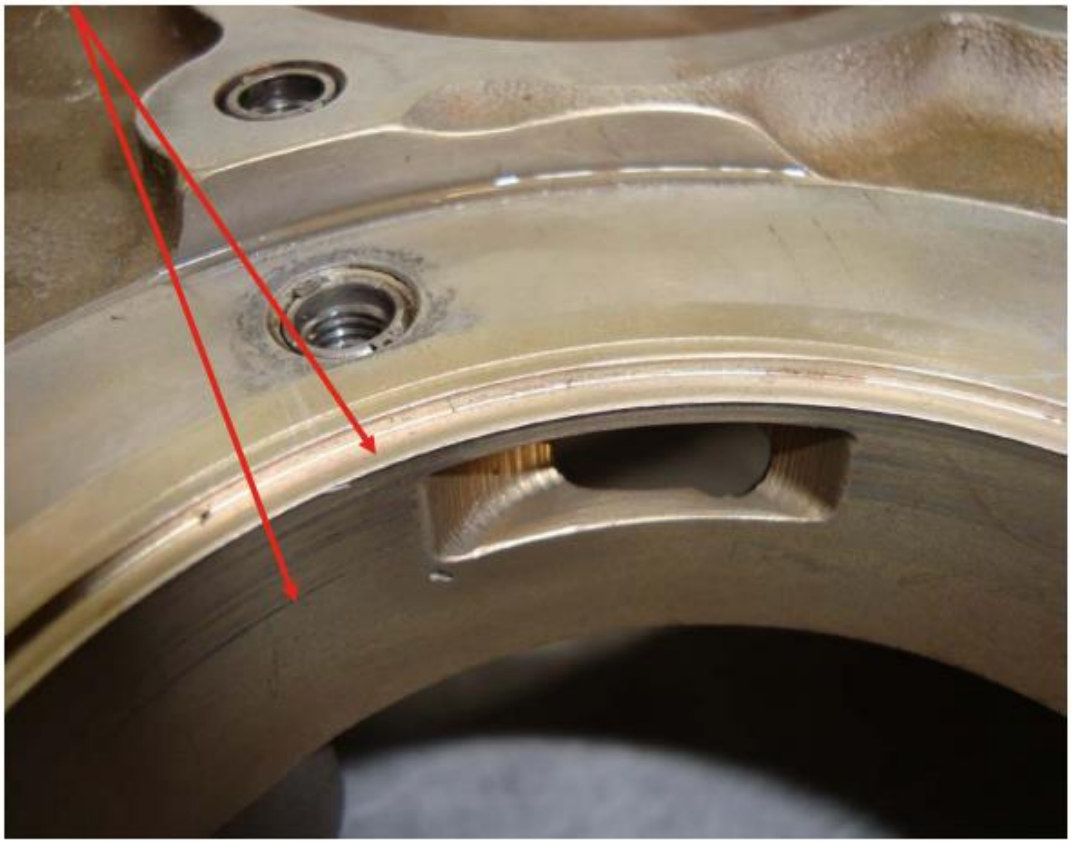


In-Situ Engine Repairs

Gas Dynamisch Koud Spuiten

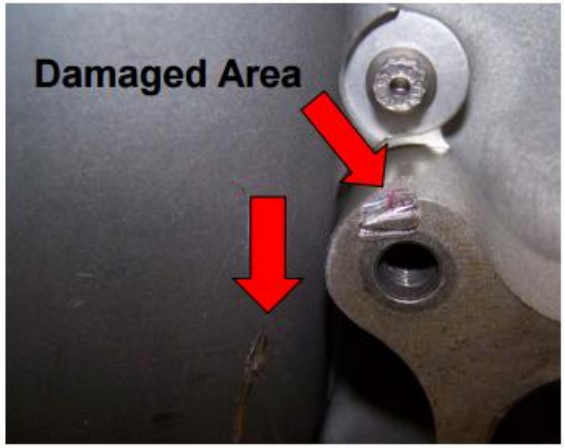
Component Repairs

Gas Dynamisch Koud Spuiten



- After cold spray implementation, the bore did not require repair at next shop visit
- Tolerance for bore is .0005 inches
- Cold spray offers longer service life

Gas Dynamisch Koud Spuiten



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Gas Dynamisch Koud Spuiten

Gearbox
Al C355-T6

Seal replacement and parent bore repairs

Gearbox
Mg ZE41A-T5

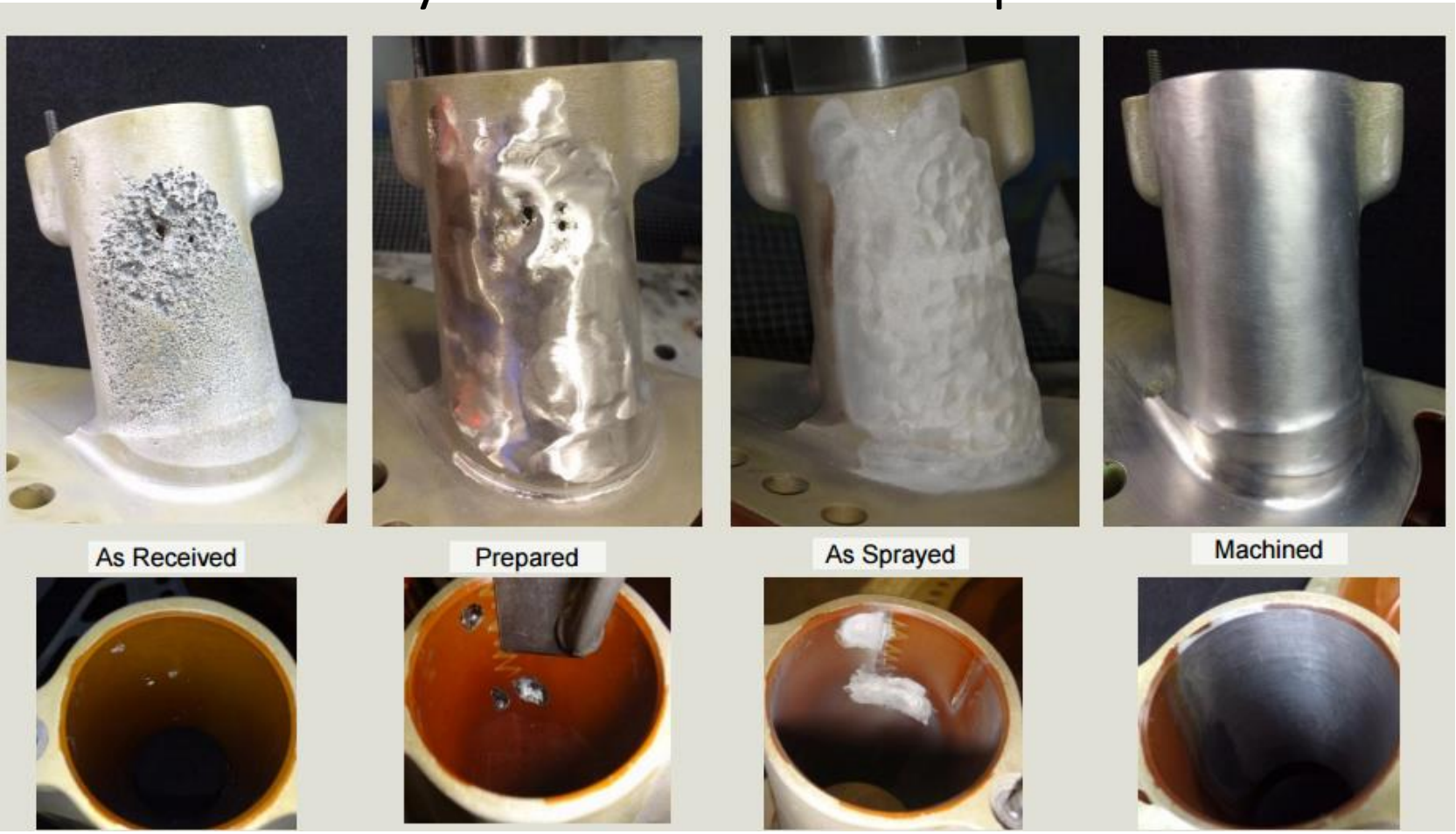
Front Frames

Engine Housing

Gas Dynamisch Koud Spuiten

Cover: Finish machined
Area A detail

Gas Dynamisch Koud Spuiten

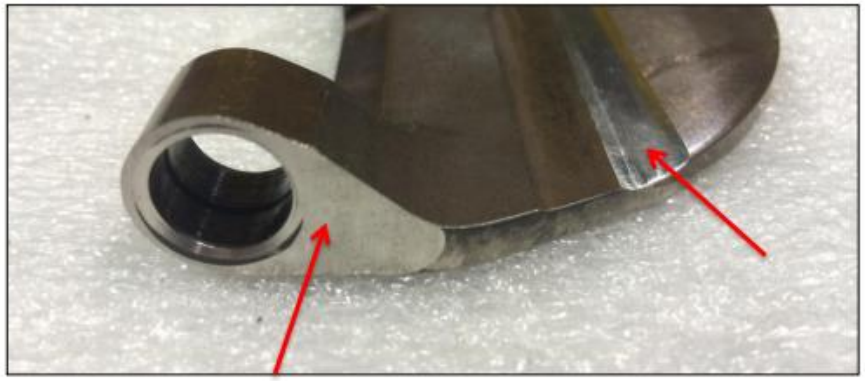


Gas Dynamisch Koud Spuiten

- Two Repair Areas
  - Mid Shaft
  - Wear Lugs

Gas Dynamisch Koud Spuiten

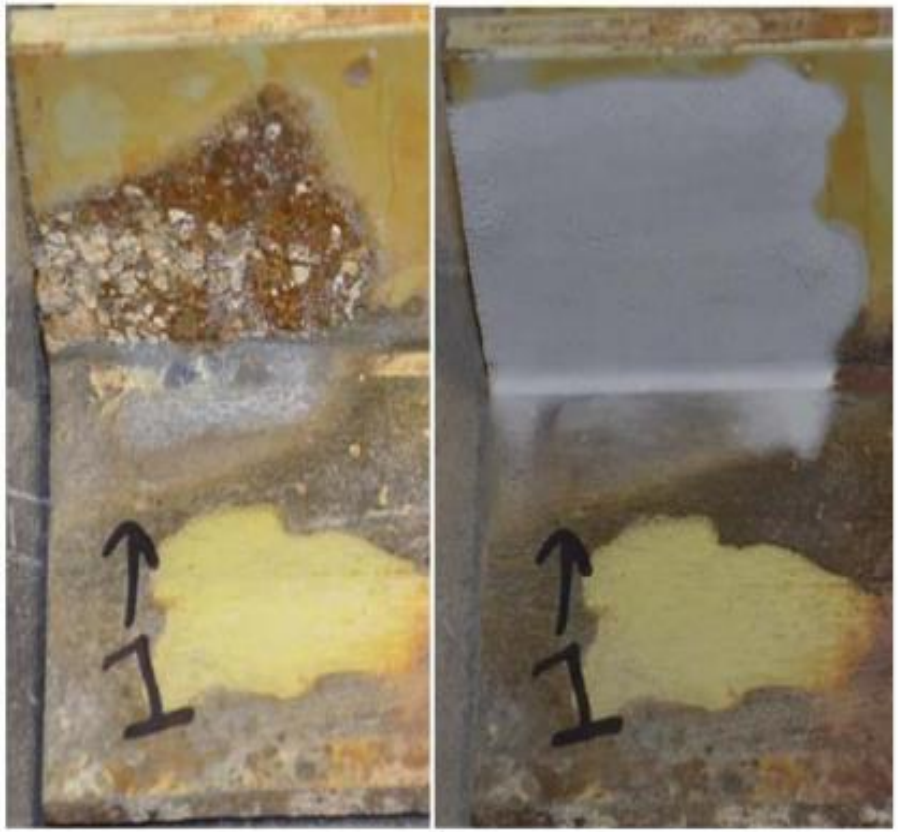
- Repair of Aerospace Valve Components



Gas Dynamisch Koud Spuiten

- Nose Wheel Steering Component
  - Refurbished with Nickel Cold Spray

Gas Dynamisch Koud Spuiten



Gas Dynamic Cold Spray – Marcel van Wonderen SPL/CF

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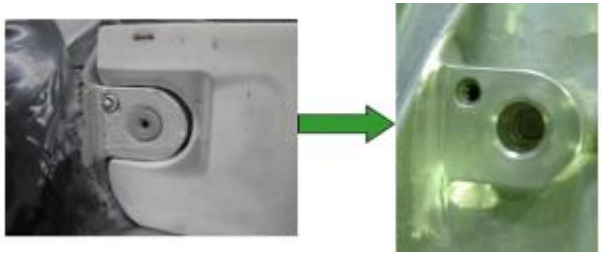
Brake Carrier Repair

Titanium Fuel Pipe Repair

Drag Brace Outer Tube Repair

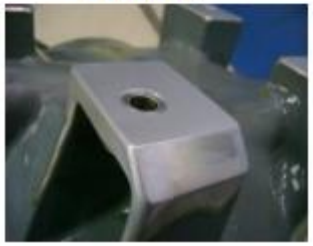


Main Module

Swivel Joint Repair

Input Module

Intermediate Gearbox



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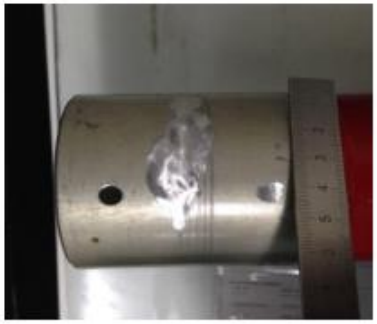
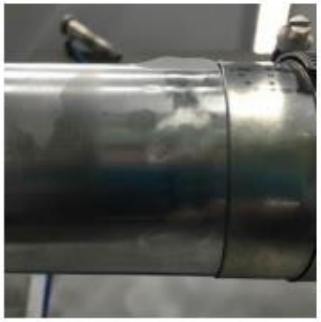
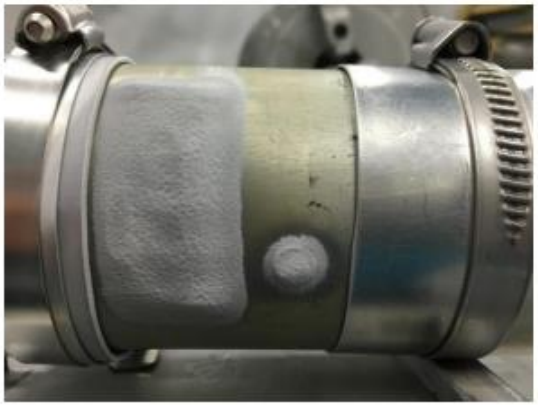
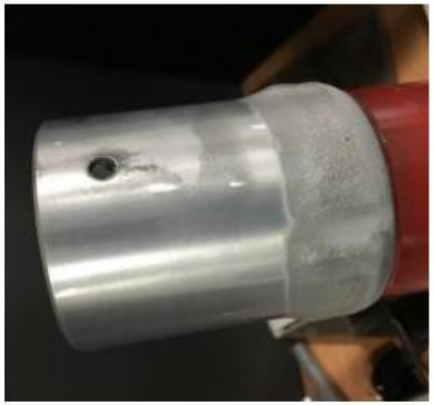
Gas Dynamisch Koud Spuiten

Corroded surfaces

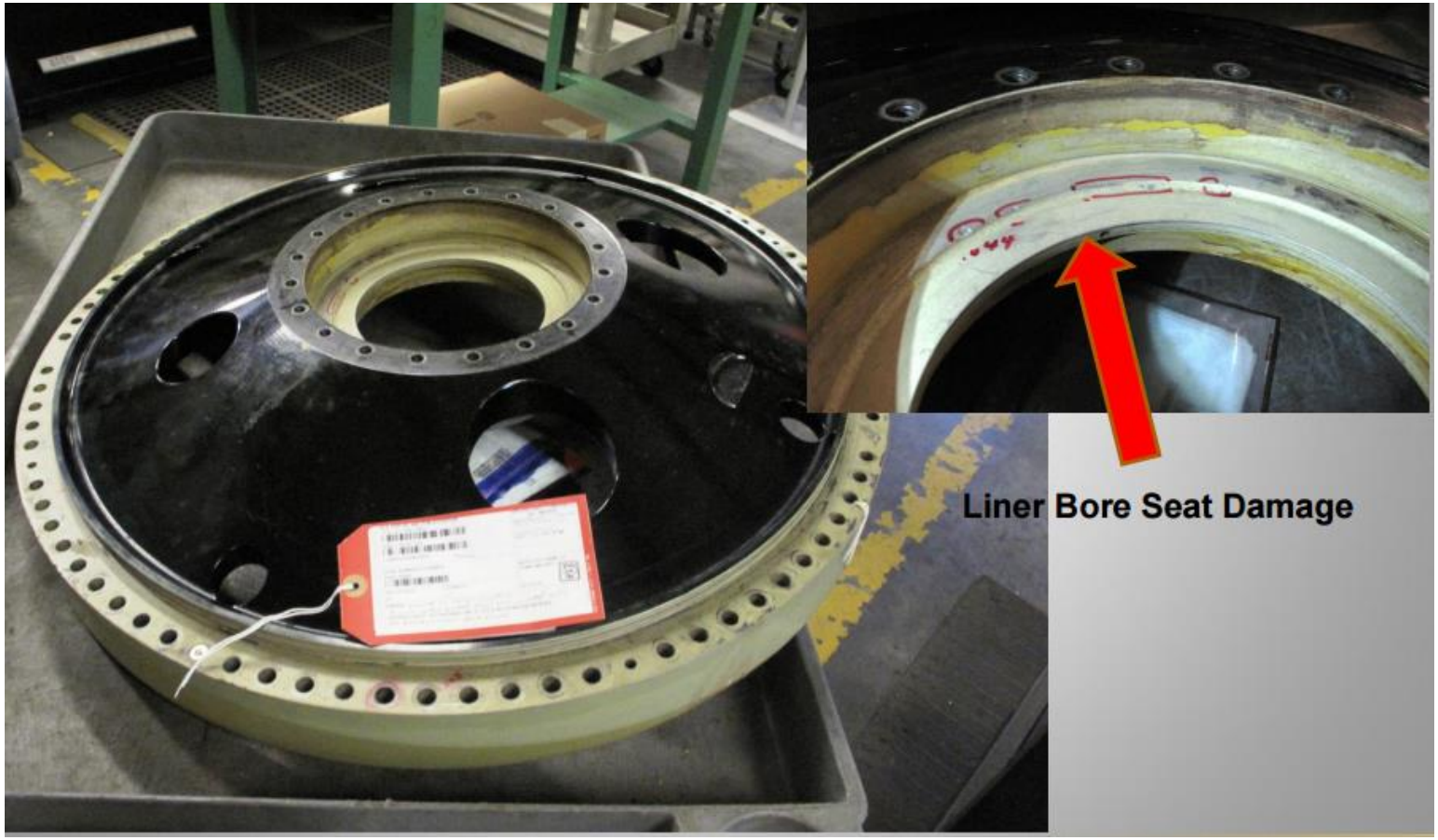



Corrosion removed & surface blended

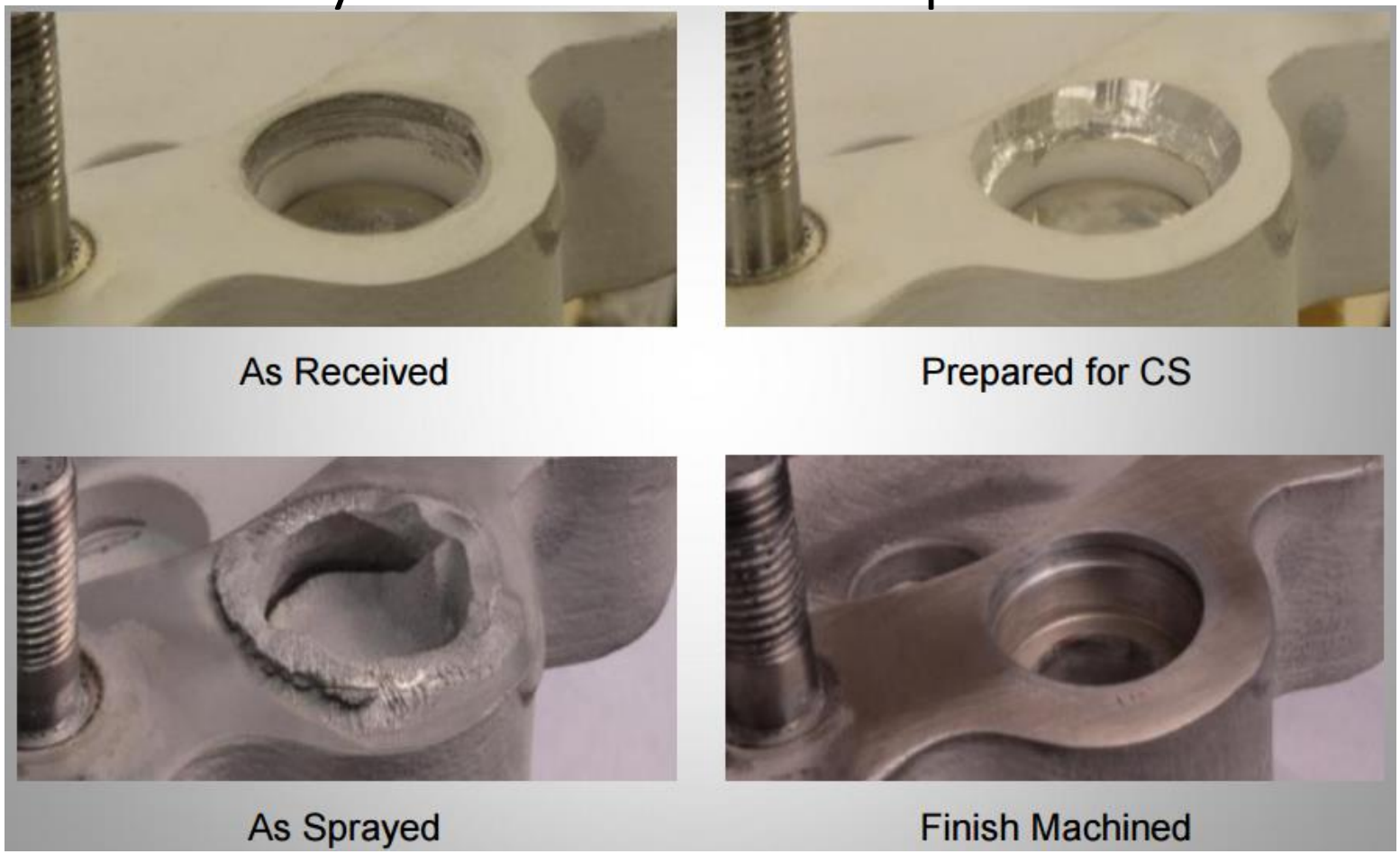




Gas Dynamisch Koud Spuiten

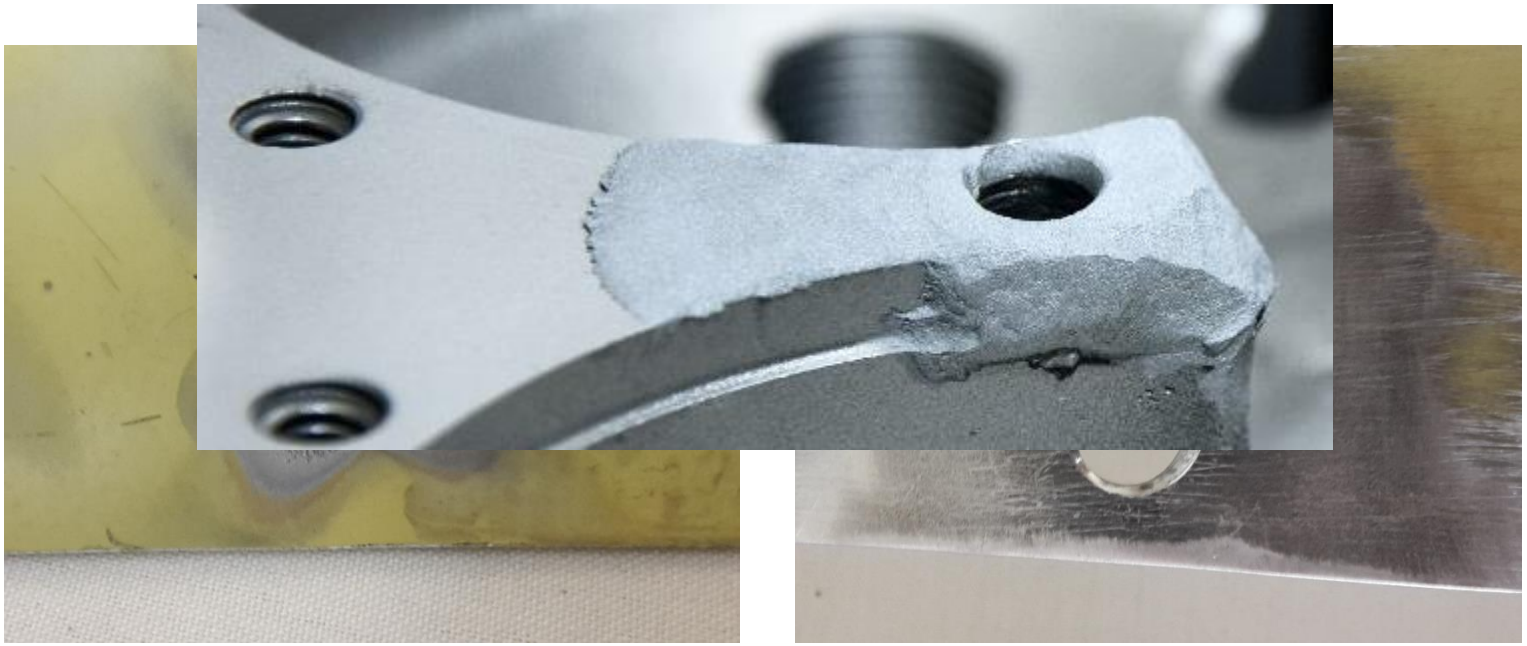


Gas Dynamisch Koud Spuiten



Gas Dynamisch Koud Spuiten

Gas Dynamisch Koud Spuiten



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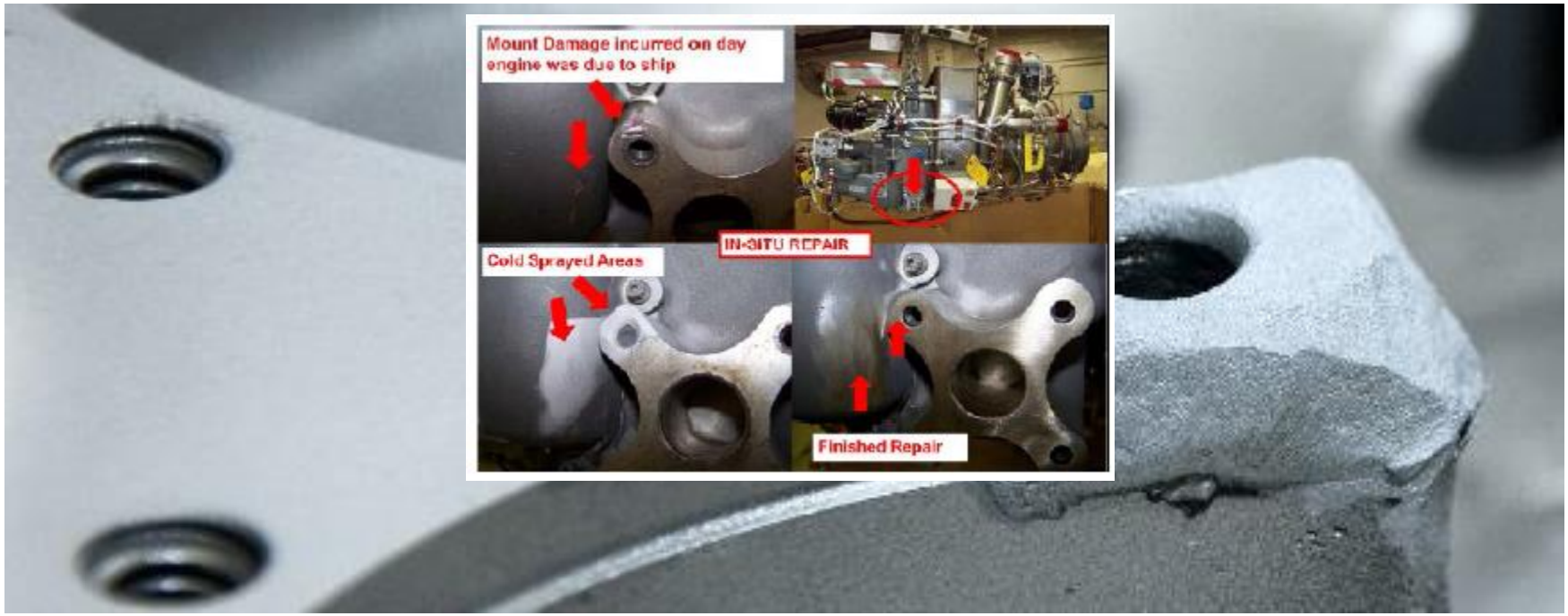
Gas Dynamisch Koud Spuiten