Training : Laser Melting and Conformal Cooling

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Content and Objectives of the training

Summary

Advantages in using DMLS
Different Case Studies:
   Technimold, Pernoud, MBP, SECO, NewPIM
Heat transfer and heat/cold process in injection
DMLS material behaviors and material requirements for tooling
   Fatigue problematic
Rules and Methods for conformal cooling:
   DMLS rules
   Guidelines for conception
   Fluidic, thermal and mechanical Simulation
   Hybrid tooling
   Post processing
Advantages to in using DMLS

Conformal cooling definition

Conformal Cooling : Wohlers 2012

“One such beneficial method is to create conformal-cooling channels within the tool. These channels allow coolant to pass through the mold in passages that conform to the shape of the mold cavity”
Advantages to in using DMLS

Advantages for injection tools

Why to use DMLS tooling?

Shape complexity (internal and external)
Faster cycle time
Thermal homogeneity
Better surface quality
Less deformation
Better accuracy
Less scrap parts
Advantages to in using DMLS

Advantages for injection tools
Advantages to in using DMLS

**Advantages for injection tools**

**Why to use DMLS tooling?** Design and production of cooling channels with free shape in order to optimize the control of the temperature

Concerned part of the mold:
Core and cavity
Pin
Mobile mold inserts
Every kind of molded elements
Sprue Bushing channel (buses)

=> Parts which need more time to decrease temperature (Hot Dot)

**Commercial Arguments:**
- Important improvement of the injected **cycle time** *(10 à 40%)*
- Part **quality** improvement (accuracy, best surface quality, decrease of residual stress)
- Decrease the number of cycle for the **thermal stabilization** of the mold : less scrap parts at the start of the production
- **Speed up the time and decrease the cost** of the tool adjustment stage
- alternative of the Beryllium Copper in the tools
Advantages to in using DMLS

Tool examples and applications

Cosmetic
Bottle closure
Electronic Box
Medical
...

![Medical Application Pin](image)
![Cosmetic packaging closure Pin](image)
![Blowing tool](image)
![Pin 4 mm](image)
DMLS process

Selective Laser Melting Machine

Conformal cooling training
DMLS process

Selective Laser Melting Machine

Arcam * (Not laser, EBM – Electron Beam Melting)

EOS - Projet UFFO

EOS - Projet RC2

Phenix
DMLS process

Selective Laser Melting Machine

**EOS machine data:**
- Build volume: 250 x 250 x 215 mm
- 250 x 250 x 325 mm for M280
- Accuracy: +/- 0.05mm
- Layer thickness: 20 ou 40 µm

**Phenix machine Data:**
- Build volume: 250 x 250 x 300 mm
- Accuracy: +/- 0.05mm
- Layer thickness: 20, 40 et 80 µm

**Usual powder:**
- Maraging steel (1.2709)
- Stainless steel 1.4545 PH1

For other applications:
- CoCr, Ti6Al4V, Inconel, Aluminium…
DMLS process

Other additive manufacturing Machine

Selective Laser melting, Lasercusing:

Data from Wohlers 2012

Conformal cooling training
Metal AM process

Other additive manufacturing Machine

Digital Part Materialisation (3D printing) : Exone
Build volume : 780 x 400 x 400 mm
Quality surface : 300 Ra
Density : >95%
Use a binder, then infiltration

Conformal cooling training
Direct Metal Deposition (Cladding) : POM Group, IREPA, OPTOMEC

Build volume : 2000 x 1500 x 800 mm  
Accuracy : +/-0,1mm  
Density : 99,9%  
Repair  
SS 316L, INCONEL, Ti, H13....
## DMLS process

### Other additive manufacturing Machine

**Selective Laser melting, Lasercusing:**

- **Concept Laser**
- **SLM-solutions**
- **Renishaw**
- **3D Systems**

<table>
<thead>
<tr>
<th></th>
<th>EOS</th>
<th>Phenix</th>
<th>Concept laser</th>
<th>Renishaw</th>
<th>SLM-solutions</th>
<th>3D Systems</th>
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<tbody>
<tr>
<td><strong>Process time</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>for 125mm cube</td>
<td>1 to 2 days</td>
<td>Application</td>
<td>2.5 days</td>
<td>Application</td>
<td>Application</td>
<td>2 to 3 days</td>
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<td></td>
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<td>dependent</td>
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<td><strong>Density</strong></td>
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<td></td>
<td>To approx.</td>
<td>&gt;99%</td>
<td>&gt; 99.5%</td>
<td>99 to 100%</td>
<td>99 to 100%</td>
<td>98 to 100%</td>
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<td></td>
<td>100% (99.8%)</td>
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<tr>
<td><strong>Materials</strong></td>
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</tr>
<tr>
<td></td>
<td>Tool Steel,</td>
<td>stainless</td>
<td>CoCr, Ti</td>
<td>Ni alloy, Al</td>
<td>With infiltration</td>
<td></td>
</tr>
<tr>
<td></td>
<td>steel,</td>
<td>alloys,</td>
<td>alloy, Al</td>
<td>alloy</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Accuracy</strong></td>
<td>+/- 0.05</td>
<td>+/- 0.05</td>
<td>+/- 0.05</td>
<td>+/- 0.05 over</td>
<td>+/- 0.05 over</td>
<td>+/- 0.25</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>100</td>
<td>100</td>
<td>Par 25mm</td>
</tr>
<tr>
<td><strong>Surface finish</strong></td>
<td>9</td>
<td>?</td>
<td>7</td>
<td>&lt;10</td>
<td>&lt;10</td>
<td>50</td>
</tr>
<tr>
<td><strong>R_a</strong></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>M280 : 250x250x280</td>
<td>PXL : 250x250x300</td>
<td>M3 : 300x350x300</td>
<td>250x250x350</td>
<td>280x280x350</td>
<td>200x250x125</td>
</tr>
</tbody>
</table>

*Data from Wohlers 2012*
DMLS process

EOS Data for M270 with 1.2709 maraging steel powder

Density of 99.8 % : no residual porosity
After polishing, possibility to have a mirror finish : with new powder, and good position of the part

Hardness : 35 HRC
After aging thermal treatment (3h at 490°C) : 52 HRC
Aging treatment could adapted to the Hardness

Mechanical behavior equivalent with H11 (1.2343, Z38CDV5)

1.2709 Hardness in function of the thermal treatment temperature
Case Studies

Technimold

Injection mold of expansion tank:
Mold dimension: 150x180x120mm (x 2 tools)
Material: PP 20% FV (polypropylene with fiber glass)
Thickness of the part: 3 à 5 mm
Warranty mold: 1 000 000 parts
Initial cycle time: 50s

Goal: Thermal homogeneity

Results:
• Cycle time 40s = Gain of 20%
• Good thermal homogeneity
• Less deformations and decrease of part cost

Conformal Cooling training
Case Studies

Pernoud

Injection mold of instrument panel for car:
Mold dimension: 165x40x175mm (x 2 tools)
Material: PA 6.6 (polyamide)
Part thickness: 3 à 5 mm
Warranty mold: 1 000 000 parts
Initial cycle time: 70s

Goal: less than 50s of cycle time

Results:
• Cycle time 43s = Gain of 35%
• Thermal homogeneity of injected part
• Better surface quality, less deformation, decrease of the cost of the part
Case Studies

MBP

Extrusion blow molding:
Mold dimension: 160x60x30mm (x 8 cavities)
Material: PE (Poly Ethylene)
Part thickness: -
Warranty mold: 1 000 000 parts
Tool built with 20µm layers

Goal: decrease cycle time, complex shapes

Results:
• Gain of 20% of cycle time
• Molding surfaces have been only Polished: good shape accuracy
Case Studies

SECO

Injection Mold for Minicup:
- Mold dimension: diameter 150 mm
- Material: PP
- Thickness of the part: 0.5 mm
- Mirror finish by polishing
- Initial cycle time with CuBe: 4 sec

Goal: same cycle time

Results:
- Cycle time = 3.9 sec (No more limited by the cooling time)
- No more part in Copper

Conformal Cooling training
Case Studies

**Alliance**

**Powder Injection Molding (PIM):**

- **Mold dimension:**
  - 50x Diameter 50mm
  - 70x50x60mm
- **Material:**
  - PC
  - Catamold 316LG (64% 316L, 36% POM+PE)
- **Thickness of the part:** 2 mm

**Goal:** test hot-cold system

**Results:**
- 52 HRC is enough for PIM
- Gain only 5% for conventional cooling
- Gain until 80% for heat and cool system
- Better surface quality
Case Studies

Alliance

Remind of PIM process:

Feedstock:
~ 60% of powder
+ 40% of polymer binder

Injection Molding

Binder Remove

Powder Sintering

Conformal Cooling training
Case Studies

Some other cases

Good welding

Gain 10% on optimized mold

Gain 20%

Cooling the spure

Thin pin (2.1mm of thickness)

Gain 10%, cost overrun 4 months

Conformal Cooling training
DMLS material behaviors

EOS MS1, Maraging steel behaviors

Compare with a standard tool steel

<table>
<thead>
<tr>
<th>Property</th>
<th>Maraging steel without thermal treatment</th>
<th>Maraging steel after thermal treatment</th>
<th>H11 (Z38CDV5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young’s modulus</td>
<td>180 Gpa</td>
<td>210 Gpa</td>
<td></td>
</tr>
<tr>
<td>Elongation at break</td>
<td>8%</td>
<td>2%</td>
<td>9%</td>
</tr>
<tr>
<td>Ultimate tensile strength</td>
<td>1100 Mpa</td>
<td>1950 Mpa</td>
<td>1990 Mpa</td>
</tr>
<tr>
<td>Hardness</td>
<td>34 HRC</td>
<td>50-54 HRC</td>
<td>56 HRC</td>
</tr>
<tr>
<td>Fatigue</td>
<td>270 Mpa</td>
<td>300 Mpa</td>
<td>~400 Mpa</td>
</tr>
</tbody>
</table>
DMLS material behaviors

EOS MS1, Maraging steel behaviors

The fatigue behavior of EOS MS1 has been tested in bending (with R=-1) and compared with usual values of the maraging steel.

Samples after 380,000 cycles with 600 MPa

INFO – Fatigue limite :
Tool steel ~ 400MPa
Aluminium alloy 175MPa

<table>
<thead>
<tr>
<th>Thermal Aging</th>
<th>Test Temperature (°C)</th>
<th>Young’s Modulus (GPa)</th>
<th>Plasticity stress Rp0,2 (en MPa)</th>
<th>Ultimate tensile strength (MPa)</th>
<th>Elongation at break (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before</td>
<td>20</td>
<td>166</td>
<td>1070</td>
<td>1175</td>
<td>8</td>
</tr>
<tr>
<td>After</td>
<td>20</td>
<td>186</td>
<td>2016</td>
<td>2088</td>
<td>3.16</td>
</tr>
</tbody>
</table>

Conformal cooling training
Rules and Methods

Planning sheet

1. CAD – thermal study of the part with rheological software
2. Fluidic study of the channels with FLOWORKS
3. Manufacture of the part with DMLS
4. Post treatment by machining
5. Control of the rate flow and thermal behaviors of the SLM inserts
6. Thermal treatment

Conformal cooling training
Rules and Methods

**Fluidic, thermal and mechanical Simulation**

**Fluidic problematic : friction loss**

**Interest of parallel cooling channel :**
- Positive: decrease of friction loss
- Negative: risk of partial obstruction,
  - difficulties to clean,
  - need to have enough flow rate
  - need to balance the channel

**Conclusion :**
Use of parallel channels in limited zones
Be careful of the balance with friction loss
Need fluidic simulation

**Design fluidic law :**

\[ S_{in} = S_{out} = \sum S_{channel\_i} \]
Rules and Methods

Fluidic, thermal and mechanical Simulation

Fluidic problematic

Example of values :
- Standard value for channels : diameter 4 mm,
- Diameter of 1,5mm minimum for water (2mm for oil, for small channel),
- Diameter of 0,6mm minimum for air (0,3mm in z direction).

Recommendations for mold makers :
- Use glycol water
- Filter in input and in output for channel with small diameter (< 1mm)
- Control flowmeter for each channel

Remark :
- maintenance more difficult than with standard channel : no possibility to remachining or made channel modification.
- => Acid cleaning or cut the defective part of the tool and rebuild
Rules and Methods

Fluidic, thermal and mechanical Simulation

Thermal simulation examples: on tool and part

Floworks cycling thermal simulation
With integration of the thermal data of the polymer part
Rules and Methods

Fluidic, thermal and mechanical Simulation

**Mechanical problematic: fatigue behavior**
No stress more than 300MPa

Bad exemple for SLM: fine tool made with AMPCO (Berrilium copper), Zone to cooling < 5mm

Conductivity Problem:
AMPCO 50W/m/K
1.2709 15W/m/K

For iso thermal behavior (same max temperature), need to be near the mold surface

=> Important increase of stress: to plasticity deformation, so above the fatigue limit of 300MPa
Rules and Methods

Control

**Laser Melting part control**

Friction loss analysis: measure with special bench the loss of pressure between the input and the output in function of the flow rate.

Storage of the data files to compare the evolution during the time.

Possibility to work like cold/hot system.

![Diagram of a cooling system](image)
Rules and Methods

Control

Laser melting part control:
Bench with a thermography can be used to evaluate the efficiency of the channel

For parallel channels, compare the different channels, detect obstruction
**Rules and Methods**

### Post processing

Evaluation of part post processing and comparison with the H11 (Z38CDV5):
Nota: internal thread (tapping) are often made before hardening thermal treatment

<table>
<thead>
<tr>
<th>Post treatment</th>
<th>Melted maraging</th>
<th>H11 steel (Z38CDV5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weldability</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Graining</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Machining</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Spark machining</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Polishing</td>
<td>+ (Ra~0,04)</td>
<td>++</td>
</tr>
<tr>
<td>Physical Vapor Deposition (PVD)</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Thermo-chemical treatment</td>
<td>-</td>
<td>++</td>
</tr>
</tbody>
</table>

*ToolMakers knowledge*
Conformal Cooling

Synthesis

Different kind of application:
packing, Electronic, Automotive, Products of consumer market...

Kind of parts:
Jug, Electronical case, part of air supply, Airbag part, Core pin, Car part
(engine compartment or passenger compartment)...

Goals:
Cycle time decrease, Remove CuBe, Improve thermal homogeneity of part.

Standard gain of cycle time between 10 and 40%, in many case 15 and 20%.

Production gain linked: 15 to 100k€/Year.

Laser melting cost overrun: 5k€ to 20k€.

Return on investment: 2 to 9 months.
Conformal Cooling

Synthesis:

A growing market!

<table>
<thead>
<tr>
<th>Year</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
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</thead>
<tbody>
<tr>
<td>PEP Nbr d'applications outillage SLM</td>
<td>6</td>
<td>15</td>
<td>50</td>
<td>90</td>
<td>110</td>
<td>145</td>
</tr>
</tbody>
</table>