North American Pultrusion Conference

New Technology Capability Through Surface Enhancement

Improve Pultrusion Production

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ACMA American Composites Manufacturers Association | EPTA

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Agenda

- **Describe Limitations** of hard chrome plated coatings currently applied to pultrusion dies
- **Outline Benefits** of applying PVD coatings using the Arc Plasma Acceleration process
- **Discuss Case Stories**
- **Describe the Arc Plasma Acceleration Process** – outline benefits of this process
- **Introduce Phygen Coatings**
- **Future**

Hard Chrome Coatings

Currently hard chrome plated coatings are applied to pultrusion dies

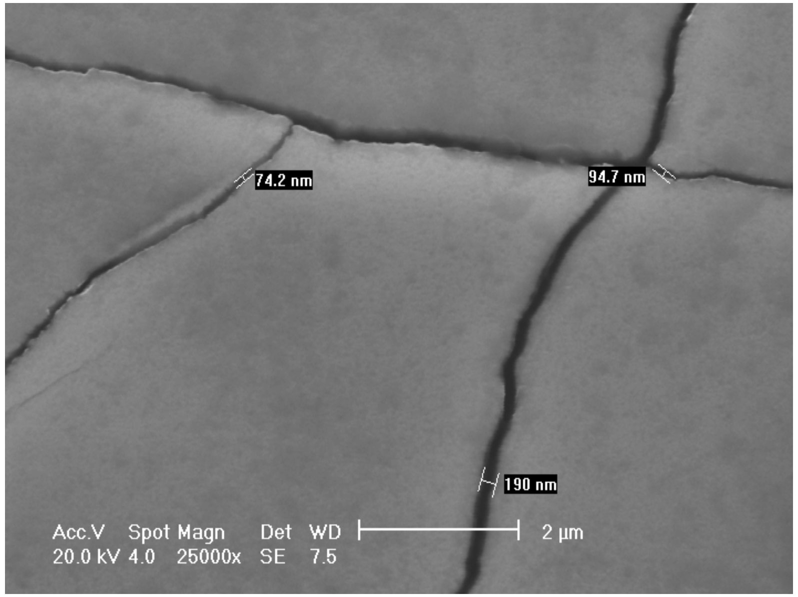
Hard chrome coatings are applied for several reasons

- Wear resistance
- Corrosion protection
    - Resins can be corrosive to steel dies
    - Especially at elevated temperatures
- Renewable surfaces
    - Chrome is cheaper and faster to replace than reworking the tool

Several drawbacks with these hard chrome coatings

Hard Chrome Coatings – Drawbacks

- Fewer companies offering chrome plating
- Plating prices have increased
- Lead times are longer
- Cleaning of coatings is troublesome
- Cracks in hard chrome plates surfaces allow penetration of corrosive materials
- Environmental issues



Cracks in surface of hard chrome plated coatings

Hard Chrome vs Phygen

4X tool life over hard chrome plating

Case Story

PVD Coatings produced by the Arc Plasma Acceleration process

Gordon Plastics is applying CrN coatings to their tools

- Coatings produced using the Arc Plasma Acceleration process

Gordon Plastics (Colorado, USA)

- Using pultrusion to produce PA6 Carbon TP tapes
- Experiencing problems with polymer build-up on tooling

With hard chrome coatings

- Cleaning of tooling requires hand scraping and a grinding wheel
- Takes a machine operator several minutes

With the CrN coating

- Let tooling sit at operating temperatures for a few minutes
- Quick and easy brushing cleans the tooling

Introduction to Physical Vapor Deposition (PVD) Coatings

Physical Vapor Deposition

Atoms are physically vaporized from a source

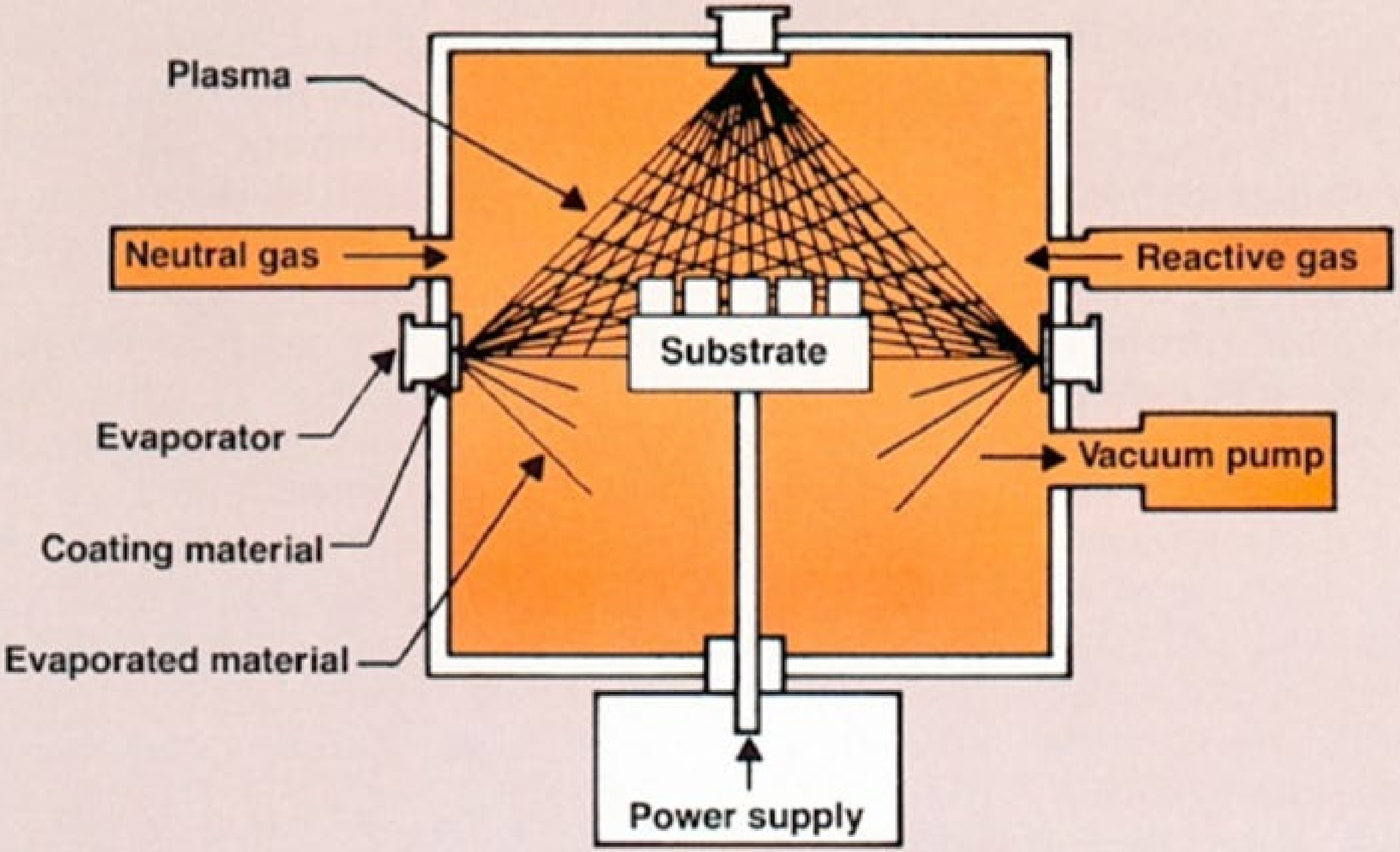
- Transported across the deposition chamber
- Deposited onto substrate
  - Pultrusion die

Most commonly used PVD coatings are metal nitrides

- Nitrogen gas is bled into deposition chamber
- Reacts with vaporized metal atoms

Common PVD coatings

- CrN, AlCrN


Plasma
Neutral gas
Reactive gas
Substrate
Evaporator
Vacuum pump
Coating material
Evaporated material
Power supply

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Benefits of the PVD Process

High quality, wear resistant coatings

Low cost

Coatings are produced at low temperatures

- Hardness of die is not compromised

Coatings are thin

- 1-to-6 μm

Coatings are smooth

- Surface mirrors contours of bulk component

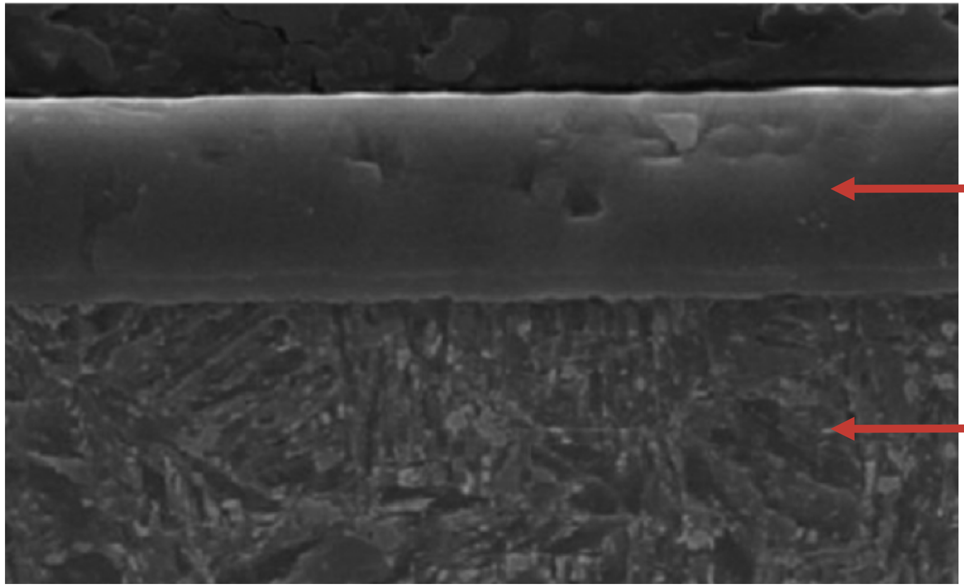
Physical Vapor Deposition (PVD)

- Typically PVD coatings are produced at temperatures less than 600ºC (1,100ºF)
- Allows PVD coating to be deposited onto fully hardened steel components
  - Without over-tempering the steel

Physical Vapor Deposition (PVD)

PVD coatings are typically 3-6 μm in thickness

- 120 - 250 micro-inches



PVD Coating Processes

Number of different PVD processes

- Cathodic arc evaporation (CAE)
- Sputtering

CAE is most commonly used PVD process

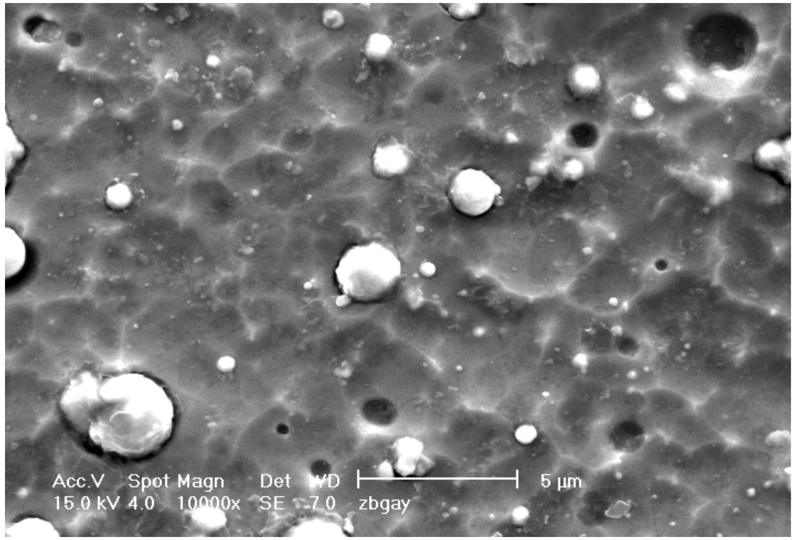
Cathodic Arc is a very high energy process

Coatings Produced

- High density
- High level of adhesion and cohesion to substrate

Cathodic Arc Process – Drawbacks

- Production of macro-particles
- Become incorporated as defects in the coatings
- Particles are similar in size to coating thickness
- Particles are poorly adhered to steel surface
- Limits the life of the coating and corrosion protection



Macro-particles within a CrN coating produced using conventional CAE process

Arc Plasma Acceleration Process

Phygen has developed and patented an improved CAE process

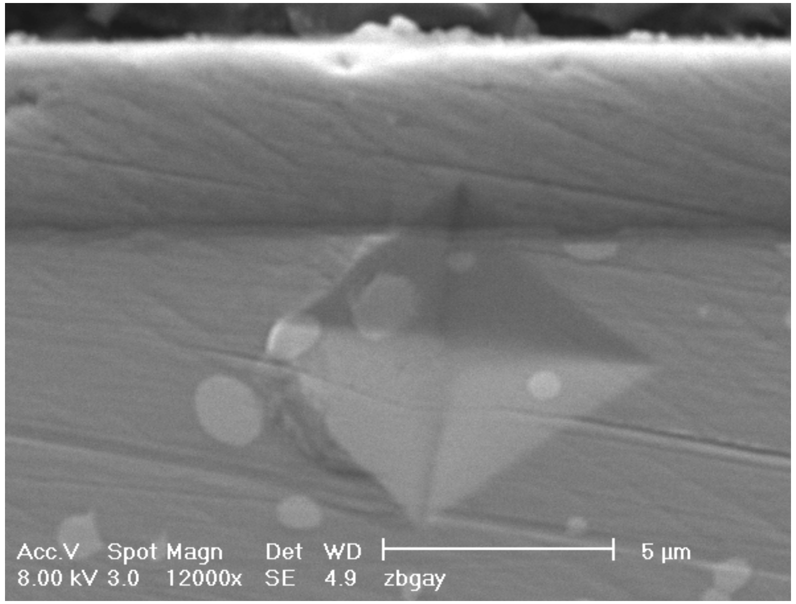
- Arc Plasma Acceleration (APA) Process

Improves upon traditional cathodic arc processes

- Produces high quality, very uniform coatings
- High coating density
- Excellent adhesion to the substrate (extends life of coating)

Arc Plasma Acceleration Process

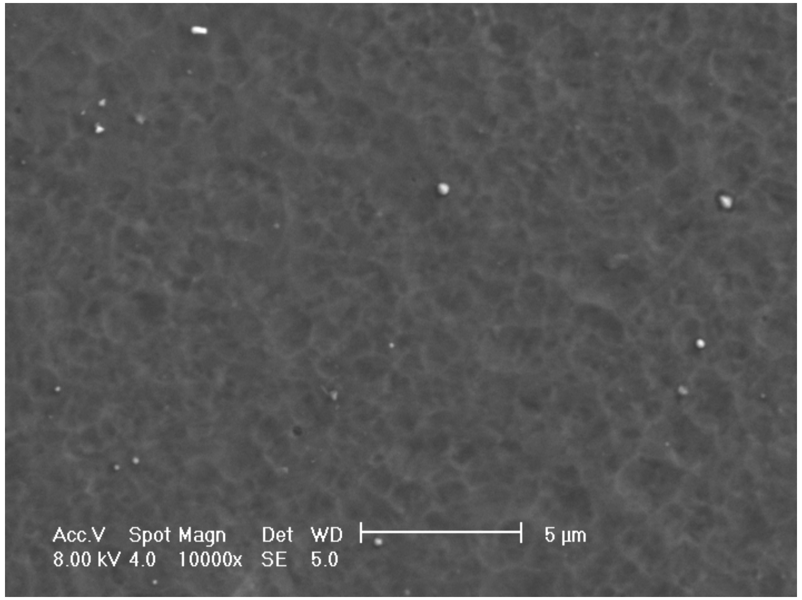
- Phygen's APA Process utilizes a magnetic field to focus the particles within the plasma
- Provides intense bombardment of particles onto the H13 steel substrate
- Promotes bonding between coating and substrate



Hardness indent applied at interface between coating and substrate (no delamination occurred). Shows excellent bonding between coating and substrate.

Arc Plasma Acceleration Process

- Coatings produced by Phygen's APA process are essentially free of macro-particles
- Eliminates the defective macro-particles from the coatings
- Life and quality of coatings are improved
- Corrosion protection significantly improved



Very few macro-particles within CrN coating produced using Arc Plasma Acceleration Process.

Arc Plasma Acceleration – Benefits

Coatings are extremely hard and wear resistant

- 20 to 28 Gpa

Extremely good adherence to due surface

Rapid and easy cleaning of the tooling

- Surface free energy of coatings is low
- CrN coatings not significantly wetted by polymers

Coatings have very low defect content

- Provide excellent corrosion resistance

Surface Free Energy Measurements

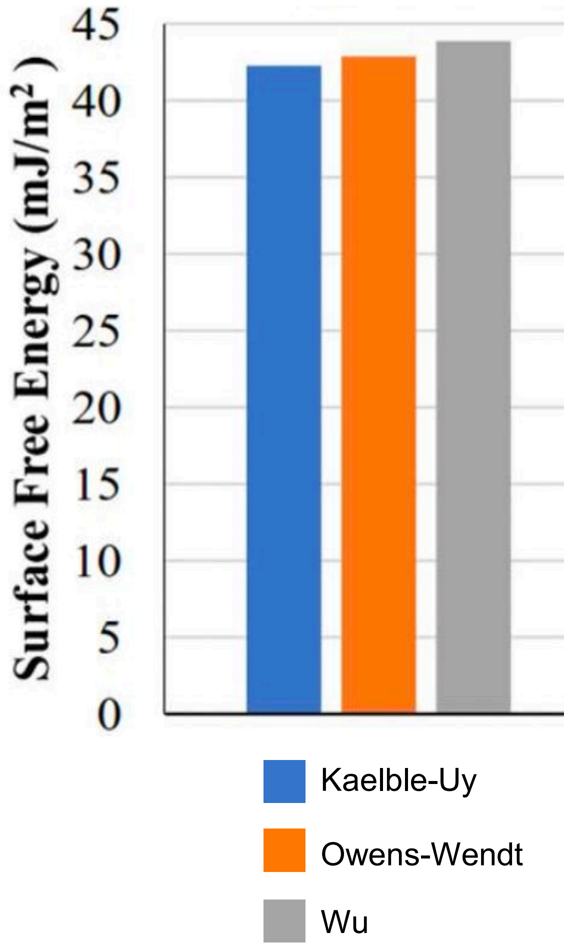
Interfacial free energy of these CrN coatings is extremely low

- 40 – 45 mJ/m^2

Low surface free energy means wetting and adherence of polymers to the coated surface

Surface free energy of chromium is much higher

- Around 1700 mJ/m^2
- Polymers tend to wet and stick to hard chrome coatings



Case Story

Low defect content of Arc Plasma Acceleration Coatings

US Army was experiencing wear and corrosion resistance of howitzer components

- Breech spindles

Spindles previously chromium plated to provide wear and corrosion resistance

- Wear and corrosion resistance were inadequate
- Led to shortened spindle life
- Created malfunctions of the howitzer

Army evaluated 12 coating solutions

- Selected Phygen’s CrN coating

Army is projecting a savings of >$5 million

- Over the life of the M777A2 howitzer

Corrosion Resistance – Phygen CrN Coating

After accelerated laboratory testing:

- Significantly better than electroplated hard chrome
- Significantly better than other PVD coatings

Phygen CrN

Phygen CrN/SiC

Electroplated Cr

Electroless Ni

Phygen Coatings

Founded in 1994

- Minneapolis, Minnesota

Patented PVD Technology

- Arc Plasma Acceleration (APA) process

Multiple PVD Chambers

Maximum Insert Size

- 50” tall by 30” wide

Short Lead Times

- 3 – 5 business days (depending on size)

Proven Successes in Coating Applications

Cold metal forming tools

- Drawing tool for brake drums
- CrN coating improved productivity to the tune of $20,000/year

Aluminum extrusion and die casting tools

- Die casting core pins with very low taper
- CrN protected the surface from aluminum soldering
- Core pins that broke after 1,700 shots showed 7x improvement in life

Machine components subjected to severe abrasive wear

- Plastic injection molding – CrN has significantly reduced wear at the most critical points
- Pistons in high-pressure paint pump – life increased from 4 months to more than one year

CrN Coating Summary

- **Nano-crystalline** (15 – 40 nanometers)
- **Non-columnar growth**
- **Significantly fewer macro-particles**
- **Hardness** 22– 28 Gpa
- **Elastic Modulus** 375 – 400 Gpa
- **Thermal Stability** 1,500ºF
- **Chemically Pure** (stoichiometric)

The Future of Phygen

- Demonstration and adoption of plasma acceleration
- Collaboration with industry leaders
- Laboratory simulation and testing
- Publication of results
- New partnerships for mutual success

Questions?

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