ITSC’2017
DÜSSELDORF
JUNE 7 - JUNE 9, 2017

CLUB COLD SPRAY
le 10 Novembre 2017
Maurice Ducos CONSULTANT
- 64 exhibitors (twelve countries)
- 700 total attendees and visitors
- 30 countries represented
- 300 papers presented
- 35 papers Cold Spray

Plenary Lecture P. Sander Airbus Operations GmbH

May 7-10, 2018
Orlando, Florida US
Gaylord Palms Resort & Convention Center

Abstract Due: 2017 September 30, 2017
Final PDF Manuscript Due: February 28, 2018
Coldgas Coatings with Adjusted Curie Temperatures for Influencing the Magnetic Susceptibility  F. Trenkle, E. Schopp, S. Hartmann obz innovation gmbh, Bad Krozingen, Germany info@obz-innovation.de

OBZ innovation presents the latest developments in the field of induction capable coatings, mainly used for induction cookware on aluminum or copper base material.

To offer additional safety and comfort to the customer, a special induction coating was developed with an immanent temperature limitation and uniform heat distribution (Patent T-LIM coating).

Pans with as sprayed cold gas induction coating (left) and after machining (right).

“Intelligent” T-Lim induction coating (left) cares for distribution, as the equally caramelization process over Conventional induction cookware (right) shows over- and under heated areas, depending on where the induction coil is placed.
Material 2 controls with its Curie point the temperature limitation. Furthermore, it cares for a uniform heat distribution over the complete coating area, since the usually not uniformly distributed magnetic field of the induction coil is forced by the alternating magnetic susceptibility (grey = lower and black = higher susceptibility) to the areas of lower temperatures.

Temperature and power development for a conventional ferritic chromium cookware and the newly developed T-Lim coating.

“Intelligent” induction coating (left) shows in the heat distribution coating (right)

obz developed “coloduct coating” can be combined with standard and T-Lim induction coatings.
An experimental approach to gain insight into cold gas spraying of ceramics
H. Gutzmann, I.Irkhin, F. Gärtner, T. Klassen, Hamburg / D

Experimental approach to investigate basic dependencies on impact and bonding of agglomerated ceramic particles in cold spraying

Two different TiO$_2$ agglomerated nanoparticles anatase powders were used as feedstock material: a pure anatase (Hombikat) and powder P25/20 that contains up to 20 % rutile. For mechanical powder testing, a single particle static compression test method was utilized.

Schematic side view of the compression experiments on single powder particles.

The powder batches shown here are Hombikat (brittle fracture), heat-treated Hombikat (multiple fracture) and P25/20 (quasi-plastic). The maximum load during the experiments was set to 200 mN.
The results show that bonding of the agglomerated TiO\textsubscript{2} particles depends on substrate material temperature, spray conditions and powder properties. Substrate temperatures of approximately minimum 300°C are necessary for successful bonding of titania particles onto the metal substrates.

Confocal microscopy images of separately positioned TiO\textsubscript{2} particles before (left) and after (right) a compression experiment.

SEM impact morphologies for agglomerated titania powders of types “brittle fracture” and “quasi-plastic” according to the deformation characteristics. Using identical N\textsubscript{2} gas temperature of 800°C and pressure of 4 MPa, the wipe tests were sprayed on stainless steel surfaces, heated to 300°C.
Fatigue strength of Mg alloy coated with Al coatings via in-situ shot-peening assisted cold spray  Ying-Kang Wei, Xiao-Tao Luo*, Cheng-xin Li, Chang-Jiu Li*

In this study, pure Al coatings were deposited on ZK60-T5 Mg alloy substrates via in-situ shot-peening assisted cold spray in order to study the effect of the Al coating on fatigue behavior of coated samples.

<table>
<thead>
<tr>
<th></th>
<th>Al</th>
<th>Mg</th>
<th>Si</th>
<th>Fe</th>
<th>Zn</th>
<th>Zr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
<td>Remainder</td>
<td>0.03</td>
<td>0.25</td>
<td>0.32</td>
<td>0.04</td>
<td>/</td>
</tr>
<tr>
<td>ZK60</td>
<td>/</td>
<td>Remainder</td>
<td>0.01</td>
<td>0.02</td>
<td>5.4</td>
<td>0.57</td>
</tr>
</tbody>
</table>

Chemical compositions of Al powders and ZK60 alloy substrates (wt.%)

DWCS-2000 cold spraying system (Dewei Automation Company, Xi’an, China).

The S–N diagram obtained from fatigue tests

The lowered toughness of the dense Al coating due to intensive hardening may be responsible for the low fatigue strength.

Morphologies of pure Al particles and stainless steel SP particles.

Overall and localized cross-sectional microstructures of pure Al coatings deposited by in-situ SP assisted cold spraying.
Cold spraying of WC-Co-Ni coatings using porous WC-17Co powders  S. Yin, T. Lupton, M. Meyer, R. Lupoi, Trinity College Dublin, the University of Dublin, Department of Mechanical and Manufacturing Engineering, Dublin / Ireland E.J. Eko, D.P. Dowling, University College Dublin, School of Mechanical and Materials Engineering, Dublin / Ireland

Cold spray has been successfully used to produce WC-Co coatings in recent years, showing great potential. However, the fabrication of cold sprayed WC-Co coating naturally requires expensive propulsive gas or very high working parameters, significantly increasing the manufacturing difficulty and cost.

Nickel (-40+15 μm, Sandivik, Sweden) and porous agglomerated-sintered WC-17Co (-48+10 μm, Xinke China) mass fraction in different powder is provided in the following: F1 (41.5 wt.%), F2 (64.5 wt.%) and F3 (74.7 wt.%).

Cross-sectional SEM images of the coatings fabricated with different feedstock. (a, d, g) F1 coating, (b, e, h) F2 coating and (c, f, i) F3 coating. Red boxes indicate the selected area for magnifying in the next slide.
Cold spraying of WC-Co-Ni coatings using porous WC-17Co powders

Fracture of WC-Co particles during the deposition process was found to be the reason for such high WC retainability, dominating the coating formation mechanism. Moreover, in the F1 and F2 coatings, inter-particle impact mostly took place between Ni and WC-Co particles. However, in the F3 coating, WC-Co particles frequently impacted onto each other due to the very high WC content in the feedstock.

Mass fraction of WC phase in the WC-CO-Ni coating as a function of that in the feedstock

The highest WC mass fraction was present in the F3 coating, reaching approximately 75% (equivalent to the feedstock), quite close to the cold sprayed WC-25Co coating. Experimental results showed that WC reinforcements had no phase transformation and were completely retained in the WC-Co-Ni coatings.

In carried out experiment Ti powder with angular shape was applied in the cold spraying process. The coatings were sprayed by means of Impact Innovations 5/8 system with nitrogen and addition of helium onto 7075 Al alloy.

Ti angular powder morphology: a) grains, b) cross section. Mean diameter of titanium powder d50 = 35.40 µm.

Titanium coatings were cold sprayed with various mixtures of nitrogen and helium, designated as: Ti-c1 – 100% nitrogen, Ti-c2 – 50% nitrogen + 50% helium, Ti-c3 – 20% nitrogen + 80% helium.

Surface morphology of cold sprayed: a) Ti-c1 coating, 200x, b) Ti-c1 coating, 1000x, c) Ti-c3 coating, 200x, d) Ti-c3 coating, 1000x.
Cross-section of cold sprayed: a) Ti-c1 coating, 100x, b) Ti-c1 coating, 1000x, c) Ti-c2 coating, 100x, d) Ti-c2 coating, 1000x, c) Ti-c3 coating, 100x, d) Ti-c3 coating, 1000x.

Increase of content of helium in process gas caused increase of hardness and Young's modulus of cold sprayed titanium coatings. The parameters of surface geometry of titanium coating decreased with all parameters.

<table>
<thead>
<tr>
<th>Param.</th>
<th>Ti-c1</th>
<th>Ti-c2</th>
<th>Ti-c3</th>
</tr>
</thead>
<tbody>
<tr>
<td>H, GPa</td>
<td>4.17±1.0</td>
<td>4.32±1.11</td>
<td>4.58±0.98</td>
</tr>
<tr>
<td>E, GPa</td>
<td>136±21.9</td>
<td>150.9±27.5</td>
<td>169.7±19.8</td>
</tr>
<tr>
<td>Porosity, %</td>
<td>1.04±0.21</td>
<td>1.00±0.13</td>
<td>0.86±0.12</td>
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</table>
A galvanic coating is quite cost intensive for parts which have to be coated only partially. For higher coating thicknesses $> 10 \, \mu m$, electroplating is less efficient due to the long process times. In this study silver coatings were developed using cold gas spraying on a Kinetiks 4000 cold gas system.

Without process optimization, especially of the surface roughness and sandblasting, hardly any economically reasonable coating in the range of 10-40 \, \mu m can be produced.
A microscopic detail (a) of the optimized silver coating illustrates the good bonding. The average coating thickness is about 18 μm and the minimum material thickness is about 13 μm. The overview (b) shows an uniform coating above the copper material.

The adhesive tensile strength is 31.2 MPa, averaged over five tests, with a standard deviation of 3.5 MPa.

With the example of silver cold gas coatings, obz innovation has shown that coatings can be carried out on the basis of conventional equipment down to a region of 10 - 20 μm.

These coatings can have an economic and / or technologic advantage in corresponding applications, compared to electroplating.
The use of cold spray in metal additive manufacturing (AM) offers well recognized advantages with typical commercial drivers being a rapid build rate, low process temperature, and wide range of usable alloys.

In this work, an investigation has been performed into producing more complex geometries and improving shape fidelity using a conventional AM strategy; namely, starting with a CAD drawing, slicing the CAD geometry into a layered structure, and performing a layer-by-layer build.

Typical and altered deposit profiles: (a) Cu sprayed normal to substrate surface (circled: peak forms and deposition no longer occurs); and (b) Cu and (c) Al sprayed at multiple angles to the substrate surface.
Layer-by-layer buildup strategy for cold spray additive manufacturing

Thin-walled features produced by cold spray: (a) linear and (b) freeform patterns on flat substrates and (c) freeform pattern on curved substrate

Hybrid manufacturing of train wheelset: (a) CAD design, (b) simplified workflow, and (c) additive + subtractive approach for wheel

(a) Partially machined wheel and (b) finished wheel (other side).
Amorphous steel coatings deposited by HVOF and Cold Gas Spray processes  M. Tului , A. Bezzon , A. Marino , F. Marra , S. Matera , G. Pulci  Centro Sviluppo Materiali S.p.A., Lamezia Terme (CZ) branch office – Italy  Dept. of Chemical Engineering, Materials, Environment, Sapienza University of Rome, INSTM Reference Laboratory for Engineering of Surface Treatments, Rome, Italy

This work focuses on the deposition of a commercial steel powder with a chemical composition that allows to obtain amorphous coatings, using two thermal spray processes: HVOF Tafa JP5000 and CGS IMPACT 5/11.

**Powder Nanosteel Company Inc.,**

<table>
<thead>
<tr>
<th>wt%</th>
<th>Cr</th>
<th>C</th>
<th>B</th>
<th>Mo</th>
<th>W</th>
<th>Mn</th>
<th>Si</th>
<th>O</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal</td>
<td>&lt;25</td>
<td>&lt;2</td>
<td>&lt;5</td>
<td>&lt;15</td>
<td>&lt;2</td>
<td>&lt;2</td>
<td>bal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ICPOS Analisys</td>
<td>18.55</td>
<td>0.97</td>
<td>3.3</td>
<td>12.88</td>
<td>6</td>
<td>1.6</td>
<td>1.57</td>
<td>0.018</td>
<td>bal</td>
</tr>
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</table>

**Chemical composition of the starting powder**

<table>
<thead>
<tr>
<th>HVOF</th>
<th>CGS</th>
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<tr>
<td>Barrel (inch)</td>
<td>Pressure (bar)</td>
</tr>
<tr>
<td>4</td>
<td>40</td>
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</tbody>
</table>

**HVOF and CGS deposition parameters**

The producer claims that spraying such a powder, amorphous coatings can be obtained

**Granulometry distribution of the starting powder**

**Cross sections, observed by SEM, of:**
- a) HV deposited coating;
- b) CGS deposited coating
Amorphous steel coatings deposited by HVOF and Cold Gas Spray processes

Results

XRD patterns of: a) starting powder; b) HVOF deposited coating; c) CGS deposited coating

A comparison between the samples obtained reveals that only the CGS coatings are completely amorphous while the HVOF ones present nanocrystalline phases.

CGS coatings are more compact and show lower hardness, with a comparable Young modulus.
Solution heat treatment of gas atomized aluminium alloy (7075) powders: microstructural changes and resultant mechanical properties A. Sabard, H. L. de Villiers Lovelock, P. McNutt, M.D.F.H. Harvey, T. Hussain Faculty of Engineering, University of Nottingham, Nottingham, NG7 2RD, UK TWI Ltd, Granta Park, Great Abington, Cambridge, CB21 6AL, UK

The solidification experienced by gas atomized powders during manufacture can lead to a non-equilibrium powder dislocations and significant localized segregation of alloying elements within each particle.

Hence, to reduce or remove the alloying element segregation prior to spraying solution heat treatment (SHT) of the powder has been considered here in the case of AA7075, a lightweight Al-Zn-Mg-Cu alloy widely used in the aerospace industry.

SHT - Solution Heat Treated at 450 °C for 5 hours in a sealed glass vial under vacuum and quenched in water.

Micrographs of an as-received AA7075 particle in cross-section.

The solute segregation occurring during gas atomization is thus confirmed, revealing a fine dispersion of solute atoms at grain boundaries and interdendritic

SEM pictures of AA7075 after solution heat treatment The lack of contrast in the BSE image reveals that the solute atoms have been dissolved into the solid solution and the matrix has been homogenized
Solution heat treatment of gas atomized aluminum alloy (7075) powders: microstructural changes and resultant mechanical properties

<table>
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<tr>
<th>AA 7075</th>
<th>As-received</th>
<th>SHT + quenched</th>
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</thead>
<tbody>
<tr>
<td>Hardness</td>
<td>101 HV</td>
<td>75.2 HV</td>
</tr>
<tr>
<td>Stand. dev</td>
<td>5.74</td>
<td>4.98</td>
</tr>
</tbody>
</table>

Microhardness measurements of AA7075 powder

a) The powder is partially embedded and most of the deformation seems to have been undergone by the substrate, with the particles retaining quite a spherical shape

b) The particle seems to be heavily deformed and is now clearly splat-shaped, whereas the substrate has apparently undergone only a slight deformation

The dendritic structure of the as received powder was eliminated and its grain structure modified by SHT

The lower hardness of the SHT particles led to greater deformation of the particles during cold spray impacts

The non-equilibrium microstructure of gas atomized aluminum alloy powders, which is not ideal for Cold spray deposition, can be homogenized using a solution heat treatment.

SE picture of the top surface of individual as received (a) and SHT (b) AA7075 particle after spraying Substrate AA6061
It is still difficult to measure the residual stress of cold-sprayed coating especially inside it. The high-energy X-rayed beam was utilized to penetrate the cold-sprayed coatings and the change of its diffraction angle can be detected. This gave a way to measure the residual strain inside the cold-sprayed coatings.
In this study, cold sprayed SS304 and In718 coatings’ residual strain was detected by using a high energy white X-ray scanning.

Compressive and tensile stress exist in the cold-sprayed coatings simultaneously.

The coating residual strain can be detected and residual stress can be calculated out.
Comparison of microstructure and tribological behavior of WC reinforced maraging steel 300 composites prepared by cold spraying and selective laser melting X.C. Yan, C.J. Huang, R. Bolot, D. Lucas, H.L. Liao, IRTES-LERMPS, ICB UMR 6303, CNRS, Univ. Bourgogne Franche-Comté, UTBM, F-90010 Belfort, France R.Z. Huang, W.Y. Ma, M. Liu*, Guangdong Institute of New Materials, 363 Changxing Road, Guangzhou 510651, P.R. China

This work focuses the microstructure and tribological behavior of WC/maraging steel 300 (WC/MS300) composites fabricated by (cold-spraying additive-manufacturing) and (selective laser melting) SLM. A comparional investigation on their microstructure and tribological behavior was carried out.

Chemical composition of MS300

<table>
<thead>
<tr>
<th></th>
<th>EL</th>
<th>Fe</th>
<th>Ni</th>
<th>Co</th>
<th>Mo</th>
<th>Ti</th>
<th>Al</th>
<th>Cr,Cu</th>
<th>C</th>
<th>Mn,Si</th>
<th>P,S</th>
</tr>
</thead>
<tbody>
<tr>
<td>wt% balance</td>
<td>17-</td>
<td>8.5-</td>
<td>4.5-</td>
<td>0.6-</td>
<td>0.05-</td>
<td>19</td>
<td>9.5</td>
<td>5.2</td>
<td>0.8</td>
<td>0.15</td>
<td>≤0.5</td>
</tr>
</tbody>
</table>

SEM micrographs of composites fabricated via CSAM (a) and SLM (b)

SEM image of the mixed powder morphology.

Illustration of the formation mechanisms of composites manufactured by CSAM (a) and SLM (b).
Comparison of microstructure and tribological behavior of WC reinforced maraging steel 300 composites prepared by cold spraying and selective laser melting

Comparison of wear rates and wear cross-sections of the CSAM and SLM-processed composites

Micro-hardness of CASM and SLM-processed composites.

Evolution curves of COF for the CSAM and SLM-processed WC/MS300 composites.

The CSAM and SLM process composites, present a different wear behavior and the wear rate of the CSAM is evidently more than the SLM. It is reasonable to believe that in the SLMed WC/MS300 part, the bonding strength of WC particles with matrix is much higher due to grain boundaries diffusion reaction.

The different contents and distributions of WC phase have a significant effect on the friction. The calculated relative contents of WC phase in CSAM and SLM composites are 3.9 and 0.6 respectively.
DEVELOPMENT OF HIGH-PERFORMANCE COLD-SPRAYED NANOSTRUCTURED NI-20Cr COATINGS FOR HARSH ENVIRONMENT OF POWER PLANT BOILERS

M. Kumar, H. Singh, N. Singh, N. M. Chavan, S. Kumar, S. V. Joshi
1) Department of Mechanical Engineering, CGC College of Engineering, Landran, Mohali, Punjab, India
2) School of Mechanical, Materials & Energy Engineering, Indian Institute of Technology Ropar, Rupnagar, Punjab, India
3) Department of Chemistry, Indian Institute of Technology Ropar, Rupnagar, Punjab, India
4, 5, 6) International Advanced Research Centre for Powder Metallurgy & New Materials (ARCI), Hyderabad 500005, India.

The outcome of the study shall be useful to explore the possibilities of use of the developed coatings for enhancing the life of boiler tubes of coal-fired power plant boilers.

Substrate SAE213-T22
Carbon 0.15, Manganese 0.3-0.6, Silicon 0.5, Sulphur 0.03, Phosphorous 0.03, Chromium 1.9-2.6, Molybdenum 0.87-1.13 and balance iron.

Coating: powder nanostructured

<table>
<thead>
<tr>
<th>Type of Powder</th>
<th>Blended powders (Wt%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Micron-sized</td>
</tr>
<tr>
<td>Name of powder</td>
<td>Ni (CA*)</td>
</tr>
<tr>
<td>Composition (%)</td>
<td>80%</td>
</tr>
<tr>
<td>Average particle size</td>
<td>74 μm</td>
</tr>
</tbody>
</table>

*CA- Commercial available, BM- Ball milled

Properties of investigated cold-spray Ni-20Cr coating on T22 steel
DEVELOPMENT OF HIGH-PERFORMANCE COLD-SPRAYED NANOSTRUCTURED NI-20Cr COATINGS FOR HARSH ENVIRONMENT OF POWER PLANT BOILERS

The coating was found to be nano-structured.

Surface SEM/EDS analysis for (a) bare T22 steel [32] (b) cold-sprayed T22 steels subjected to cyclic oxidation in air at 900°C for 50 cycles.

X-ray diffraction analysis of the cold-spray coated T22 steel, reveals the presence of NiO, Cr2O3, SiO2 and Al2O3 phases. Out of these phases, Al2O3 belongs to the ash constituents, where Cr2O3 might have formed by selective oxidation of Cr present in the coating.

The coating was found to be spallation-free

This higher hardness is useful to enhance the erosion-corrosion resistance of the coatings

The developed coating was found to be useful to control the high temperature oxidation and erosion-corrosion of T22 steel by a substantial magnitude.

Moreover, the high temperature performance of the coating was observed to be better than its microstructured counterpart
Metallization of various polymers by cold spray Hanqing Che, Phuong Vo, Stephen Yue, Montreal/CDN Hanqing Che, Phuong Vo, Stephen Yue, Montreal/CDN

This work studies the cold sprayability of various metal powders on different polymeric substrates. Five different substrates were used, including carbon fibre reinforced polymer (CFRP), acrylonitrile butadiene styrene (ABS), polyether ether ketone (PEEK), polyethylenimine (PEI); mild steel was also used as a bench mark substrate.

Three single-component powders, copper, tin and iron, were used in this work.

Both a low-pressure nterLine SST system and a high-pressure Plasma GikenCe

SEM images (left) and cross-sectional optical micrographs (right) of the feedstock powders (images for iron are at lower magnification).
Deposition efficiency of tin at various pressures at 200°C.

Optical micrographs showing the crosssections of the tin coatings cold sprayed at 200°C and 1.4 MPa on ABS (left) and PEEK (right).

Deposition efficiency measurements of iron at various pressures at 425°C.

Cross-sectional optical micrographs of PEEK (left) and PEI (right) after cold spray of iron at 425°C and 1.4 MPa.
Metallization of various polymers by cold spray

Results

The cold spray campaign was performed with both a low-pressure system and a high-pressure system to examine a wide range of particle velocities.

In general, cold spray on the thermoplastic polymers rendered more positive results than the thermosetting polymers.

Thick copper coatings were successfully deposited on PEEK and PEI at 425°C.

Deposition efficiency measurements of copper at various pressures at 425°C.

Cross-sectional optical micrographs of PEEK (left) and ABS (right) after cold spray of copper at 425°C and 2.0 MPa.
Thank you for your attention

If you need more information about the Cold Spray presentation at the ITSC 2017 you can contact me

maurice_ducos@orange.fr