An Overview of Thermal Spray Processes

American Galvanizer’s Association
TECHFORUM, New Orleans
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Robert K. Betts, P.E.  The VERY IDEA !, LLC
THE THERMAL SPRAY PROCESS

It is unlike any other coating method!!

Essentially the functional principles are:

A. Melt particles of metallic and/or ceramic materials

B. Project particles onto a surface where they adhere and solidify to form a coating

C. Utilize spray devices which generate a very high velocity gas jet and temperature adaptable to coating component surfaces
Visual Dynamics of Thermal Spray

Heat coloration and kinetic trajectories of molten particles
Interesting functional principles adapt

[1] Spray System features and

Produce coatings which

PROTECT
IMPROVE
RESTORE

Functional Requirements of parts to be coated.
This presentation will discuss:

1. Brief background of Thermal Spraying
2. Fundamentals of the Thermal Spray process
3. Coating characteristics and properties
4. Materials and thermal spray devices

as it is adapted to Galvanizing Operations.
THE THERMAL SPRAY PROCESS

PART 1

Brief background of Thermal Spraying
General Electric CF6 Commercial Turbofan Engines

--- FOUNDATION of CTS’ expertise & diverse business ---
 Classified by Aerospace and other industries as a **Special Process**

Requires ISO 9001 quality system compliance for Equipment, Materials, Procedures, as well as **Certification of personnel and product.**
THE THERMAL SPRAY PROCESS

PART 2

Thermal Spray Fundamentals
Principles of Thermal Spraying

I. Any ADAPTABLE MATERIAL may be Thermal Sprayed

Includes: Metallic, Ceramic or Polymeric materials having useful physical & chemical properties – and will:
- **Melt** to form sprayable particulates in a hot gas jet
- **Adhere** by impact onto a surface, forming a coating
- **Re-solidify** with desired engineering properties

II. Any SURFACE MATERIAL may be Thermal Spray Coated

Metallic, Ceramic, Polymer, Glass, Paper – that:
- Has line-of-sight access to the spray stream
- Can be cleaned and textured for adherence
- Will not be degraded by the heat and stress
OVERVIEW

What are some Applications?

- **Aircraft jet engines** - blades, vanes, combustors
- **Steel Mill** - galvanize, aluminize, furnace, bridle rolls
- **Steel Caster** - copper narrows and broadfaces
- **Power Generation Turbines** - Steam Turbine Systems
- **Automotive** - shifter forks, valves, rings, cylinders
- **Aircraft Structures** - flap actuators, landing gear
- **Ships** - container conditioner compressors
- **Medical Prostheses** - surgical devices, implants
- **Paper Mills** - chippers, tanks, driers, rolls
- **Petro-Chemical Plants** - pumps, compressors, valves
What are some Specialized Functions?

- Wear Resistance
- Corrosion Protection
- Erosion Resistance
- Restoration/Repair
- Molten Metal resistance
What are some Specialized Materials?

**METALS**
- Pure
  - Aluminum
  - Copper
  - Zinc
- Alloys
  - Cu-Ni-In
  - Ni-Cr Co-Mo
  - Plain C-steel
  - Stainless Steel

**CERAMS**
- Oxides
  - Alumina
  - Chromia
  - Zirconia-Yttria

**CERMETS**
- Carbides
  - WC-Co
  - CrC-NiCr
  - TiC-Ni

**POLYMERS**
- Plastics
  - Ekonol
  - Teflon
  - Polyethylene

**BLENDs/COMPOSITES**
- Ni-Graphite
- Al-Polyester

**LUBES**
- MoS$_2$
- Graphite
- Oxides

**SEALERS**
- Na-K Silicates
- Boron nitride
- Epoxy
Potential benefit of Thermal Spray Coating for Galvanize Line Maintenance

> Molten galvanizing of steel alloy strip involves fundamental metallurgical diffusion reactions which form Fe-Zn and Fe-Al metalides

> Vital reaction bonds the functional ZnAlSi alloy layer, initiates the robust galvanize coating.

> At pot liquid temperature ~850°F, diffusion is fast and thin, during the 9-sec strip passage.
Diffusion: a two-edged sword for productivity

- Submerged fixtures, baskets, rolls, etc., are continuously reacted, forming thick, brittle Fe-Zn-Al metalide surface layers.

- Structural metals dissolve, loading-unloading wear away this re-forming metalide layer.

- Equipment must be replaced, affecting productivity.
Equipment life can be effectively extended by Thermal Spray coatings

> Coatings are essentially inert to molten metal, retaining structural integrity for longer production campaigns.

> Coatings are beneficial to structures for batch dipping and electrolytic galvanizing.
THERMAL SPRAY PROCESS

Part 2

Coating Principles
THERMAL SPRAY PROCESS

THE FUNCTIONAL FORCE: **HEAT ENERGY**

Process uses **Heat Energy** to melt coating material.

Conversion:
- Burning Fuel
- Electric Arc

Converts to **Kinetic Energy** to spray melted particles onto a surface.

**High Velocity Gas Expansion Jet Spray Devices**
Visual Dynamics of Thermal Spray
Heat coloration and kinetic trajectories of molten particles
THERMAL SPRAY PROCESS

What are the Heat (Thermal) Sources?

- **Combustion Flame**
  - Heat from Burning a Fuel Gas with Oxygen

- **Electric Arc**
  - Heat Energy Transfer by Electrical Resistance

--- SPRAY SYSTEMS ---

**HEAT does Two Things:**

2. Softens & Melts the Material to be Sprayed.
Starting material usually powder. Particles 10 - 200µm.
- Softened, melted, and projected by the hot gas jet.
- Similar to paint spraying, but far more dynamic and complex.
- Involves Micro and Macro phenomena

Visualize particles as **CLAY BALLS** thrown at brick wall.
- Rough brick is like grit blasted surface preparation of parts.
- **Clay balls flatten, stick to brick, and to each other.**
- Physical interlocking forms a Mechanical bond.

> No **chemical / metallurgical fusion reaction** <

*Physical and van der Waals atomic force adhesion*

**Profound technical word describes this particle impact:**
THERMAL SPRAY PROCESS

Profound Mechanism

SPLAT !!
THERMAL SPRAY PROCESS

SPLAT

!!

Photo J. of Thermal Spray Technology, Sep. 1999
Mostaghimi, Psasandideh-Fard, Chandra, and University of Toronto.
Coating Analogy of Clay Balls, Brick Walls and Splats

Basis for Characterizing Coating Properties

Rough Brick Wall Surface
Blasted, warmed part surface

Thrower
Spray Gun

Coating

Bond Layer

Analogy of Clay Balls, Brick Walls Basis for Characterizing Coating
Thermal Spray Coating MICROSTRUCTURE
Quality System Certification

CERTIFICATE

TUV USA Inc.
Accredited under the Aerospace Registration Management Program
hereby certifies that

Cincinnati Thermal Spray, Inc.
5901 Creek Road
Cincinnati, OH 45242

has established and applies
a quality system for the

Coatings, Technology, Solutions for Aircraft Engine, Land
Based Turbine, Automotive, Industrial Equipment, Medical,
Steel and other Commercial Markets.
(Exclusion 7.3 Design and 7.5.1.4 Post Delivery Support)

Proof has been furnished that the requirements according to

ISO 9001:2008/AS9100C
are fulfilled.

ISO
International Standards Organization
WHAT ARE COATING CHARACTERISTICS AND PROPERTIES?

**Physical**
- Thickness
- Porosity
- Layering
- Cracking
- Texture
- Uniformity

**Mechanical**
- Adhesion
- Cohesion
- Hardness
- Erosivity
- Ductility
- Cyclic

**Engineering**
- Expansion
- Conductivity
  - Thermal
  - Electrical
- Modulous
- Wear
- Chemical
COATING CHARACTERISTICS

Top Coat
Intermediate Blend Layers
Bond Coat

Each having functional Structures
Physical & Mechanical Properties
THERMAL SPRAY COATING QUALITY
METALLOGRAPHY

Microstructure

50 – 500x magnification

Microstructure
Ceramic Top-Bond Coat, MICROSTRUCTURE

Mount
Top Coat
Blend Layer
Bond Coat
Grit Blast
Base Metal
MICROMETER THICKNESS

0.01085 inch
10.85 mils
## Relevant Thickness Comparisons

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Conversion reference: $1 = 1000 = 25.4$
Hardness - Softness
TENSILE BOND STRENGTH

**Adhesion** – Bonding of Coating to Surface

*First layer of individual particles* that actually splat onto, and stick to the part surface.

**Cohesion** – Inter-particle Bonding of Coating

*All other particles* splat and attach to previous layers of the coating itself, as thickness builds.
Tensile Test Machine
SEPARATED SURFACE

Strength measured as: PSI
Pounds per Square Inch
COATING BOND STRENGTHS

POUNDS PER SQUARE INCH (psi)

0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000

WC - Co
Cr₃C₂ - NiCr
M33

HVOF

NiCrAl

718

R80

T800

T400

NiCrAlY

NiCrAl

NiAl

Cr₂C₂ - NiAl

CuNi T800

NiCg 80:20
NiCg 75:25

NiCg 85:15

Al Polyester
NiCg 60:40
AlBr - NiCg
NiCrAl Bentonite

ZrO₂
Al₂O₃

Al

Abradable Composites
Flame Spray

Plasma

Oxides, Metals, Alloys, Carbides
WHAT IS A RELEVANT BOND STRENGTH COMPARISON?

5000 PSI, **POUNDS PER SQUARE INCH**

1 square inch

5000 pounds pull

(approx.) 5000 lbs., 2.5 Tons

2 ½ ton pick-up
Part 4
Thermal Spray Materials and Spray Application Devices
THERMAL SPRAY PROCESS

What are the HEAT Sources for Thermal Spraying?

**CHEMICAL**
- Combustible Gas
  - Heat from Burning a Fuel Gas with Oxygen
- Flame
- HVOF

**PHYSICAL**
- Electrical Energy
  - Heat generation/transfer by $I^2R$ Arc Resistance
- Wire Arc
- Plasma

**SPRAY SYSTEMS**

**STOICHIOMETRY**
- Ideal max temperature & mass efficiency of combustion flame

**ENTHALPY**
- BTU ‘Heat Content’ of a Reaction
THERMAL SPRAY PROCESS

What are the Basic Thermal Spray Systems?

- FLAME
- HVOF
- WIRE ARC
- PLASMA

**Systems Have in Common:**

- Internal Heat Energy Generation Device ('gun')
- Nozzle to Form & Direct the Kinetic Gas Jet
- Controls & Monitors for Power and Gas Flow
- Powder or Wire Feed systems
- Cooling Water & Compressed Air systems
- Mechanized and Robotic Manipulation
Thermal Spray Systems

- System is a modified oxy-acetylene torch.
- Burns highest temperature fuel gas, 5800 °F.
- Nozzle design adds aerodynamic velocity to source pressure of gas and heat expansion.
- Material powder, wire, or rod, feeds thru the gun into the nozzle, is melted and sprayed.
COMBUSTION FLAME SPRAY GUN

SULZER METCO

- Siphon Plug
- Air Cap Body
- Cooling Air
- Baffle
- Air Cap
- Powder Injection
- Sleeve
- Nozzle
Why Acetylene?

Highest Flame Temperature Hydrocarbon Fuel Gas

Oxy-Fuel Combustion:

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<td>CH₄</td>
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<td>Kerosene</td>
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</table>
WHY FLAME SPRAY?

Simple, modified oxy-acetylene torch methodology.

Adaptable oxy-acetylene 5800°F flame melts all practical materials in powder, wire or rod form.

Easily portable for on-site work, needs only bottle gas, air and basic electricity.

Economical, low cost gases and electric use.

Low velocity spray and deposition rates.
What in the World is…?

PLASMA

4TH Physical State of Matter

colder → SOLID → LIQUID → GAS → PLASMA → hotter

diAtom MOLECULES are SEPARATED

ATOMS are DISSOCIATED

GAS is IONIZED with FREE ELECTRONS and UNSTABLE NUCLEUS
Plasma Spray

- **HEAT** is generated by ~**ELECTRIC ARC**~ inside gun.

  **NO COMBUSTION**—It’s **PHYSICAL TRANSFER OF HEAT**

- **INERT GAS** flows around **ELECTRODE**, exits thru **NOZZLE**.

- 70 **VOLTS DC** **energizes an arc** across the electrode-nozzle gap.

- **400 AMPs** flow through the gas. Creates **Resistance Heat**.

  \[ I^2R \text{ Arc Current} \] heats gas stream to >10,000 °F

  **Thermal Power** \[ @ 400 \text{ A} \quad & \quad 200 \text{ Ω} \quad = \quad 32 \text{ MW} \]

  Gas in the arc path **IONIZES**, forms the **PLASMA** state

- **SUPER-HOT** gas expands violently out the nozzle. \[ PV=nRT \]

- **HIGH VELOCITY** gas jet transfers **heat** and **kinetic** energies to melt and spray the powder injected into exiting gas jet.
PLASMA GUN CROSS SECTION

How does this basic electrical principle relate to plasma gun operation?
Plasma produces highest temperature/enthalpy gas jet.  

- Capability to melt any useful engineering material.  

- Quantitative Heat input and High velocity enable wide variation of desired coating properties.  

- Process capable of high economical deposition rate.  

- ARC HEAT results from electrical $I^2R$ amps-ohms.
Wire Arc Spray

- Electric arc shorting, melting twin wires.
- Spray atomized by compressed gas.
- Nozzle adds aerodynamic gas velocity.
- Sprays metals readily available as wire.
- Sprays cermet composite cored wires.
Electric Arc Short Circuit
Twin Wire Arc Spray Gun
C. WHY **WIRE ARC**?

- **Wire Less Expensive** than sized powder.
- **High Capacity** melting energy, feed rate.
- Portable for **Off-Site** use.
- Overall **Economy** for Limited Materials.
HVOF  Big League Velocity

© 2006 by Larry A. Woolis
Rocket science for supersonic velocity.
Combustion of $\text{H}_2$ or kerosene fuel.
Oxygen for max flame temperature
Chamber-nozzle design pressure for max kinetic gas jet propulsion of particles.
Excellent coating adhesion and density.
THERMAL SPRAY PROCESS

Supersonic Shock Diamonds  HVOF JP-5000
Shock diamonds from the Space Shuttle Main Engines
Steam Power!
Why HVOF?

- Excellent coating characteristics.
- Supersonic particle splatting velocity.
- Strong adhesion.
- High density, low porosity.
- Responds to stoichiometry.
Adjunct Processes for Coatings

Post-application processes can further enhance primary Thermal Spray coatings

2. Sealers as final top coats fill natural inter-splat porosity, adding further corrosion resistance.
3. Lubricants of the dry-film type are applied to improve wear resistance.
4. Spray & Fuse is a flame type Thermal Spray process used to apply coatings composited for melting point suppression, to promote post-spray diffusion solidification.
5. Plasma Transferred Arc adapts plasma arc spraying, wherein the anodic arc is struck to a work surface, melting the flowing powder and surface for a weld-like coating.
Thank you for the opportunity

Robert Betts, P.E. The VERY IDEA !, LLC
- rkbetts231@gmail.com
Our Service is Your Solution

Coatings, Technology, Solutions
Cincinnati Thermal Spray, Inc. (CTS) is the preeminent provider of coatings, technology and solutions to protect and enhance products for a wide range of industrial uses. We can help you improve the performance of your components by selectively applying top-quality metal, ceramic and lubricating coatings, and offering component manufacturing.
Established in 1978
Offshoot of GE Aircraft Engine thermal spray operation
Started with aerospace applications only
Developed additional applications in a wide range of industries
Among the nation’s most respected and largest thermal spray companies
Our facilities serve customers worldwide

- Cincinnati, OH
- Wilmington, NC
- Springfield, NJ
- Houston, TX
FACILITIES - MIDWEST

- Thermal Spray Equipment
  - Plasma
    - Metco 3M, 9M, 7M
  - Wire Arc
  - Combustion Flame (Wire and Flame)
  - HVOF
    - JP 5000, JetKote
  - Production Painting
  - Dry Film Lubrication
  - Metallographic Laboratory
  - 19 Spray Booths
  - 42,000 Sq. Ft. Facility

- Quality Certifications
  - AS9100
  - Nadcap (Coatings)
  - ISO 9001
  - FAA CKNR597K
We specialize in component performance enhancement solutions in many industries, including:

- Aerospace
- Land Based Gas Turbine
- Steel
- Industrial Pump

- Commercial
- Oil & Gas
- Military/Defense
- Medical Device
Market Split - CTS 2011

- AERO: 49%
- LAND BASED GAS TURBINE: 21%
- COMMERCIAL: 9%
- INDUSTRIAL PUMP: 9%
- STEEL: 12%
## Aerospace-Approved Coatings List

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<td>Thermal spray and machining</td>
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Wear Coatings
Chrome plating alternative coating applied to bearing journal.
Thermal Protection
Yttria Stabilized Zirconia thermal barrier coating applied to inner combustor ring.
Fan Disk
Copper Nickel Indium plasma spray coating applied to pressure faces on CF6 Fan Disk.
AlSeal™

Compressor Midseal, AlSeal™ coating applied to prevent sulfidation within aircraft engine.
Gas turbine compressor blade, power generation

Compressor blades in tooling rack
Dome Assembly
Thermal barrier coating applied to Combustor Dome Assembly.
CFM 56, stage 4-9 spool
Aluminum Oxide wear coating applied to seals.
CFM 56, stage 1-2 spool

Aluminum Oxide wear coating applied to seals. Dry film lubricant applied within dovetail slots for fret wear protection.
Aircraft and commercial actuators for control systems

Apply thermal sprayed coatings as a Chrome plating alternative for impact wear protection in service on airframes and other actuation systems.
Quality

Depending on your components and the coating solution, we employ the latest technologies in inspection equipment, including:

- Gauging and measuring equipment
- Hardness testers
- Laboratories for conventional testing
  - Tensile bond strength
  - Microhardness
  - Macrohardness
  - Metallographic evaluation to standards
  - Erosion Testing
  - Furnace Cycle Testing
Fixed processes

*Thermal barrier coating applied utilizing fixed air stands as part of controlled plasma spray process.* CTS easily transfers engineered processes across facilities.
Masking techniques

CTS utilizes various masking techniques to protect cooling holes during coating applications. U/V liquid masking and hard tooling masking can be engineered to maintain airflow on a case by case basis.
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<td>Alstom Power</td>
<td>HZLM 601 501</td>
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<td>HZLM 603 610</td>
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Combustion assembly

Ceramic coating for thermal barrier protection in power generation applications. Assembly of combustion hardware details after coating.
Transition Spray Process
HVOF Coat and Grind Fuel Nozzle
Aluminum and Zinc coatings

Sacrificial coatings to protect against oxidation from atmospheric corrosion. Extends mild steel service life, exceeding 10 years in service.
Coatings used in Corrosion Applications

- Sealed coatings for environmental corrosion protection
  - all exposed exterior components
- Aluminum, Zinc, Zinc/Aluminum, Stainless Steel
- Coatings provide long term corrosion protection in severe applications such as exposure to marine environments or in chemical plants
Steel Industry

Applications

- Hot dip coating lines
- Galvanize
- Galvanneal
- Aluminize
- Temper mills
- Pickling lines

- Steel making
- Continuous caster
- BOF
- LMF
- Annealing lines
- Slitting lines
- Tin mills
- Tandem mills
Steel

• 5-7 days turn around time (TAT) for coat and polish
• 24-hour outage support
• Customer-consigned rolls in finished goods for immediate shipment
• 2-3 weeks full service restoration
• Surface finish at 5-10 minimum Ra increments
• Custom roll profiling (crowning)

Tungsten Carbide Wear Coating-Bridle Roll
(prevents pickup, replaces rubber)
Continuous Caster Mold Broadface
Paper roller tubes

Wear coating applied and polished, providing extended service life within harsh wear environments.
On-Site Services

On-Site Coating Services
CTS can take any of our thermal spray processes onsite to apply coatings to components that are too big to move or where scheduling will not permit delay.
On-Site Coating Services
We mobilize very quickly and arrive at your site prepared to apply any of our thermal spray coatings to your components.
Pump Industry

Manufactures Pump Components

- CNC & Manual Machining and Grinding
  - Sleeves
  - Shafts
  - Wear rings
  - Bushings

- Integrated Thermal Spray
  - HVOF
  - Plasma

- Spray and Fuse
  - Wire Spray
Tungsten carbide coated pump impeller

NCrB coated sleeves

Tungsten Carbide, Chrome Oxide, and HVOF Stellite coated sleeves
Throttle bearing sleeves

Chrome Oxide coated Plungers and Shaft

Screw Pump Rotor – Alumina Titania
At CTS, our specialty is developing and applying innovative solutions for your unique situations – on task, on time and on budget. Put our superior customer service, uncompromising quality solutions and innovative technology to the test.

We’ve got you covered every step of the way.