Oerlikon
High Temperature creep resistant solutions

Claude Bouillot
ALW Key Segment Manager
Power Generation & Petrochemicals
High Temperature creep resistant steel

**Power Station Industry**
- Improve the thermal efficiency of steam power station to reduce use of fuel resources
- Steam at high temperature and high pressure raising
- Development of heat resistant steel with high creep strength

**Requirement for heat resistant steels**
- Long time creep testing 100000h
- Satisfactory oxidation resistance

By 2030, the world's demand for electricity will increase by more than 80%
High Temperature creep resistant steel

- Petrochemical industry (hydrocracking reactors)
- Process severity
  - Temperature
  - Hydrogen pressure
- Requirement for heat resistant steels
  - hydrogen attack resistance
  - temper embrittlement resistant
  - high tensile strength steels

The driving force for developments is the growing demand for energy mainly from India and China. According EIA, Fossil fuel continue to supply almost 80% of world energy use in 2035

## High Temperature creep resistant steel

<table>
<thead>
<tr>
<th>Alloy Type</th>
<th>Service Temperature</th>
<th>Plate ASTM / EN 10028-2</th>
<th>Tube/Pipe ASTM / EN 10216-2</th>
<th>Forging ASTM / EN 10222-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5Mo</td>
<td>450°C</td>
<td>A204Gr. A, B, C 16Mo3 18MnMo4-5</td>
<td>A209 Gr. T1, T1a, T1b A335 Gr. P1 16Mo3 8MoB5-4</td>
<td>A182 Gr.F1 A336 Gr.F1 16Mo3</td>
</tr>
<tr>
<td>1Ni 0.5Mo (Cu)</td>
<td>250°C-450°C</td>
<td>15NiCuMoNb5-6-4 20 MnMoNi 5-5</td>
<td>A335 Grade P36 15NiCuMoNb5-6-4 (WB 36) 20 MnMoNi 5-5</td>
<td>A182 Grade F36</td>
</tr>
<tr>
<td>0.5Cr-0.5Mo</td>
<td>500°C</td>
<td>A387Gr.2 Cl.1, Cl.2</td>
<td>A213Gr.T2 A335 Gr. P2 14MoV6-3</td>
<td>A182 Gr.F2</td>
</tr>
<tr>
<td>1Cr-0.5Mo 1.25Cr-0.5Mo</td>
<td>550°C</td>
<td>A387 Gr.11 Cl.1, 2 A387 Gr.12 Cl.1, 2 13CrMo4-5 13CrMoSi5-5</td>
<td>A213 Gr. T11, T12 A335 Gr. P11, P12 13CrMo4-5 10CrMo5-5</td>
<td>A182 Gr.F11Cl.1, 2, 3 A182 Gr.F12Cl.1, 2 A336 Gr.F11Cl.1, 2, 3 A336 Gr.F12 13CrMo4-5</td>
</tr>
<tr>
<td>2.25Cr-1Mo</td>
<td>550°C</td>
<td>A387 Gr.22 Cl.1, 2 10CrMo9-10 12CrMo9-10</td>
<td>A213 Gr. T22 A335 Gr. P22 10CrMo9-10 11CrMo9-10</td>
<td>A182 Gr. F22 Cl.1, 3 A336 Gr. F22 Cl.1, 3 11CrMo9-10</td>
</tr>
<tr>
<td>9Cr-1Mo</td>
<td>550°C</td>
<td>A387Gr.9 Cl.1, Cl.2</td>
<td>A213 Gr. T9 A335 Gr. P9 X11CrMo9-1 +I,+NT</td>
<td>A182 Gr.F9 A336 Gr.F9</td>
</tr>
<tr>
<td>9Cr-1Mo-V-Nb (91)</td>
<td>600°C</td>
<td>A387Gr.91 Cl.2 X10CrMoVNb9-1</td>
<td>A213 Gr. T91 A335 Gr. P91 X10CrMoVNb9-1</td>
<td>A182 Gr.F91 A336 Gr.F91 X10CrMoVNb9-1</td>
</tr>
<tr>
<td>9Cr-0.5Mo-2WVNb (92)</td>
<td>600°C</td>
<td>A387Gr.92</td>
<td>A213 Gr. T92 A335 Gr. P92</td>
<td>A182 Gr.F92 A336 Gr.F92</td>
</tr>
</tbody>
</table>
### OERLIKON Range abstract

<table>
<thead>
<tr>
<th>Alloy Type</th>
<th>SMAW</th>
<th>FCAW</th>
<th>GTA W</th>
<th>GMAW</th>
<th>SAW</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5Mo</td>
<td>MOLYCORD Ti (E 8013-G)</td>
<td>FLUXOFIL 25</td>
<td>CARBOROD Mo (ER 70S A1)</td>
<td>CARBOFIL Mo (ER 70S A1)</td>
<td>OE-S2Mo / OP 121TT</td>
</tr>
<tr>
<td></td>
<td>MOLYCORD Kb OE-KV2HR (E 7018-A1 H4R)</td>
<td>FLUXOFIL 35</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1Ni 0.5Mo (WB36)</td>
<td>TENACITO 65 R (9018 – G) TENAX 118-D2 (10018 D2)</td>
<td>FLUXOFIL 41</td>
<td>CARBOROD MnMo (ER 80S D2)</td>
<td>CARBOFIL Ni Mo1 (ER 100S-G)</td>
<td>OE-SD3 1Ni1/2Mo / OP 121TT F9P8 EF3 F3</td>
</tr>
<tr>
<td>0.5Cr-0.5Mo</td>
<td>CROMOCORD 5S (E 8018-B1)</td>
<td>FLUXOFIL 37</td>
<td>CARBOROD CrMo1 (ER 805 G) CARBOROD KV5 (ER 805 B2)</td>
<td>CARBOFIL CrMo1 (ER 805 G) CARBOROD KV5 (ER 805 B2)</td>
<td>-</td>
</tr>
<tr>
<td>1Cr-0.5Mo</td>
<td>CROMOCORD Kb OE-KV5HR (E 8018-B2-H4R)</td>
<td>CARBOROD CrMo1 (ER 805 G)</td>
<td>CARBOROD KV5 (ER 805 B2)</td>
<td>CARBOFIL CrMo1 (ER 805 G) CARBOROD KV5 (ER 805 B2)</td>
<td>OE-S2 CrMo1/ OP 121TT</td>
</tr>
<tr>
<td>1.25Cr-0.5Mo</td>
<td>CROMOCORD 2 STC OE-KV3HR (E 9018-B3-H4R)</td>
<td>FLUXOFIL 37</td>
<td>CARBOROD CrMo2 (ER 905 G) CARBOROD KV3 (ER 905 B3)</td>
<td>CARBOFIL CrMo2 (ER 905 G) CARBOROD KV3 (ER 905 B3)</td>
<td>OE-S1 CrMo2/ OP 121TTW</td>
</tr>
<tr>
<td>2.25Cr-1Mo</td>
<td>CROMOCORD 9 (E 8015-B8)</td>
<td>CARBOROD CrMo9 (ER 805 B8)</td>
<td>CARBOFIL CrMo9 (ER 805 B8)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>9Cr-1Mo</td>
<td>CROMOCORD 9 (E 9018-B9-H4)</td>
<td>CARBOROD CrMo91 (ER 905 B9)</td>
<td>-</td>
<td>-</td>
<td>OE-S1 CrMo91 /OP 90</td>
</tr>
<tr>
<td>9Cr-1Mo-V-Nb (91)</td>
<td>CROMOCORD 9M (E 9018-B9-H4)</td>
<td>CARBOROD CrMo92 (ER 905 B9)</td>
<td>CARBOROD WF 92</td>
<td>-</td>
<td>OE-S1 CrMo92 /OP90</td>
</tr>
<tr>
<td>9Cr-0.5Mo-2WVNb (92)</td>
<td>CROMO E 92 CROMOCORD 92</td>
<td>CARBOROD CrMo92 CARBOROD WF 92</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Creep resistant 0.5Mo steel

Materials
- Plates
  - ASTM A204Gr. A, B, C
  - EN 10028-2 16Mo3
  - EN 10028-2 18MnMo4-5

Applications
- 0.5%Mo improved elevated temperature strength and creep resistance.
- Fabrication of pressure vessel and associated pipes where service temperature up to 550°C is necessary.
- In the petrochemical industry, Mo improves resistance to hydrogen stress corrosion cracking risk.

Oerlikon Solution
- Reliable mechanical properties in as-welded and stress-relieved weld metal with good ductility at low temperature. High level of acicular ferrite.
- ASME VIII div1 recommend preheating 79°C when thickness joint in excess of 16mm.
- Oerlikon consumables are regularly validated according to ASME recommendation and customer specification.

<table>
<thead>
<tr>
<th>SMAW</th>
<th>FCAW</th>
<th>GTAW</th>
<th>GMAW</th>
<th>SAW</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOLYCORD Ti</td>
<td>FLUXOFIL 25</td>
<td>CARBOROD Mo</td>
<td>CARBOFIL Mo</td>
<td>OE-S2Mo / OP 121TT</td>
</tr>
<tr>
<td>(E 8013-G)</td>
<td>(E81T1-A1M-H4)</td>
<td>(ER 70S A1)</td>
<td>(ER 70S A1)</td>
<td>(F8P4-EA2-A2)</td>
</tr>
<tr>
<td>MOLYCORD Kb</td>
<td>FLUXOFIL 35</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OE-KV2HR</td>
<td>(E80T5-GC-H4)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(E 7018-A1 H4R)</td>
<td>(E80T5-GM-H4)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
OERLIKON Double coating SMAW electrodes

- Oerlikon Technology FOCUS
- wider range of parameters, enables welding in typical on-site welding joint configurations with non-homogeneous root gap.
- The profile of the welding bead reduces the risk of both slag inclusions or lack of fusion.
- OERLIKON double coating stick electrode assures better penetration without porosities, undercut and spatter.

Inner coating
Arc stabilization
No undercut
Penetration
Premium core steel
Low temperature toughness

Outer coating
Guaranteed Mechanical properties

Standard SMAW
OERLIKON Technology
1Cr-0.5Mo & 1.25Cr-0.5Mo

- **Plates**
  - ASTM A387Gr. 11 cl. 1, 2
  - ASTM A387Gr. 12 cl. 1, 2
  - EN 10028-2 13CrMo4-5
  - EN 10028-2 13CrMOSi5-5

- **Pipe/tube**
  - ASTM A213 grade T11, T12
  - ASTM A335 grade P11, P12
  - EN 10216-2 13CrMo4-5
  - EN 10216-2 10CrMo5-5

- **OERLIKON Solution**
  - Engineered for use in elevated temperature service, Oerlikon chrome molybdenum alloy dedicated consumables are use in pressure vessels, industrial boilers and associated pipework.

  **Lower susceptibility to cold crack** risk Extra low hydrogen level

  **Lower susceptibility to hot crack** risk extra high quality raw material with extra-low phosphorus levels

  Better mechanical properties for extended PWHT

  Reliable microstructure for better creep resistance at elevated temperature

- **Excellent low temperature impact toughness properties.**

- **Oerlikon CROMOCORD Kb** has regularly earned reputation has a much higher heat resistance and it is thus exceptionally useful for applications where hot fluids or gases are being processed at high temperatures.

<table>
<thead>
<tr>
<th>Alloy Type</th>
<th>SMAW</th>
<th>FCAW</th>
<th>GTAW</th>
<th>GMAW</th>
<th>SAW</th>
</tr>
</thead>
<tbody>
<tr>
<td>1Cr-0.5Mo</td>
<td>CROMOCORD Kb (E 8018-B2-H4R)</td>
<td>FLUXOFIL 36 (E80T5-B2C-H4 E80T5-B2M-H4)</td>
<td>CARBOROD CrMo1 (ER 80S G)</td>
<td>CARBOFIL CrMo1 (ER 80S G)</td>
<td>OE-S2 CrMo1/ OP 121TT (F7P4-EB2-B2)</td>
</tr>
<tr>
<td>1.25Cr-0.5Mo</td>
<td></td>
<td></td>
<td>CARBOROD KV5 (ER 80S B2)</td>
<td>CARBOROD KV5 (ER 80S B2)</td>
<td></td>
</tr>
</tbody>
</table>
2.25Cr-1Mo CREEP RESISTING STEEL

Application Oerlikon solutions

- Oerlikon consumables designed for prolonged elevated temperature service up to 600°C.
- Main areas of application associated with steam generating power plant (piping, turbine castings, steam chests, valve bodies and boiler superheaters).
- in refineries for corrosion resistance to sulphur bearing crude oil at 250-450°C. Some of the petro-chemical industries for resistance to hydrogen attack in the fabrication of hydrocrackers,

<table>
<thead>
<tr>
<th>Alloy Type</th>
<th>SMAW</th>
<th>FCAW</th>
<th>GTAW</th>
<th>GMAW</th>
<th>SAW</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.25Cr-1Mo</td>
<td>CROMOCORD 2 STC OE-KV3HR (E 9018-B3-H4R)</td>
<td>FLUXOFIL 37 (E 80T5 B3C H4/ E 80T5 B3M H4)</td>
<td>CARBOROD CrMo2 (ER 90S G) CARBOROD KV3 (ER 90S B3)</td>
<td>CARBOFIL CrMo2 (ER 90S G) CARBOFIL KV3 (ER 90S B3)</td>
<td>OE-S1 CrMo2/ OP 121TTW (F8P2 EB3 B3)</td>
</tr>
</tbody>
</table>
Petro-chemical application
CrMo – CrMoV Oerlikon solution
oil processing industry (API 934)

- **Oerlikon world reference for 2.25Cr-1Mo and enhanced 2.25Cr-1Mo-V material and practice**
- **2.25Cr–1Mo steel**
  - early 1990s for hydrogen refining equipment in chemical plants
- **2.25Cr–1Mo–V steel**
  - high-strength raised the limiting temperature to 482°C by 1995.

<table>
<thead>
<tr>
<th>Product</th>
<th>ASME</th>
<th>2.25Cr-1Mo</th>
<th>2.25-1Mo V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SA 387</td>
<td>Gr. 22 Cl. 2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SA 542</td>
<td></td>
<td>Type D Cl. 4</td>
</tr>
<tr>
<td></td>
<td>SA 832</td>
<td></td>
<td>Gr. 22V</td>
</tr>
<tr>
<td>Forging</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SA 182</td>
<td>Gr. F22 Cl. 3</td>
<td>Gr. F22V</td>
</tr>
<tr>
<td></td>
<td>SA 336</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SA 541</td>
<td></td>
<td>Gr. F22V</td>
</tr>
<tr>
<td>Pipe</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SA 335</td>
<td>Gr. P22</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SA 369</td>
<td>Gr. FP22</td>
<td></td>
</tr>
</tbody>
</table>
Oerlikon consumables
Main Applications

- Reactors for secondary petroleum refining processes, including hydrocracking, catalytic cracking and hydrofining.
- Heavy wall thickness

API RP 934 last edition has incorporated OERLIKON welding recommendations
2.25Cr-1Mo-0.25V focus

Application 2.25Cr-1Mo-0.25V
- Pressure vessels for petrochemical hydrocracker
- Heavy wall thickness
  Typically above 150mm

2¼Cr-1Mo-0.25V advantages
- Higher strength
- Better resistance to hydrogen attack
- Better resistance to overlay disbonding
- Refinery
  - Piping
  - Pressure vessel
  - Reactor
  - Tanks
Project for Petrochemical Industry

- Project Owner: Oil & gas companies
  - TOTAL, EXXON, BP, SHELL, PETROBRAS, Saudi ARAMCO

- Engineering
  - Samsung Engineering
  - SHAW group
  - TECHNIP
  - CB&I
  - Technicas Reunidas

- Contractors
  - ATB, L&T, DOOSAN, Walter TOSTO, Belleli Energy SPA; SBW (China); Borsig GmbH; BHEL (India); Felguera (Spain); Godrej & Boyce MFG Co. Ltd (India); Manoir Industries group (France); Nordon (France); SEWON (Korea); ENSA (Spain); BILFAL (KSA); CONFAB (Brasil)
Cold cracking link to diffusible hydrogen

- Has been encountered several years ago

**Oerlikon solution**

- Low diffusible hydrogen consumables design
- Oerlikon Moisture proof packaging *(DRYBAG)*
- Oerlikon fluxes have limited moisture pick up kinetic.
- Careful control of welding conditions, storage and use of consumables
- ISR (or DHT) immediately after welding: in that case, hydrogen level is negligible
Hydrogen induced cracking risk

Hydrogen Sources:
- Hydrogen is produced in the arc cavern by the dissociation of hydrogenous compounds.
  - Welding consumables (Wire & Flux).
  - Base material paints or coatings,
  - Lubricants or degreasing fluid and rust.
  - Surrounding air moisture content

Hydrogen in the weld pool:
- Relative contribution of the different sources
- Solubility variation during phase transformation from austenite to ferrite
- Time temperature cooling conditions (heat input)

Hydrogen level control:
- Minimizing initial amount
- Ensuring that sufficient time is allowed to escape by diffusion before the weld cools.
Controlling Temper Embrittlement

- **Toughness in weld metal**
  - Of primary importance due to high thickness of the joints

- **Controlling temper embrittlement**
  - Decrease in toughness when the material is heated or cooled through the 300°–600°C range.
  - Unintentional additions Si, P, Sn, Sb, As
  - X factor 1960s, CB&I researcher Robert Bruscato

  - **Oerlikon X < 10 ppm**

  - **PE = \((C+Mn+Mo+Cr/3+Si/4)+ 3,5x(X\text{-factor})x100 < 3.3\)**

- Fabricators and end-users must be vigilant in defining material limits for proper procurement of high-quality products.
Prevention of reheat cracking Cr-Mo-V heavy reactors fabrication

- Not detected by usual NDT
- API RP 934A committee OELIKON participation
  - “Mini JIP” / Standard procedure for 2.25Cr-1Mo – V SAW quality control & acceptance
- Oerlikon consumable design
  - Very low tramp impurities
  - Very low Pb and Bi impurities

Oelikon only Systematic determination of Kf and RHC Gleeble® tests for production control

\[
K_f = Pb + Bi + 0.03Sb \leq 1.5 \text{ ppm}
\]
## Welding parameters

<table>
<thead>
<tr>
<th>Wire</th>
<th>CURRENT</th>
<th>Current (Amp)</th>
<th>Voltage</th>
<th>Welding speed</th>
<th>Heat Input</th>
<th>Preheat Interpass</th>
</tr>
</thead>
<tbody>
<tr>
<td>OE CROMO S225 V 4.0mm</td>
<td>AC</td>
<td>550</td>
<td>31-32</td>
<td>50cm/min</td>
<td>20kJ/cm</td>
<td>200 – 250°C</td>
</tr>
</tbody>
</table>

## Results

<table>
<thead>
<tr>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Mo</th>
<th>Ni</th>
<th>As</th>
<th>Sb</th>
<th>Sn</th>
<th>Cu</th>
<th>V</th>
<th>Nb</th>
<th>X</th>
<th>J</th>
<th>PE</th>
</tr>
</thead>
<tbody>
<tr>
<td>0,12</td>
<td>0,9</td>
<td>0,18</td>
<td>0,005</td>
<td>0,002</td>
<td>2,13</td>
<td>0,92</td>
<td>0,13</td>
<td>0,003</td>
<td>0,003</td>
<td>0,002</td>
<td>0,020</td>
<td>0,26</td>
<td>0,02</td>
<td>9,6</td>
<td>75,6</td>
<td>3,2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>705°C X 8Hrs</th>
<th>705°C X 30Hrs</th>
<th>705°C X 8Hrs + Step Cooling</th>
</tr>
</thead>
<tbody>
<tr>
<td>YS (Mpa) RT</td>
<td>630</td>
<td>575</td>
<td></td>
</tr>
<tr>
<td>TS (Mpa) RT</td>
<td>715</td>
<td>685</td>
<td></td>
</tr>
<tr>
<td>E (%) RT</td>
<td>19</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>TS (Mpa) + 454°C</td>
<td></td>
<td></td>
<td>580</td>
</tr>
<tr>
<td>Kv (J) @ -20°C</td>
<td>224-231-227</td>
<td>148-156-165</td>
<td>201-105-127</td>
</tr>
<tr>
<td>Kv (J) @ -30°C</td>
<td>292-227-205</td>
<td>168-118-134</td>
<td>187-164-154</td>
</tr>
<tr>
<td>HV 10</td>
<td>229</td>
<td>215</td>
<td></td>
</tr>
</tbody>
</table>
Oerlikon CrMoV experience

- 200 heavy hydrotreater made with Oerlikon solution
- Oerlikon Consumables design
  - Low impurities level
  - Low hydrogen
- Technical team dedicated
- Customer service
  - 3.2 certificate

![Graph showing temperature cooling rates and impact absorbances](image)

**Graph Details:**
- **STEP COOLING - API 934**
- **Welding Parameters:**
  - SAW 1 wire
  - PWHT min
  - PWHT min+SC
- **Impact Absorbances:**
  - 1W-BSC
  - 1W-ASC
  - 54J
- **Temperature Cooling Rates:**
  - 1h, 6h, 15h, 24h, 60h, 100h, 28°C/h, 3° C/h, 6°C/h, 6°C/h, 56°C/h
- **Impact Values:**
  - Free, 1W, 1W-ASC, 54J
Segment SOLUTIONS literature

- OERLIKON Market Solutions Literature

- 8 Industrial Segments
  - Oil & Gas
  - Pipe Mills
  - Shipbuilding
  - Cranes and Heavy Lifting Equipment
  - LNG and Cryogenic Gas Storage
  - Petrochemicals
  - Wind Energy
  - Pipe Laying - new
  - Next: Power Generation

- Available printed or on line: OERLIKON web site
  
Claude Bouillot
claude.bouillot@airliquide.com
ALW Key Segment Manager
Power Generation & Petrochemicals