Contents

- Brief introduction to Deloro Stellite
- HVOF coatings
  - Process overview
  - Factors influencing coating quality
- Weld overlay coatings
  - Overview of various processes
  - Stellite hardfacing
- FusionStell™ coatings
  - Process overview
  - Engineered coating solutions
Deloro Stellite is a global provider of innovative solutions to challenging wear problems.

We deliver advanced wear protection to extend the life of components in demanding environments where heat, corrosion and wear are prevalent.
The company dates back to 1907 with the invention of a Co-Cr alloy called “Stellite”, known for its superior wear resistance.

Today it is a global company with $300m sales, operating out of 12 factories in 9 countries.

Industry leader for solving wear and corrosion problems, and a supplier to diverse industry sectors.

Portfolio of alloys and coatings for aggressive and demanding environments.
Our ability to provide wear solutions in demanding environments is based on a wealth of experience & know-how of wear problems.

Deloro Stellite has around 200 alloys and an extensive materials data-base for material selection in a wide range of applications.

- Each alloy has its own characteristics and properties.

We match the alloy characteristics with the service conditions:

- What type of wear?
- What is the operating temperature?
- Is it an environment with a combination of wear and corrosion degradation?

Use field service experience and application know-how to select most suitable alloy and manufacturing route:

- Custom alloy development capability for new applications.
Suite of Processes

Manufacture of components for high wear applications

- Variety of casting processes available within our network of six foundries
  - Sand casting
  - Centrifugal casting
  - Investment casting
  - Resin shell casting
  - Vacuum casting

- Machining and finishing of hard alloys to high surface finish specs
  - Modern machine shops at various locations

- Powder metallurgy products
- Wrought products
- Prototyping and Rapid Product Development
Wear-Resistant Coatings

- HVOF coatings
- Plasma Transferred Arc (PTA) welding
- Tungsten Inert Gas (TIG) Welding
- Submerged Arc Welding
- Metal Inert Gas (MIG) Welding

Wear-resistant materials

- Cobalt and Nickel welding consumables
  - Power, rod, wire & electrodes
- HVOF thermal spray powders

Coating equipment systems

- Jet-Kote® HVOF coating systems
- Starweld® & Hettiger® Plasma Transferred Arc (PTA) welding systems
Balance *kinetic energy* (velocity) and *thermal energy* (heat) by dwell in flame

Extremely high particle velocity generating heat/bonding on impact due to mechanical deformation
Features in Thermal Spray Coatings

- Flame and Plasma Spray coatings have a greater tendency to form oxides, porosity and unmelted particles than HVOF coatings.

- HVOF generally produces a denser coating with less oxides.
Advantages & Limitations of Thermal Spray Coatings

**Advantages**

- Minimal heat input into substrate, <150°C and no dilution
- No change in properties of substrate, base material retains heat treatment
- Alloys which are difficult or not recommended to be welded can have coatings applied to them
- Coating compositions can be applied not possible by welding
  - Tungsten-carbide, Chromium-carbide, and ceramic coatings

**Limitations**

- Coatings adhere by a mechanical bond, which is not as strong as the metallurgical bond of a weld deposit – Lower impact resistance
- Complex geometries such as inside diameters where low spray angle would be necessary leads to lower coating quality
- Only materials that are available in the correct powder/wire size can be used as coatings
The birth of HVOF

- Jim Browning develops first portable, continuous spray (non-detonation) process in 1981 with coating quality comparable to the D-gun

D-GUN Commercialized 1953
The HVOF Process

- High Velocity Oxy Fuel
- Supersonic flame
- Lower temp than plasma spray
  - Ideal for carbides (no decomposition)
  - Not for ceramics (too high melting point)
  - Good for metals, alloys

Ideal for high density wear resistant coatings
Many Factors Influencing Coating Quality
So What’s Important?

**POWDER**
- **Quality** – consistency between batches
- **Type of powder** – all tungsten-carbides are not the same!
- **Powder feed rate and settings**

**SUBSTRATE SURFACE**
- **Cleanliness** (proper degreasing)
- **Roughness** (correct grit blasting with clean alumina grit)
- **Interface** (over-blasting results in too much grit in bond line)
- **No moisture or oxides on the surface** (max. 4 hours wait before spraying)

**SPRAY PARAMETERS**
- **How to heat and accelerate the powder** (gas flow settings)
- **Correct angle and stand-off** (robot programme & rpm)
- **Spray program** (thickness of each layer, heat into substrate, dwell time on part)

The same powder can be sprayed with different parameters resulting in coatings with completely different properties
Coating quality depends on spray angle – robotic manipulation for complex geometries (images of same coating on different sections of a ball valve)
Spray Parameters – Type of Torch

Coatings deposited with Propylene torch

Coatings deposited with hydrogen torch

$\text{Cr}_3\text{C}_2/\text{NiCr}$

Stellite 6
The right coating for each application

- **Cr-carbide coating for a super-critical steam application**
  - Coating failed due to low thermal shock tolerance in severe environments
  - Problem solved by *developing* coating to increase *toughness*
  - Furnace fused NiCrSiB coating provides acceptable coating toughness, but not as good erosion resistance as WC composite coating
Powder Quality

- Shape (morphology)
- Particle size distribution
- Flowability
- Bulk Density
Gas atomized alloy powder

‘Dogbones’

Density variations

Satellites
Various WC-Co powders → different coating properties

- Cast (fused) and crushed
- Sintered and crushed
- Agglomerated (spray dried) & sintered
- Agglomerated & sintered & plasma densified
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Cladding Methods – Overview
GTAW and GMAW Processes

**Gas Tungsten Arc Welding**
- Arc between electrode & work piece
- Consumable (welding rod) fed into arc
- Advantages: simple manual operation and good control of welding arc
- Also known as TIG process

**Gas Metal Arc Welding**
- Arc between welding wire & work piece
- High deposition rates possible
- Process can be fully mechanized
- High deposition efficiency
- Also known as MIG
Plasma Transferred Arc (PTA) Process

- Arc between Tungsten electrode and work piece (similar to GTAW)
- Welding consumable is metal powder that is melted in the arc
- Main advantage process can be easily automated, providing high degree of reproducibility
- Wide variety of overlay materials possible
  - also combinations of materials (metals + carbides)

**Advantages** due to highly concentrated heat source:
- High deposit rates
- High powder utilization
- **Very low level of Fe-dilution**
Laser Welding

- Work piece heated with a laser beam
- Powder material fed into the laser beam and melted

**Advantages:**
- Narrow heat-affected zone
- Fast cooling rate
- Low heat input

......therefore
- A finer microstructure
- Usually higher hardness

**A word of caution:**
The fast cooling leads to a higher hardness, but in Stellite alloys that rely on time-dependent carbide growth during solidification for their wear properties, it can lead to unexpectedly poor wear resistance
So What’s Important?

- **POWer**
  - Quality – consistency between batches, no oxides
  - Particle shape and uniformity – Hall flow rate

- **SUBSTRATE**
  - Pre-heat (varies for different alloys)
  - Cooling rate
  - Post-weld heat treatment

- **WELDING PARAMETERS**
  - Selection of hardfacing material and welding process
  - Heat input (Fe-dilution)
  - Heat-affected zone (HAZ)
  - Welding parameters (inter-pass temperature, feed rate, oscillation, etc.)
  - Reproducibility (manual welding vs. automated process)

The same alloy can have very different properties depending on hardfacing method selected
Powder Quality

- Powder quality is one of the most important aspects to obtain good weld overlays......but often neglected by weld operators.

- Particle shape and uniformity is critical for powder flow, constant feed rate, and weld pool stability.

- Undesirable powder particle shapes
  - Requires more carrier gas that disrupt the arc
  - Lead to pulsing powder feeding

- Oxidized particles lead to increased slag and defects in the coating.
Stellite® Alloys

- Family of alloys that exhibit excellent resistance to wear and corrosion
  - Main constituents of Stellite alloys are Co, Cr, W, Mo, C
  - Hardness from 32 – 63HRC

- Known for their properties in high temperature applications
  - Excellent resistance to galling & metal-to-metal adhesive wear
  - Particularly in the absence of lubrication
  - Low coefficient of friction gives good sliding wear properties

- Variety of manufacturing methods, including various casting and surfacing processes

- Good corrosion resistance due to high Cr content (28 – 32%)
  - Corrosion behaviour similar to 316 stainless steel
Alloy Selection

Two types of Stellite alloys

- **Carbide type - C > 0.8%**
  - Strengthened by carbides of Cr, W, Mo
  - Hypo-eutectic (M_{23}C_{6} carbides) – **Stellite 6**
  - Hyper-eutectic (M_{7}C_{3} carbides) – **Stellite 1**

- **Solid Solution type - C < 0.4%**
  - Co, Cr, Mo alloys (no W) – **Stellite 21**
  - Co, Cr, Mo, Ni (low W) – **Ultimet**
  - Work hardening provides wear resistance
# Hardness vs. Ductility

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Composition</th>
<th>Hardness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stellite 21</td>
<td>27Cr, 0.2C, 5.5Mo</td>
<td>32 HRC</td>
</tr>
<tr>
<td>Stellite 6</td>
<td>28Cr, 1.2C, 5W</td>
<td>42 HRC</td>
</tr>
<tr>
<td>Stellite 4</td>
<td>31.5Cr, 1C, 14W</td>
<td>47 HRC</td>
</tr>
<tr>
<td>Stellite 12</td>
<td>29Cr, 1.85C, 9W</td>
<td>49 HRC</td>
</tr>
<tr>
<td>Stellite 1</td>
<td>33Cr, 2.45C, 13W</td>
<td>55 HRC</td>
</tr>
<tr>
<td>Stellite 20</td>
<td>22Cr, 2.45C, 17.5W</td>
<td>57 HRC</td>
</tr>
<tr>
<td>Stellite 100</td>
<td>33.5Cr, 2C, 18.5W</td>
<td>63 HRC</td>
</tr>
</tbody>
</table>
Maintain Hardness at High Temperatures

![Hot Hardness Graph]

- **Stellite 1**
- **H13**
- **Stellite 6**
- **Stellite 21**

Steel hardness decline
Effect of deposition method on Hardness

Stellite 6 in various hardfacing forms

- Stellite SF6 deposit (DS43)
- Stellite 6 oxyacet (DS43)
- Cast Stellite 6 (DS43)
- Stellite 6 TIG (DS43)

DPH (20kg, 8 seconds) vs Temperature (°C)
Metallurgical issues related with hardfacing of various classes of steels:

- Carbon steels
- Alloy steels, Martensitic steels, Tool steels
- Austenitic Stainless steels & duplex stainless steels
Weldability directly related to their hardenability
- Resulting in the formation of brittle heat affected zone (HAZ)

If the part is cooled too fast, or pre-heat is too low, then HAZ zone is quenched from austenitic to brittle semi-martensitic structure

Weldability of steel (tendency to form martensitic) based on C level

Martensitic formation unavoidable when C is above 0.5%
- Post-weld HT essential to temper brittleness in HAZ and prevent cracking

Alloys with C above 1% generally a hardfacing challenge
Austenitic Stainless Steels

- Unlike other steels, no formation of brittle martensitic in HAZ
- Difficulty is diffusion of C from Stellite into alloy in HAZ, forming carbides at the grain boundaries – *sensitization*
- The result is a decrease in corrosion resistance
  - Solution a Ni-based buffer layer to inhibit C diffusion

Duplex Stainless Steels

- Both sensitization and embrittlement occur during typical welding cycle due to formation of secondary brittle phases
- Welding parameters with minimum time in embrittlement range
  - Minimum pre-heat; fastest cooling rate, low inter-pass temperatures
  - Apply ductile Ni-based buffer layer with little or no pre-heat to shield substrate
Why is Fe-Dilution important?

- Dilution of Stellite weld overlays from substrate is inevitable
  - Dilution is amount of Fe or Ni (when using IN625 butter layer) in the Stellite

- Dilution in Stellite generally has the following effect:
  - Decreases the hardness – more pronounced at higher temperatures
  - Decreases the corrosion resistance
  - Decreases the wear resistance

- What are acceptable?
  - General guideline dilution should be kept below 20%
  - With max 10% in the 2nd layer
  - And a 3rd layer to reach 5%

[Dilution levels in Stellite 12 graph]
Hot Hardness and the Effect of Dilution

- Hardness drops linearly with dilution up to levels of about 15%
  - Trend is more profound the higher the temperature

- Hot hardness is very important to ensure good wear resistance at higher operating temperatures

![Graph showing the effect of temperature and dilution on hardness of Stellite 6](image)

![Graph showing the effect of Fe-dilution on hardness of Stellite 12](image)
Effect of Dilution on Wear Resistance

- Erosion doubles when hardness decrease from 320 to 200 DPH
- Abrasion wear increases 6x in Stellite 1 weld overlays as dilution increases to 6% and hot hardness decrease.
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FusionStell™ Coatings
FusionStell™ Process

- A novel technology to metallurgically bond a thin layer of Stellite with full density onto metal substrates

- The coating offers the wear resistance of a cast cobalt component on a non-cobalt substrate, typically steel

- Properties of the FusionStell™ coating the same as cast alloy
  - Chemical composition identical
  - Hardness the same
  - Finish the same as equivalent cast alloys

- No Fe-dilution or heat affected zone as in hardfacing of Stellite

- More consistent coating sintering than spray & fuse coatings
FusionStell™ Process

- Stellite powder is mixed with water, organic binder, and various additives to form a slurry
- Substrate components are dipped into the slurry and the metal coating adheres to the component surface
- The coating is air dried to remove the water, before sintering in a vacuum furnace at temperatures of 1100 – 1300°C
FusionStell™ samples

Outside diameters

Inside diameters

Complex shapes
Metallurgically bonded coatings

Stellite 12 coating on Stellite 12 casting

Stellite on steel

Stellite 12 coating on Stellite 12 casting
Certain substrates cannot be subjected to high temperature sintering

- Stress cracking in the coating on some martensitic steels due to the volume change during the phase transformation
  - Limit range of coatings to ‘more ductile’ compositions such as Stellite 6 or 12

- Changes in mechanical properties of substrate during high temperature sintering (can sometimes be recovered with HT)
  - Increased strength, but decreased ductility of 410 stainless steel
  - Grain growth of IN718 after sintering, although tensile strength can be recovered

- Ti alloys cannot be coated due to chemical reaction and formation of low melting point eutectic between Ti alloys and Stellite
Substrate Mechanical Properties

- Mechanical properties of steels recovered with post-coating heat treatment
  - Austenitic steels unaffected
  - Precipitation hardened and martensitic steels fully recovered

- Cast IN 718 properties fairly well recovered after heat treatment
  - Slight reduction in yield strength

- Wrought IN 625 properties reduced around 25% due to grain growth
  - Yield strength mostly affected

---

**CAST IN 718**

<table>
<thead>
<tr>
<th>Temperature</th>
<th>0.2% YS (ksi)</th>
<th>UTS (ksi)</th>
<th>Elongation %</th>
</tr>
</thead>
<tbody>
<tr>
<td>2170 F FusionStell &amp; HT</td>
<td>160</td>
<td>140</td>
<td>60</td>
</tr>
<tr>
<td>2250 F FusionStell &amp; HT</td>
<td>140</td>
<td>120</td>
<td>50</td>
</tr>
<tr>
<td>AMS 5383 spec</td>
<td>120</td>
<td>100</td>
<td>40</td>
</tr>
</tbody>
</table>

**Wrought IN 625**

<table>
<thead>
<tr>
<th>Condition</th>
<th>0.2% YS (ksi)</th>
<th>UTS (ksi)</th>
<th>Elongation %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wrought</td>
<td>160</td>
<td>140</td>
<td>60</td>
</tr>
<tr>
<td>2190 F Sintered</td>
<td>140</td>
<td>120</td>
<td>50</td>
</tr>
<tr>
<td>AMS 5401 cast spec</td>
<td>120</td>
<td>100</td>
<td>40</td>
</tr>
</tbody>
</table>
# Substrate compatibility

<table>
<thead>
<tr>
<th></th>
<th>Common Stellite</th>
<th>Very hard Stellite</th>
<th>Tribaloy alloys</th>
<th>Ni-based alloys (Hast C276, IN718)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Carbon &amp; Alloy steels</strong></td>
<td><strong>Austenitic stainless steels</strong></td>
<td><strong>Precipitation hardened steels</strong></td>
<td><strong>Martensitic steels</strong></td>
<td><strong>Ni-based alloys</strong></td>
</tr>
<tr>
<td>(1026, 4130, 1018)</td>
<td>(316, 304, 308, 303, 347)</td>
<td>(17-4 PH)</td>
<td>(410, 420, 440C, 9Cr1Mo, F9, F91)</td>
<td></td>
</tr>
<tr>
<td>Common Stellite Stellite 6 &amp; 12 (hardness range 40 – 48 HRc)</td>
<td></td>
<td></td>
<td>440C</td>
<td></td>
</tr>
<tr>
<td>Very hard Stellite Stellite 720, Star J (hardness range 53 - 58 HRC)</td>
<td></td>
<td></td>
<td>9Cr1Mo*</td>
<td></td>
</tr>
<tr>
<td>Tribaloy alloys T400, T800 (hardness range 53 - 56 HRC)</td>
<td></td>
<td></td>
<td>440C</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>9Cr1Mo</td>
<td></td>
</tr>
</tbody>
</table>

Incoloy 800H

*9Cr1Mo**
Engineered Solutions for Severe Service Valves

- Hardfacing material choice often compromised by manufacturability
  - Stellite 1 has high wear resistance, but prone to cracking during weld overlay
  - Tribaloy alloys have exceptional corrosion and wear resistance, but nearly impossible to hardface

- The FusionStell™ process is ideal to produce coatings from alloys that cannot be hardfaced best material for a specific application

<table>
<thead>
<tr>
<th>Alloy Family</th>
<th>Hot hardness</th>
<th>Abrasion</th>
<th>Erosion</th>
<th>Cavitation</th>
<th>Galling</th>
<th>Corrosion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stellite alloys</td>
<td>H</td>
<td>M - H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>M - H</td>
</tr>
<tr>
<td>Tribaloy alloys</td>
<td>H</td>
<td>H</td>
<td>M - H</td>
<td>M - H</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>Deloro alloys (Ni-base spray &amp; fuse)</td>
<td>M - H</td>
<td>M - H</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>L - M</td>
</tr>
</tbody>
</table>
The FusionStell™ process produces a ‘pure’ Stellite coating.

- Dilution only occurs in the diffusion zone for metallurgical bonding.
- Diffusion zone is typically 0.001” thick.
Tribaloy T800 and Stellite 720 have substantial higher corrosion and wear resistance than Stellite 6 or spray & fuse alloys.
Better Wear Resistance than Hardfacing

**ASTM G65-B Abrasion Wear Resistance**

- **Material loss (mm³):**
  - FusionStell cladded Stellite 720
  - Cast Stellite 6
  - Weld layer Stellite 6 (low dilution)
  - Weld layer Stellite 6 (high dilution)
  - AISI 410
Better metal-on-metal Wear than Hardfacing

G77 block-on-ring test

Volume loss (mm$^3$)

- Stellite 720*
- Tribaloy T-400
- Tribaloy T-800
- Stellite 12
- Stellite 6

300lbs
150lbs
Better High Temperature Erosion Resistance

Erosion Testing at 700 deg. C and 60 degree angle

Mass loss mg/g erodent

- Stellite 720
- T-800
- Stellite 712
- Stellite 1
- Stellite 6
- Stellite 12
- AISI 304H
- AISI 410
Better Hot Hardness than Spray & Fuse

![Graph showing hardness vs temperature for different materials.](image-url)
Benefits of FusionStell™ Technology

- Process can produce coated solutions not possible with any other technology
- Metallurgically bonded coatings with superior wear and corrosion resistance relative to spray & fuse coatings or Stellite hardfacing
- Coating of inside diameters not possible with any other coating technology
- No need for a “one coating fits all” approach
- Engineered materials solutions for severe service environments
  - Select optimum coating compositions for a specific application
Contact Details

Danie De Wet
VP: Technology & Business Development
Deloro Stellite Group
471 Dundas Street East
Belleville, ON, K8N 1G2
Canada

Tel: (613) 968 3481
E-mail: ddewet@stellite.com
Web site: www.stellite.com

Regional Sales Managers:

Mike Wartko
(281) 610 5001
mwartko@stellite.com

Barry Craig
(832) 428 4152
bcraig@stellite.com

Ray Antes
(913) 481 7123
rantes@stellite.com

John Blake
(713) 818 4737
jblake@stellite.com