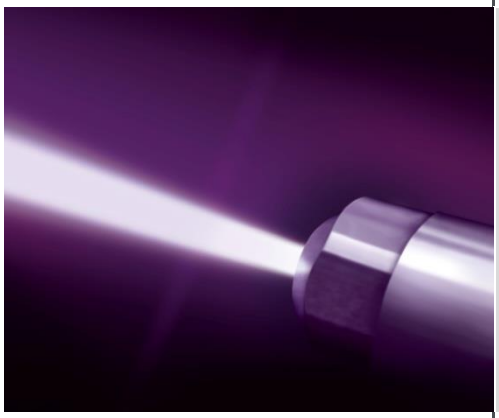
GfE Coating Materials
Freiberg/Brand-Erbisdorf, Germany



CSAT Meeting

Cold Spray Coatings on Hard Surfaces
Other Commercial Applications

June 18th, 2013

GfE Materials Technology Inc.
Wayne, PA
Cameron R. May

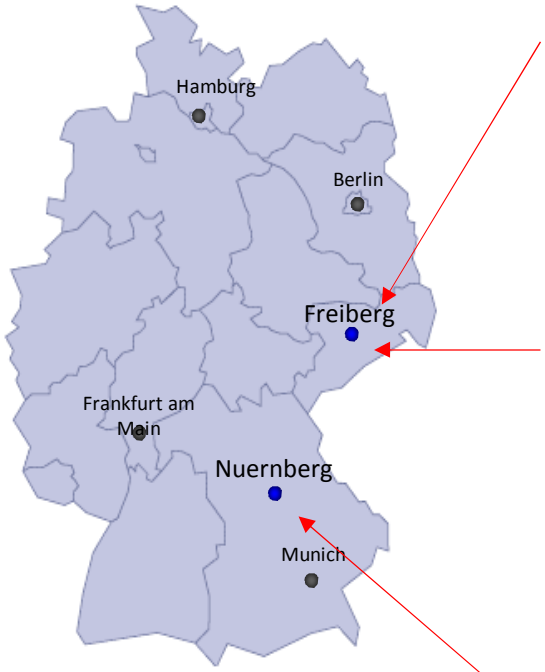
Selected R&D Results and Industrial Applications

Cameron May
Dr. Steffen Marx
Alexander Paul

GfE Fremat GmbH, Freiberg

Introduction

GfE Gesellschaft für Elektrometallurgie, Germany



Freiberg –Saxony R&D
GfE Fremat GmbH

Production facility near Freiberg

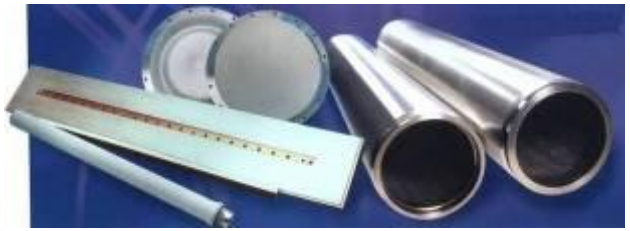
Nuernberg / Bavaria
GfE Gesellschaft für Elektrometallurgie mbH
GfE Metalle und Materialien GmbH

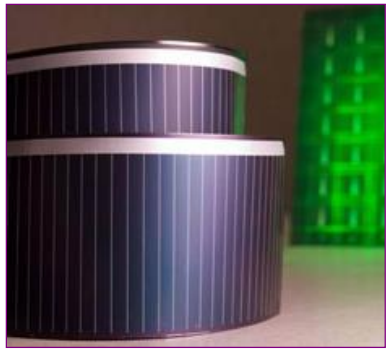
- **Diversified manufacturer of high performance metals and materials**
- **Scientific technical services**
- **€ 85m ($ 111 m) revenues in 2010**
- **400 employees**
- **1911 to 2011 – 100 year anniversary.**
- **Headquarter in Nuernberg with additional location in Freiberg**
- **Worldwide distribution network via sales partners**

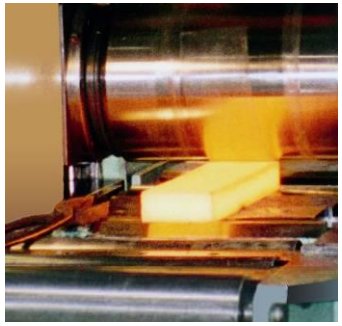
Business Fields

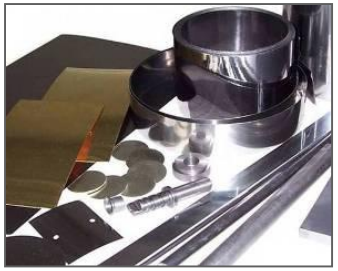
GfE Fremat GmbH

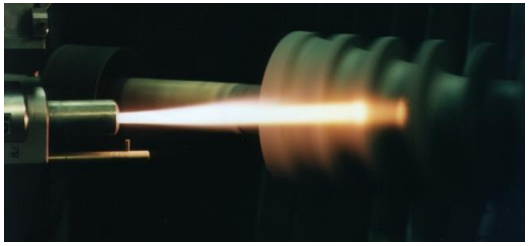
Coating Materials	Semi-finished Products	Coating Services











Cold Gas Spray R&D at GfE

Hard Substrates

(Al &Ti on Glass, Ceramics)

Applications:

Ti coatings on monolithic ceramic implants

Heating layers on glass

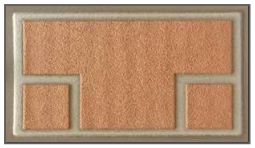
Electrical contact layers for glass photovoltaic modules or other thin film connectors

Power Electronics

Applications:

Conducting layers on power electronic heat sinks for

1. Compensation of CTE mismatch
2. Solderability + heat transfer



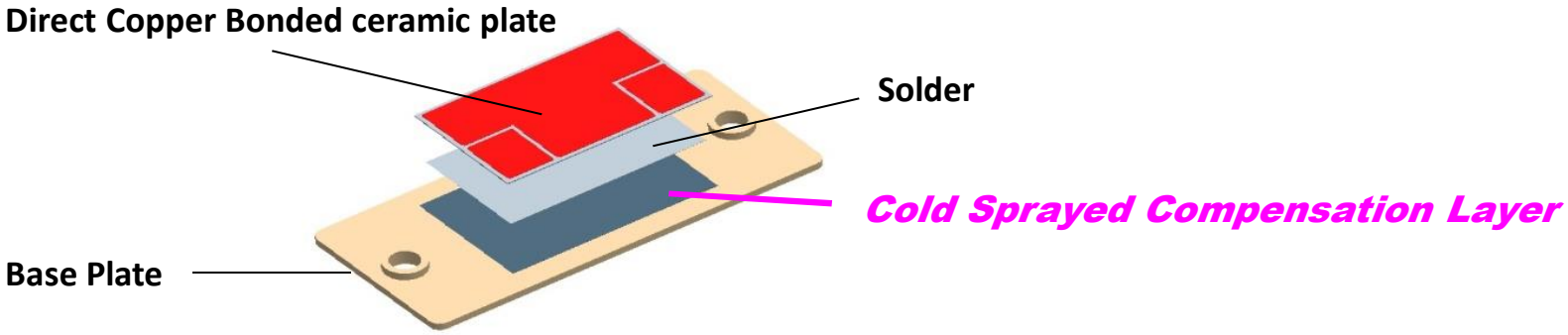
Structural Repair

Applications:

Dimensional restoration and structural repair of aerospace components (housings, fan cases,…), especially from Al or Mg alloys

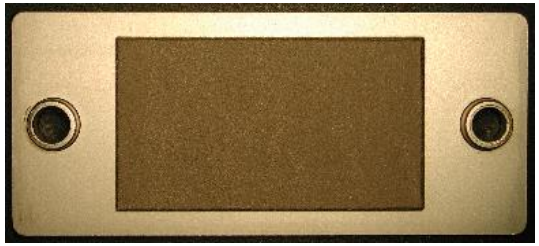
Cold Sprayed Coatings for Power Electronics

Compensation of CTE Mismatch

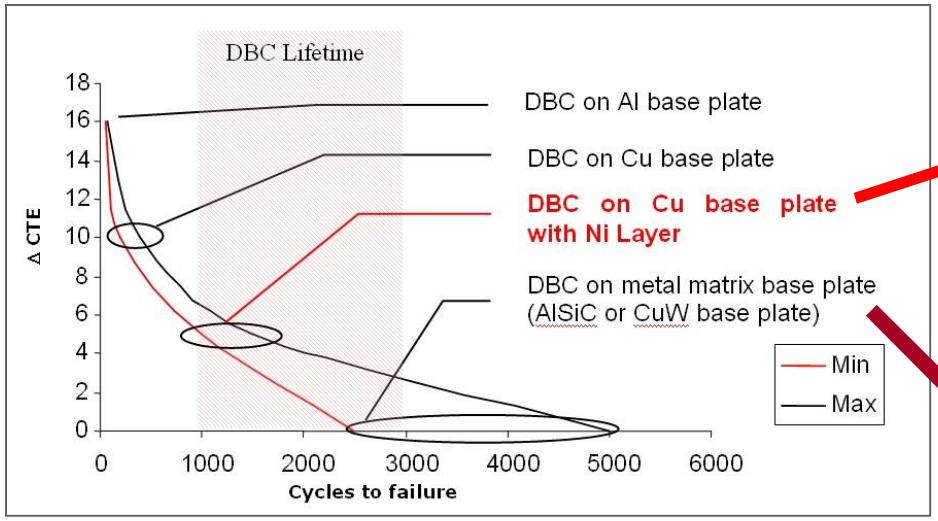


Applications include: Optoelectronics, Electric drives, Electric automotive drives

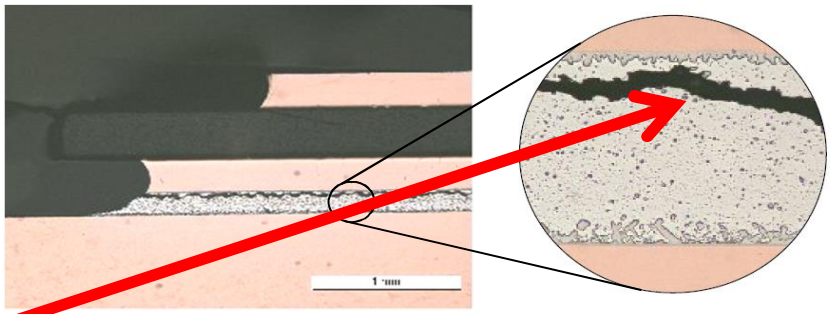
Demonstrator with 500 µm Ni intermediate layer

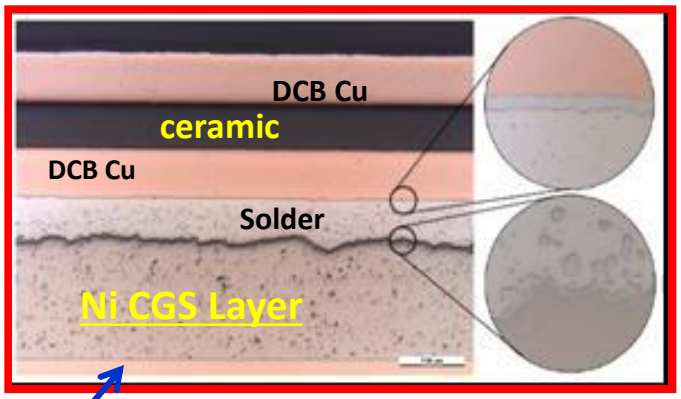


Power Electronics (cont'd)



(Source: F. Osterwald, M. Kock, K. Olesen, R. Eisele, Danfoss Silicon Power GmbH, Sprayed Stress Reducing Interlayers for Highly Reliable Large Solder Joints, PCIM Europe 2007)

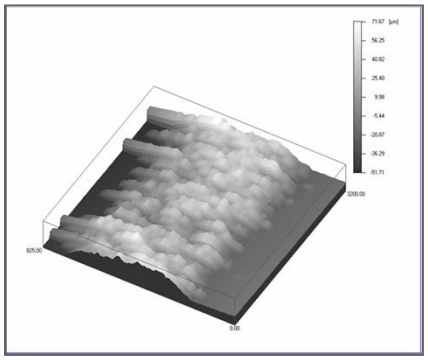




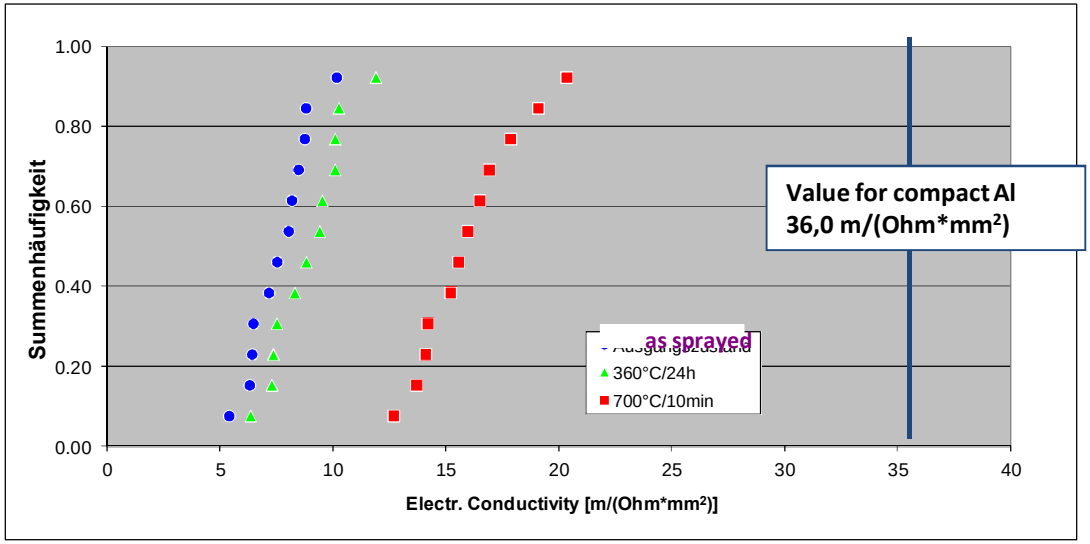
Cu Base Plate

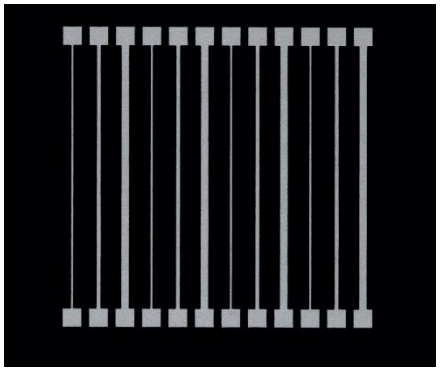
Cold Sprayed Coatings on Hard Substrates

CGS Al on Glass



Laser scan of a conductor line





Sample layout for measuring electrical conductivity (Al on float glass)

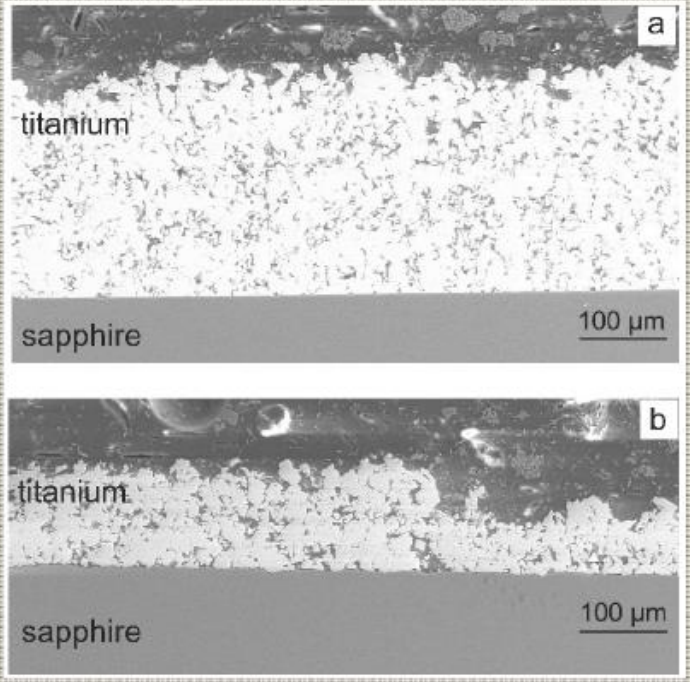
Cold sprayed Al on glass

- Only thin layers
- *25 %* of nominal electrical conductivity (without heat treatment)
- No reduction of conductivity after 200h Damp Heat Test
- High strength and bonding strength

Cold Spray Coating on Hard Surfaces

Effect of the Surface Roughness

CGS-Ti on Sapphire Substrate



Polished side ⟶ R_a<0.3nm

Uniform thickness of the coating of 250µm

Ground side (R_a<1µm)

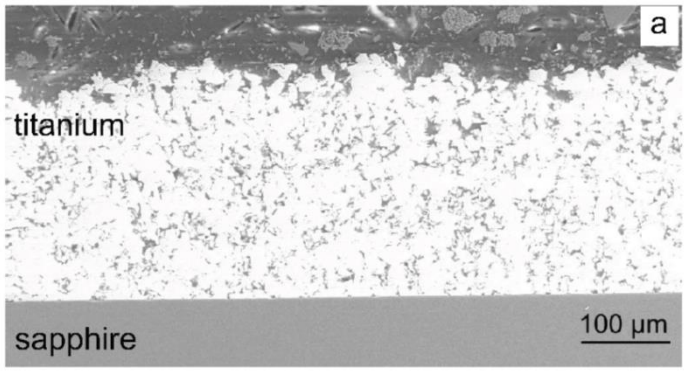
Non-uniform thickness of the coating of max. 150µm

Much better adhesion on the polished substrate!!

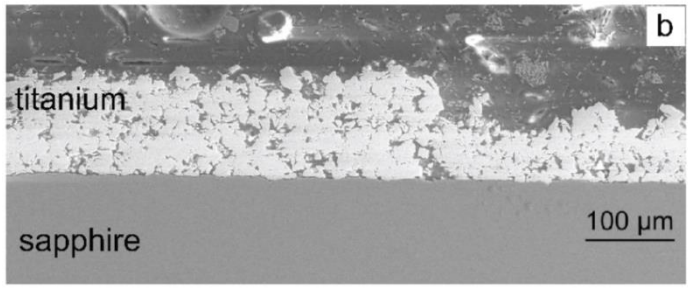
Cold Sprayed Coatings on Hard Substrates

Effect of Surface Roughness

CGS-Ti on Sapphire Substrate



Polished side (R_a<0.3 nm)
Uniform thickness of the coating of 250µm

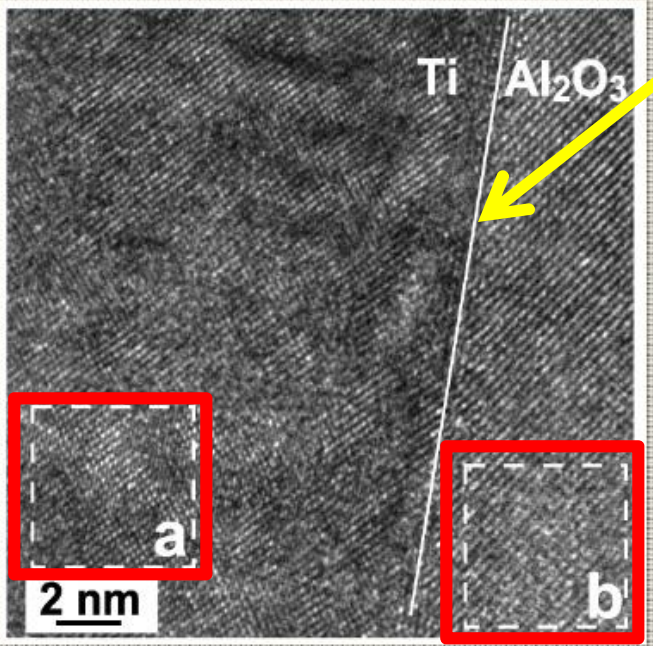


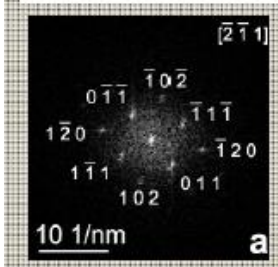
Ground side (R_a<1 µm)
Non-uniform thickness
of the coating of max. 150µm

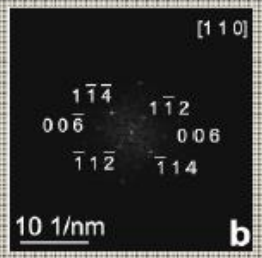
Better adhesion on the polished substrate

Cold Spray Coating on Hard Surfaces

Effect of the Surface Roughness







CGS-Ti / Sapphire Interface (HRTEM)

Bonding mechanism between CGS titanium & polycrystalline sapphire:

Strong plastic deformation, especially at the sapphire surface

Deformation energy resulting from impact energy triggers recrystallization

Crystallites immediate to the polycrystalline surface show partial hetero-epitaxy due to energy of recrystallization.

Source: Microstructural characterisation of titanium coatings deposited using cold gas spraying on Al2O3 substrates, David Rafaja, Torsten Schuknecht, Volker Klemm, Alexander Paul, Harry Berek, Surface & Coating Technology 203 (2009) 3206-3213

Bonding Discussion

Dense titanium coatings with a good adhesion to sapphire (aka corundum, alumina, Al_2O_3) substrates were successfully deposited using cold gas spraying. The porosity of the coatings was approximately 10%.

Severe plastic deformation of titanium particulates and elevated temperature at the Ti/sapphire interface, caused by the impact of titanium particles on the substrate, supplied additional energy promoting re-crystallization of titanium next to the surface of the sapphire substrate.

The re-crystallization of titanium supported re-organization of atoms, which is necessary for establishing the partial hetero-epitaxy between Ti and Al_2O_3. The hetero-epitaxy between Ti and Al_2O_3 is regarded as a phenomenon that enhances the adhesion of Ti coatings to Al_2O_3 substrates.

Another consequence of the partial hetero-epitaxy at the Ti/Al_2O_3 interface and the re-crystallization of titanium was the nano-size of the Ti grains at the surface of the substrate.

As the formation of the partial hetero-epitaxy and the formation of the re-crystallized titanium decline with increasing distance from the Ti/Al_2O_3 interface, a gradient of increasing grain size was observed in the CGS Ti.

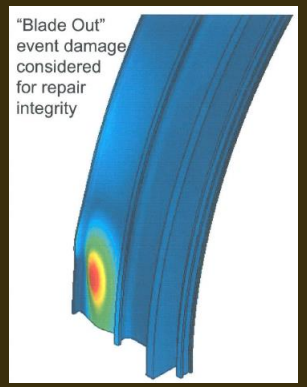
2. Selected R&D Results

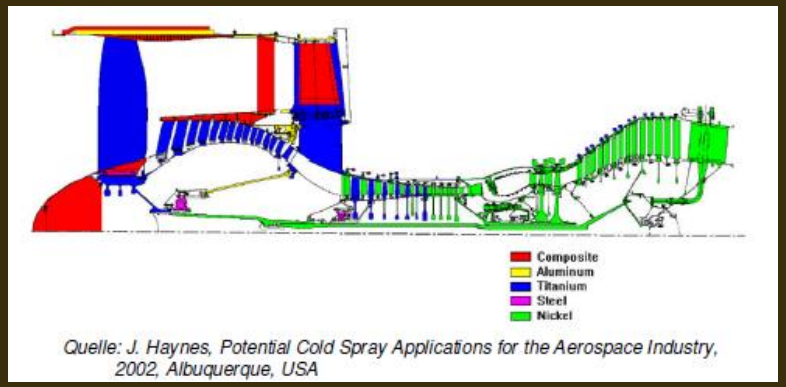
Cold Sprayed Coatings for Structural Repair

Development of Repair Technology

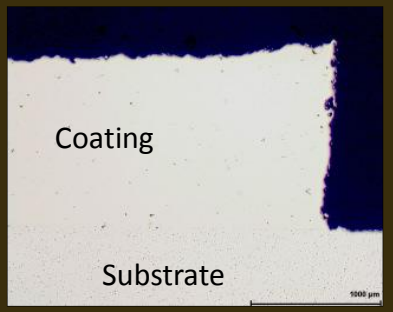
Fan Case Repair by Cold Spray of Al Alloys

- No remarkable heat transfer into the substrate material – no softening
- Repair of very fine defined areas, coating thickness up to several mm
- Rapid process, simple surface preparation, excellent machinability
- Full annealed cold sprayed Al alloys equal to plate material





Quelle: J. Haynes, Potential Cold Spray Applications for the Aerospace Industry, 2002, Albuquerque, USA

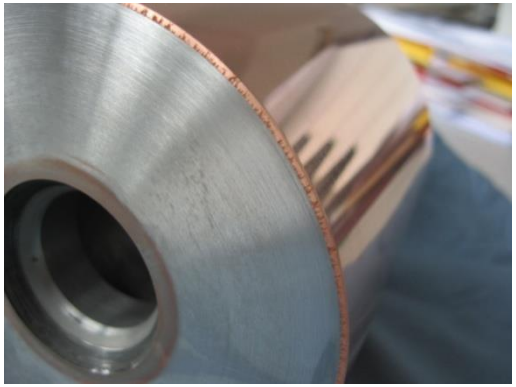


3. Examples of Inductrial Applications

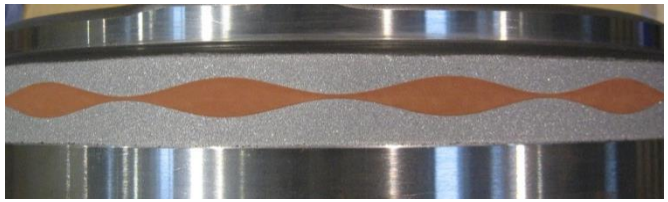
Cu Coatings on Rollers and for Automotive Application

Cu coating as sprayed

Cu coating finished



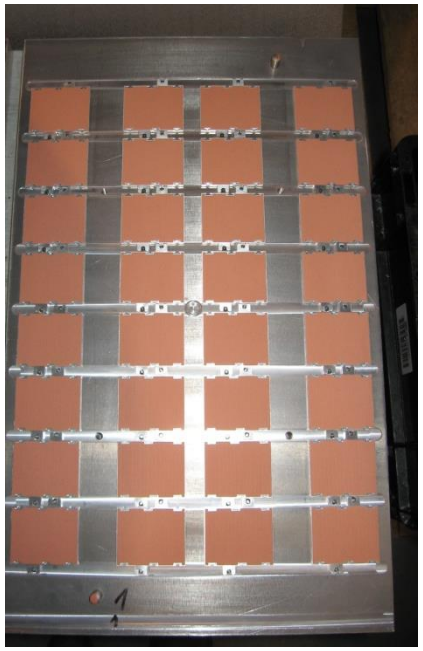
- Cold sprayed Cu for engraved printing rolls
- Thickness up to several mm
- High bonding strength
- Low oxygen content
- Excellent machinability (turning, grinding, finishing)
- Engravebility comparable to electroplated Cu
- Very short production time

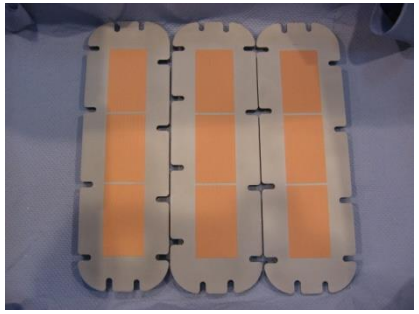


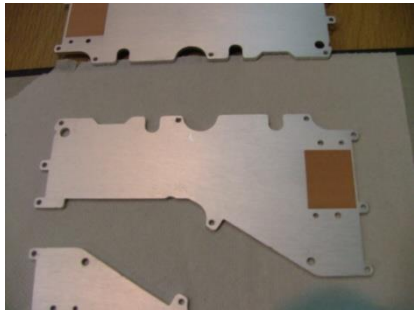
Cu Coating for Automotive Application

3. Examples of Inductrial Applications

Power Electronic Heat Sinks and Refrigeration Units





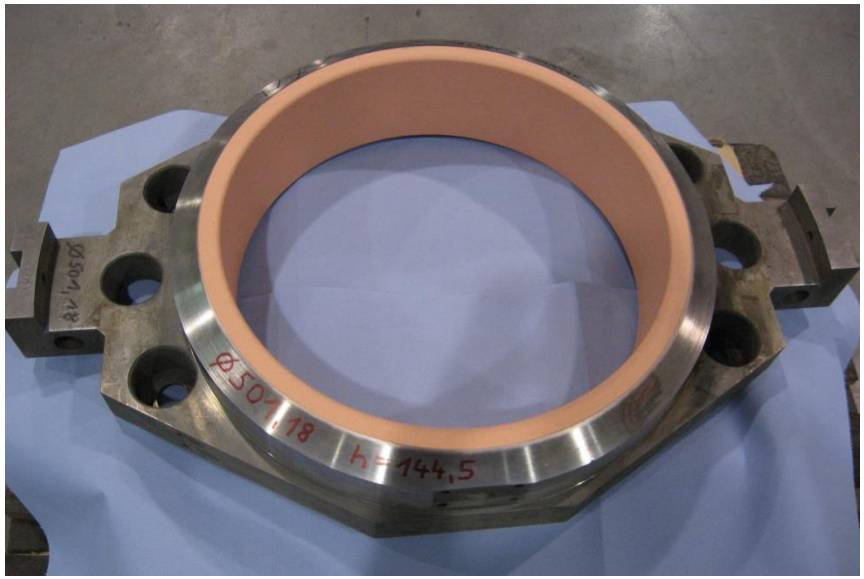


- Heat sinks for power electronic applications
- Cold sprayed Cu on Al surface
- High bonding strength
- Low oxygen content
- Very good solderability and heat conductivity

- Refrigeration vessels for apparatus engineering
- Cold sprayed Cu
- High bonding strength
- Low oxygen content
- Very good heat conductivity

3. Examples of Industrial Applications

Pressure Ring



- Pressure ring for food processing machine
- Equalising and bonding layer for hardchromium top coating
- Cold sprayed Cu
- High bonding strength
- Low oxygen content
- Excellent machinability

4. Subjects for Development

Conclusions from Practical Experiences

- **Long time spraying without interrupts**

  Nozzle plugging for good adhering powders as Inconel, Al, Ti

  Agglomeration of powders with low oxygen content

- **Improving of surface quality for electronic applications**

  Powder feeding equability

  Control of powder mass flow

- **Quality control of coated parts**

  Implementation of methods and equipment for control of coating and surface properties, dimensions…