Hardfacing with novel low heat input welding methods

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Outline

- Low heat input welding methods (CMT, laser)
- Hardfacing alloys
  - Fe-based
  - Co- and Ni-based
  - MMCs
- Wear properties:
  - Rubber wheel abrasion
  - High-speed dry-pot erosion
  - Hammer-mill impact
  - Pin-on-disc sliding
- Summary

Fusion bond
Low dilution (single layer)

\[ D = \frac{A_{BM}}{A_{BM} + A_{FM}} \times 100 \]

\[ D = \text{dilution} \]
Weld surfacing: classification

Chattopadhyay 2014
Cold metal transfer (CMT) cladding & additive manufacturing

- Advanced MIG/MAG
- Developed for thin sheet welding (≥0.3mm) and joining Al to steel
- High speed digital control
- Wire retracted at up to 140Hz
- Wire motion directly incorporated to electrical control
- Max I = 280 A
- Solid wires up to Ø1.2mm
- Tubular wires up to Ø1.6mm

Main benefits:
- Low dilution
- Low heat input
- High productivity
- Material efficient
- Energy efficient (wall-plug, process)
- Power by aggregate
- On-site eligible
- Low investments
- No optical elements
- Low safety precautions
- Closed-loop process control???
Cold Metal Transfer (CMT) cycle

Reciprocating wire feed

Stringer bead
Solid wire

Molten droplet detaches with a small short-circuit current value -> No spatter, low heat input
Cold Metal Transfer (CMT) cycles

Weaving mode, cored wire, Raex®400 base material

Cavitar Welding Camera (Camera and integrated laser illumination, 29 x 29 x 85 mm³)
CMT operating principle

- Synergic line welding (wire feed rate adjusted, one knob control)
- Fine tuning: Arc length correction (ALC) and dynamic correction (DC)
- DC affects short-circuit current
- ALC affects arc length (and wire speed and frequency)
- Points on synergic line can be adjusted and saved

Master’s thesis (Tapiola 2017)
CMT at TUT

- Fronius CMT Advanced 4000R single wire
  - 400A (50%), 320A (100%) duty cycle
- ABB IRB 4600-40/2.55 (40kg) + ABB IRBP A-750 turn table (700kg)

Process monitoring, 10ms (100Hz) (Stjerna 2017)
Other reciprocating wire-feed methods

- Jetline Engineering (Controlled Short Circuit (CSC)), process control, installation to various power sources, wires up to Ø2.4mm, USA
- SKS Welding Systems (micro-Mig), Germany
- Panasonic (Active Wire Process (AWP)), Japan
Coaxial hot-wire laser cladding & additive manufacturing

Main benefits:
- High process stability
- Less parameters in wire alignment
- Omni-directional
- Increased productivity
- Material efficient

Duplex: 3.5kW, 4m/min, 250A, 7V, 5kg/h (150 mm³/s)
Coaxial wire laser cladding & additive manufacturing

Laser cladding with thick wires, up to 10kW, Ø3.2mm wires, 10 kW Laserline HPDL

**Inconel 625** Ø1.6mm solid wire, geometrical dilution 6.2%, 6.1kg/h

**Sanicro 28** Ø1.6mm solid wire, geometrical dilution 8.8%, 5.5kg/h
Laser strip cladding & additive manufacturing

Inconel 625 30 x 0.5 mm² solid strip, 8.5kW, 300mm/min, 7.6kg/h, single bead

Laser cladding with strips, up to 20kW, 30 x 0.5 mm² strips, 20 kW Laserline HPDL

M-Era.Net: HiDEPO project
Weld surfacing: productivity & HI

<table>
<thead>
<tr>
<th>Method</th>
<th>HI (J/mm)</th>
<th>HI (J/mm²)</th>
<th>DR (kg/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMT stringer*</td>
<td>110-200</td>
<td>15-45</td>
<td>3-5</td>
</tr>
<tr>
<td>CMT weave*</td>
<td>200-900</td>
<td>30-50</td>
<td>3-5</td>
</tr>
<tr>
<td>Laser powder</td>
<td>60-120</td>
<td>10-25</td>
<td>0.5-2</td>
</tr>
<tr>
<td>Laser wire</td>
<td>45-190</td>
<td>16-30</td>
<td>2-6</td>
</tr>
<tr>
<td>Laser strip (30mm)</td>
<td>600-900</td>
<td>15-30</td>
<td>6-8</td>
</tr>
</tbody>
</table>

\[ \eta = (CMT \ 0.9, \ laser \ 0.5) \]

*Arc power \( (U_{ave} \times I_{ave}) \) (AIP method
would give higher values)
Hardfacing alloys

Cobalt containing stainless steels and Stellitees for cavitation-erosion

Fe-base hardfacing alloys (CMT)

Fe-28Cr-3Ni-0.8Mo-1.9C / S355, geometrical dilution 12.0%, 2.5kg/h

Primary austenite with austenite-carbide eutectic ($M_{23}C_6$)

Fe-28Cr-7Mo-7Nb-2W-1V-5.2C / 304L, geometrical dilution 8.4%

Primary carbides ($M_7C_3$) and smaller alloy carbides (Mo-Nb) in an eutectic austenite/carbide ($M_{23}C_6$) matrix
Tool steels (CMT)

Martensitic with complex alloy carbides (hot work tool steel)

Fe-5.5Cr-1.4Mo-1.6W-0.5V-0.45C / S235, geometrical dilution 15.6%, 3.6kg/h

Max. 450HV₁, HAZ

Primary austenite with austenite-carbide eutectic (VC-rich)

Fe-7.5Cr-1.2Mo-11.5V-2.6C / Raex®400, geometrical dilution 10.9%
Co-base hardfacing alloys (CMT)

St12 / Mart. SS, geometrical dilution 1.7%, 3.0kg/h

465HV₁

Unmelted W and Cr particles

St12 / Spheroidal graphite cast iron, geometrical dilution 3.8%, 2.4kg/h

495HV₁
Ni-base hardfacing alloys (CMT)

IN-718 / Hot work tool steel, geometrical dilution 1.6%, 6.1kg/h

Ni-38Cr-4Al / Mart. SS, geometrical dilution 2.8%, 5.8kg/h
Metal matrix composites (CMT)

NiCrBSi + 60% Fused Tungsten Carbide (WC/W\textsubscript{2}C) / 304L, geometrical dilution 11%

Dissolution of WC/W\textsubscript{2}C to be avoided!

Primary carbide 2500HV\textsubscript{0.3} (~20 vol.%)  
Matrix 530 HV\textsubscript{0.3}

Primary carbide 2500HV\textsubscript{0.3} (~20 vol.%)  
Matrix 260 HV\textsubscript{0.3}
Metal matrix composites (CMT)

Fe-7.5Cr-1.2Mo-11.5V-2.6C + VC (50-150µm) (externally added) / S355, geometrical dilution 11.1% 4.0kg/h

Matrix 820-930HV$_{0.3}$
VC 1600-2100HV$_{0.3}$
VC ~10 vol.%

External addition of particulates
Rubber wheel abrasion

- Low-stress 3-body rubber wheel abrasion
- Crushed dry quartz sand (0.1-0.6 mm)
- Abrasive feed rate 20-30 g/min per specimen
- Load 23 N
- Surface speed of wheel 1.64 m/s
- Testing time 60 min
High-speed dry-pot erosion

- Abrasive: Kuru granite (8-10mm)
- Mass loss (mg) graph showing comparison between MAG, Wrought, and CMT.
- WC/W$_2$C after the test.
- High-speed slurry/dry-pot erosion tester.
Hammer-mill impact wear

![Image of hammer-mill wear test setup]

![Graph showing wear plate and CMT mass loss for different materials]

![Bar graph showing surface hardness before the test for different materials]

**Tool steel (Aust. Mart.)**
- Wear plate (welded): 200 mg
- CMT: 40 mg

**Fe-based hardfacing (65HRC)**
- Wear plate (welded): 160 mg
- CMT: 80 mg

**Fe-based hardfacing (65HRC) + buffer**
- Wear plate (welded): 120 mg
- CMT: 60 mg

**Ni-WC/W2C (20 vol.%)**
- Wear plate (welded): 100 mg
- CMT: 50 mg

**Aust. 6Mn SS**
- Wear plate (welded): 80 mg
- CMT: 40 mg

**CCO**
- Wear plate (welded): 200 mg
- CMT: 100 mg

**Surface hardness before the test**

- Tool steel (Aust. Mart.): 1000 HVS
- Fe-based hardfacing (65HRC): 900 HVS
- Ni-WC/W2C (20 vol.%): 800 HVS
- Aust. 6Mn SS: 700 HVS
- CCO: 600 HVS
Pin-on-disc sliding wear

- CETR UMT-2
- Dry conditions
- Testing temperature RT and 300°C
- Load 150N
- Surface speed 2400 mm/min
- Test duration 6h
- ASTM G99-95a

Master's thesis
(Tapiola 2017)
Pin-on-disc seal wear

**PTFE-GF-MoS$_2$**

- **Volume loss** ($\text{mm}^3 \times 10^{-2}$)
- **Counter surface**, **Seal**, **Hardness**

![Graph showing volume loss, counter surface, seal, and hardness over time.](image)

- **CETR UMT-2**
- **Dry conditions**
- **Testing temperature RT**
- **Load 170N**
- **Surface speed 15000 mm/min**
- **Test duration 24h**
- **ASTM G99-95a**
Summary

- New weld surfacing processes available and under development capable to produce low diluted single layer coatings with high productivity
- CMT, coaxial-wire laser and laser strip cladding
- For hardfacing applications several wear-resistant alloys available as solid and cored wires, limited amount available as strips
- Fe-, Ni-, Co-based alloys and MMCs
- Wear performance testing of clads manufactured with new methods in progress (abrasion, erosion, impact, adhesive etc.)

THANK YOU!