Use of (P)ECM on Titanium applications

Hans-Henk Wolters
CEO ECM Technologies

Titanium conference
May 20th 2014
Flow of electrons

Anode

Dissolution of metal from anode

Me^{n+}

Me^{n+}

Cathode

Deposition of metal on cathode

Me

Me

Metal salt solution

Michael Faraday (1791-1867)
The founding father of the modern ECM technique
Flow of electrons

Anode

Dissolution of metal from anode

Metal salt solution

Cathode

Deposition of metal on cathode

Flow of electrons

Me

Men+
ECM ANIMATION
Process characteristics 1/2

- Tool has the “inverse shape” of the end products
- High dimensional accuracy feasible
  - Repeatability extremely high
- Product free of burrs after electrochemical machining
- Product machined without any contact
  - No physical strain
  - No thermal load
- No HAZ or toplayer deformation
- 3D complex shape machined with 1 single axis
- High surface quality feasible Ra<0.02 micrometer depending on type of material
- Additional freedom in design by using ECM
Process characteristics 2/2

- Process MRR is not depending on hardness or toughness of the material nor pre hardening
- High MRR at relatively low costs
  - MRR is roughly 1.5 cm³/min at 1000 Amps DC, systems are known from a few Amps up to 10,000’s of Amps
  - Material type has a limited influence on the MRR (max factor 3-4)
- “No” tool wear
  - Tool is cathodic protected and is not physically or thermally loaded during the process
Stainless Steel
Steel grades
Hard metal
Tungsten (carbide)
Cobalt (alloys)
Nickel (alloys)
Titanium (alloys)
Aluminum (alloys)
AlNiCo
Molybdenum
Copper (alloys)
Other conductive materials/metal

Additive machined manufactured materials
e.g. Ti grades, Inconel, TiAl, CoCr etc
Are you dealing with:

- Products with complex and precise geometries
- Tough or impossible to machine alloys by conventional machining
- Higher production numbers

Your product might benefit from an ECM process.
DEVELOPMENT STEPS

Fundamental research; 2nd of 5 phases

Application research; 3rd of 5 phases
Material characteristics

- Electrical parameters
  - Current (density)
    - DC, pulsed, bipolar
  - Pulse length
  - Pause length
  - P/P ratio
- Electrolyte parameters
  - Temperature
  - pH
  - Conductivity
  - Salt type (single/mixtures)
    - Passivating/non-passivating
- Measurements
  - Efficiency
  - Surface quality
  - Surface roughness
  - SEM analysis
ECM Technologies
Innovative Electrochemical Machining Solutions

material:
Q_{spec}: 4667 C.g^{-1} (based on: Fe^{2+}, Cr^{6+}, Mo^{6+}, Mn^{2+}, C^{6+}, Si^{4+})
date: May 31, 2010
electrolyte: 3M NaNO_{3} (255 g.L^{-1})
temperature: 24°C
flow: 1.8 L.min^{-1} (15 m.s^{-1})
gap: 200 μm
cathode: platinum
cathode area: 0.342 cm^{2}
anode area: 0.339 cm^{2}
current: pulsed current
power supply: Munk

3M NaNO_{3}
pulse on = 10ms, pulse off = 40ms

specific mass removal (mg/cm^{2})
current density (A/cm^{2})
sample 516 529 517 530 518 531 519 532 526 520 533 527 534 528 521 522 523 524 525
---
current density (A/cm^{2}) 13.6 19.2 25.4 30.7 37.2 42.5 48.7 54.9 64.6 69.6 76.7 80.8 87.9 92.0 98.8 112.7 126.8 141.0 154.0
 spec. mass removal (mg/cm^{2}) 0.024 0.044 0.053 0.068 0.112 0.133 0.157 0.163 0.170 0.170 0.173 0.173 0.173 0.175 0.176 0.177 0.177 0.178
 current efficiency (%) 11.1 20.3 24.8 31.9 52.4 61.9 73.1 76.2 79.3 79.5 80.6 80.6 80.9 81.6 81.5 82.0 82.5 82.7 82.9
Anode reaction: $\text{Me} \rightarrow \text{Me}^{n+} + \text{ne}^{-}$
Anode reaction: \[ 6\text{H}_2\text{O} \rightarrow \text{O}_2 \uparrow + 4\text{H}_3\text{O}^+ + 4\text{e}^- \]
Step 1: high speed machining, $v \approx 2.5$ mm/min at 150A/cm$^2$ DC
Step 2: accurate machining
Step 3: polishing
Additive Manufacturing combined with ECM

FUNDAMENTAL RESEARCH
- EBM Ti64
- EBM Inconel 718
- TiAl
- CoCr

Magnification: 50x
Magnification: 200x
Magnification: 90x, tilted
Inconel 718 untreated
2M NaNO₃
t_{on} = 1ms, t_{off} = 4ms

<table>
<thead>
<tr>
<th>sample</th>
<th>98</th>
<th>99</th>
<th>100</th>
<th>101</th>
<th>102</th>
<th>103</th>
<th>104</th>
<th>105</th>
<th>106</th>
<th>107</th>
<th>108</th>
<th>109</th>
<th>110</th>
<th>111</th>
<th>112</th>
<th>113</th>
<th>114</th>
</tr>
</thead>
<tbody>
<tr>
<td>current density (A·cm⁻²)</td>
<td>15.2</td>
<td>22.8</td>
<td>31.7</td>
<td>37.1</td>
<td>44.2</td>
<td>50.3</td>
<td>56.7</td>
<td>63.4</td>
<td>70.1</td>
<td>76.4</td>
<td>84.0</td>
<td>91.3</td>
<td>96.0</td>
<td>112.1</td>
<td>130.0</td>
<td>147.0</td>
<td>162.2</td>
</tr>
<tr>
<td>eff. mass removal (µg·cm⁻²)</td>
<td>156.4</td>
<td>174.4</td>
<td>189.0</td>
<td>188.6</td>
<td>190.5</td>
<td>191.4</td>
<td>191.5</td>
<td>192.7</td>
<td>193.1</td>
<td>192.7</td>
<td>192.1</td>
<td>192.8</td>
<td>193.1</td>
<td>193.3</td>
<td>194.0</td>
<td>194.2</td>
<td>194.4</td>
</tr>
<tr>
<td>current efficiency (%)</td>
<td>78.3</td>
<td>87.5</td>
<td>94.8</td>
<td>94.6</td>
<td>95.5</td>
<td>96.0</td>
<td>96.1</td>
<td>96.7</td>
<td>96.8</td>
<td>96.7</td>
<td>96.4</td>
<td>96.7</td>
<td>96.9</td>
<td>97.0</td>
<td>97.3</td>
<td>97.4</td>
<td>97.5</td>
</tr>
</tbody>
</table>
Microstructure

<table>
<thead>
<tr>
<th>Feature</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter pilar</td>
<td>60-70 μm</td>
</tr>
<tr>
<td>Centre centre distance</td>
<td>200 μm</td>
</tr>
<tr>
<td>Height pilar</td>
<td>250 μm</td>
</tr>
</tbody>
</table>

Process time: 12 min
Thin wall profile
   Thickness=60, 45, 30 & 15 μm
   Length=7mm
   Height=1,5 mm
Process time: 45 min
Polished part
Ra < 0.02 μm
Process time: < 1 min
Polished part of an Additive Manufactured Ti64 dental implant

Technology: Plasma Polishing
INTERNAL COOLING RIBS: HEATER HEADS
ELECTRODE IN COMBINATION WITH SUPER ALLOY: HEAT EXCHANGER
HEAT EXCHANGER CELL

PROCESS TIME: 6 MIN
FUEL CELL
TURBOCHARGER
Turbine wheel

Process time: 12 min
Additive manufacturing combined with ECM

pECM of EBM Ti64 strip at different depth

- 200μm
- 400μm
- 600μm
- 800μm
800μm
Conclusions & recommendations:

The Ti 6-4 material made with the EBM process can be electrochemically machined in a NaNO3 electrolyte with high effective mass removal for the entire current density range investigated.

The initial rough EBM structure can be removed by machining to a depth of roughly 800μm.

The fundamental dissolving behavior of EBM Ti64 compared to sheet Ti64 is comparable but differs in behavior for the first 200-250μm.

Follow up research should be applied on more complex structures to finish a full part e.g. blades.
Conclusions & recommendations:

Additional research will be required to research the different used AM materials.

ECM finishing of AM components can benefit of the advantages and flexibility of machining parts by AM and benefit of the fast finishing quality of ECM for surface quality and surface details and accuracy.
THANK YOU FOR YOUR ATTENTION!

For more information please visit

www.electrochemicalmachining.com

Hans-Henk Wolters
CEO ECM Technologies

May 20th 2014
JET ECM movie
- Nozzle diameter 100 µm
- Total length 218 mm
- Groove width 190 µm
- Depth 50 µm
- Electrolyte NaNO₃
- Rz ≈ 1 µm and Ra ≈ 0,1 µm
- Edge Radius ca. 3,5 µm