Innovative Lead Time and Cost Efficient Tools and Dies for Lightweight Autobody Components

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3D metal printing: current possibilities and limitations
Business cases: conventional process vs 3D printing of automotive stamping tools & dies
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Car Production

- Car body components
- Body Shop
- Painting
- Final Assembly
- Powertrain
- Interior
- Customer
FOCUS IN THIS PRESENTATION
Tools and Dies for Car Body Components Production

Ultra-High-strength hot-formed steel
Extra-high-strength steel
High-strength steel
Ultra-high-strength steel
Ultra-high-strength steel
Aluminium
FACTS & FIGURES

Car Body Tools & Dies

- Ca 120 new car models per year
- 750 dies per model
- **4050 tons grey/nodular iron per model** (5.4 tons grey/nodular iron per die)
- **450 tons tool/die steel per model** (0.6 ton tool/die steel per die)
- Investment in car body dies for each
  - completely new car model = m€ 100-140
  - new die = 130 k€ - 187 k€
- Current lead time for stamping tools & dies per car model = 10-12 months
Lead Time (or Time to Market) Reduction

Volvo Cars Target

1991
Volvo 850 – 60 months

1998
Volvo S80 – 50 months

2012
New S80 – 40 months

2020
– 20 months

Courtsey of Volvo Cars
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Product Development
Product Development

Source: Autoform Engineering, www.autoform.com
Product Development

Calmax + plasma nitriding + CrN (PVD) (Calmax + Duplex treatment)

Inserts in Calmax

CVD -coated insert

Forming die - B-pillar, Volvo Cars

Source:
Nader Asnafi: “Tooling and Technologies for Processing of Ultra High Strength Sheet Steels”, Conf. Proc. of Tools and Technologies for Processing Ultra High Strength Materials, Sept 19-21, 2011, Graz, Austria, At Graz, Austria
Product Development

Forming die - B-pillar, Volvo Cars

Is it possible to 3D print these die segments?

Source:
Nader Asnafi: “Tooling and Technologies for Processing of Ultra High Strength Sheet Steels”, Conf. Proc. of Tools and Technologies for Processing Ultra High Strength Materials, Sept 19-21, 2011, Graz, Austria, At Graz, Austria
Product Development

Cold work tool/die failure mechanisms

- **Wear**: Abrasive, adhesive or mixed, Sliding contact
- **Chipping**: Cracking at cutting edges and corners, Fatigue
- **Plastic deformation**: Exceeding yield strength locally, Contact pressure
- **Cracking**: Total cracking of the tool, Fatigue
- **Galling**: Material pick-up (same mechanism as in adhesive wear), Sliding contact

Source:
Nader Asnafi: “Tooling and Technologies for Processing of Ultra High Strength Sheet Steels”, Conf. Proc. of Tools and Technologies for Processing Ultra High Strength Materials, Sept 19-21, 2011, Graz, Austria, At Graz, Austria
## Product Development

<table>
<thead>
<tr>
<th>Concept/ Styling</th>
<th>Product Design</th>
<th>Production Planning</th>
<th>Process Engineering</th>
<th>Tool Design &amp; Manufacturing</th>
<th>Tryout</th>
<th>Part Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forming dies</td>
<td>Trim dies</td>
<td>Restrike/Flange dies</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Sheet materials
- X

### Operational severity
- X

### Lubrication
- X

### Production volume size
- X

### Tool/die

<table>
<thead>
<tr>
<th>Material</th>
<th>Forming dies</th>
<th>Trim dies</th>
<th>Restrike/Flange dies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Strength</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Machinability</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Polishability</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Surface roughness</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Hardness (initial &amp; after hardening)</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Wear</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Chipping</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Cracking</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Cracking</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Gallling</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Weldability</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Hardenability</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Coating</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>
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3D metal printing: current possibilities & limitations

- The current maximum size of the metal piece to 3Dprint?
- The metallic materials that can be printed?
- Tool/die weight/design: Solid structure vs hollow honeycomb structure?
- The strength of the printed metallic material?
- Surface roughness of the printed metal piece?
- Hardness of the printed metal piece?
- Can the printed metal piece be machined, polished, hardened and surface-coated?
The current maximum size of the metal piece to 3D-print?

Source: 3D Systems, http://www.3dsystems.com/
The metallic materials that can be printed?

Source: 3D Systems, http://www.3dsystems.com/
The metallic materials that can be printed?

Processing is understood but standard build parameters and data sheet are not available. Powder could be stocked but is not today.

Source: 3D Systems, http://www.3dsystems.com/
The metallic materials that can be printed?

Source: 3D Systems, http://www.3dsystems.com/
Maraging steel (1.2709)...

... for production of tools and molds as well as high-performance parts that require high strength and hardness

Applications
- Tools and molds for injecting molding, die casting and extrusion
- High-performance industrial parts, e.g. tire manufacturing and automotive
- High-wear components
- Aerospace

Features
- High strength
- Easily heat treatable
- High hardness
- Good corrosion and wear resistance
- Good weldability and machinability

### Mechanical Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Condition</th>
<th>As-built</th>
<th>After post heat treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultimate Tensile Strength, MPa</td>
<td>ASTM E8</td>
<td>1110 ± 50</td>
<td>2000 ± 50</td>
</tr>
<tr>
<td>Yield Strength, MPa</td>
<td>ASTM E8</td>
<td>860 ± 50</td>
<td>1930 ± 50</td>
</tr>
<tr>
<td>Elongation at break, %</td>
<td>ASTM E8</td>
<td>11 ± 3</td>
<td>~ 1</td>
</tr>
<tr>
<td>Hardness</td>
<td></td>
<td>37 ± 2 HRC</td>
<td>55 ± 2 HRC</td>
</tr>
<tr>
<td>Density</td>
<td></td>
<td>approx. 100%</td>
<td></td>
</tr>
</tbody>
</table>

1. Parts built on a ProX 200 Direct Metal Production Printer
2. As-built refers to the state of components built on the ProX 200 Direct Metal Printer before any post processing except removal from the build platform
3. Recommended post heat treatment at 490 °C for 6 hours (exact time dependent on part volume)

### Chemical Composition

<table>
<thead>
<tr>
<th>Element</th>
<th>% of weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe</td>
<td>Balance</td>
</tr>
<tr>
<td>Ni</td>
<td>17.0 - 19.0</td>
</tr>
<tr>
<td>Co</td>
<td>9.0 - 11.0</td>
</tr>
<tr>
<td>Mo</td>
<td>4.0 - 6.0</td>
</tr>
<tr>
<td>Ti</td>
<td>0.9 - 1.0</td>
</tr>
<tr>
<td>Si</td>
<td>≤ 1.0</td>
</tr>
<tr>
<td>Mn</td>
<td>≤ 1.0</td>
</tr>
<tr>
<td>C</td>
<td>≤ 0.03</td>
</tr>
</tbody>
</table>

Source: 3D Systems, http://www.3dsystems.com/
## Comparison: AISI D2/DIN 1.2379 vs Maraging Steel

<table>
<thead>
<tr>
<th></th>
<th>As delivered/built</th>
<th>After post heat treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AISI D2/ DIN 1.2379</strong>*</td>
<td><strong>Maraging steel (1.2709)</strong></td>
<td><strong>AISI D2/ DIN 1.2379</strong>*</td>
</tr>
<tr>
<td><strong>Yield strength</strong></td>
<td>350-550 MPa</td>
<td>860 MPa</td>
</tr>
<tr>
<td><strong>Ultimate tensile strength</strong></td>
<td>706-870 MPa</td>
<td>1110 MPa</td>
</tr>
<tr>
<td><strong>Fracture elongation</strong></td>
<td>&gt;11% &amp; &lt;20%</td>
<td>11%</td>
</tr>
<tr>
<td><strong>Hardness</strong></td>
<td>210-255 HB</td>
<td>37 HRC</td>
</tr>
<tr>
<td></td>
<td>(18-26 HRC*)</td>
<td></td>
</tr>
</tbody>
</table>

* Sources: matweb.com, steelexpress.co.uk & saajsteel.com

** Compressive yield strength.

*** AISI D2/DIN 1.2379 can be hardened to 62 HRC but maraging steel’s maximum attainable hardness is 55 HRC.
Output quality

Feature resolution: $\approx 150 \ \mu m$

Surface roughness, $R_a$: Controlled.
In many regions $\approx 10-25 \ \mu m$.
Smallest after printing, $R_a = 5 \ \mu m$.
Can be polished as usual to lower $R_a$.

Tolerances: $\approx 50-100 \ \mu m$
Repeatability: $\approx 30 \ \mu m$

Facade on hollow structures: 1.5-2 mm
Can be machined/milled as usual.
How could 3D metal printing be included in the tool/die manufacturing process/production system?

Combine milling with 3D printing:

3D printed section:
- Complex external shape
- Difficult internal conformal cooling channels

CNC machined section:
- Massive and simple structure
- Crossing channels straightness
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C-Bow Lower Progressive Die

Puller

Punch

240

140

58
Punch and Puller Made in a Metallic Material
Punch and Puller Made in Metallic Materials
Conventional Procedure Compared to 3D Printing

CONVENTIONAL PROCESS

**Punch**
Requirements:
- Hardness (after hardening) = 60 HRC
- Surface roughness in the working area = $R_a = 0.8 \mu m$

Material = SS2263 (tempered)

Process:
1: Ordering and home-taking of the material
2: Milling
3: Hardening
4: Wire EDM

Total lead time = 8 working days
Total cost = 10500 SEK

**Puller**
Requirements:
- Hardness (after hardening) = No requirement
- Surface roughness in the working area = $R_a = 2-3 \mu m$

Material = SS2172

Process:
1: Ordering and home-taking of the material
2: Milling
3: Wire EDM

Total lead time = 6 working days
Total cost = 15500 SEK

3D PRINTING

**Punch**
Requirements:
- Hardness (after hardening) = 60 HRC
- Surface roughness in the working area = $R_a = 0.8 \mu m$

Material = Maraging steel (1.2709)

Hardness after 3D Printing = 37 HRC

Hardness after hardening = 55-57 HRC

Surface roughness in the working area after 3D Printing: $R_a = 5 \mu m$

Polishing of the working area to $R_a = 0.8 \mu m$

**Puller**
Material = Maraging steel (1.2709)

Hardness after hardening = No requirement but equal to 37 HRC

Surface roughness in the working area, $R_a = 5 mm$

Process:
1: 3D printing of punch and puller
2: Post-processing
3: Hardening of the punch
4: Polishing of the punch

Total lead time (both punch & puller) = 3.7 days
Total cost (both punch & puller) = 31000 SEK (based on a depreciation period of 5 years)
Punch and Puller Made in a Metallic Material
Conventional Procedure Compared to 3D Printing
Punch and Puller Made in a Metallic Material
Conventional Procedure Compared to 3D Printing
Surface texture – radially generated

When there is no run-out in the cutter, the height of the cusp, \( h \), will be equally high and can be calculated using the formula:

\[
R_t = \frac{f_z^2}{4 \times D}
\]

When there is a run-out in the cutter, the feed per tooth, \( f_z \), and consequently the height of the cusp, \( h \), will vary depending on the TIR.

As mentioned, surface texture and climbing tendencies may limit the feed rate, especially when the radial depth of cut is small.

When using the side of an end mill to mill a profile, a series of ‘cusps’ are generated. The height of the cusp, \( -h \), is determined by:

- Cutter diameter, \( D_c \)
- Feed per tooth, \( f_z \)
- Tool indicator reading of the run-out, TIR.
Surface roughness

Directly after 3D Printing
\[ R_a = 4.92 \, \mu m \]

After 3D Printing and milling at Cusp height 6\( \mu m \)
\[ R_a = 1.08 \, \mu m \]
Surface roughness

After 3D Printing & milling at Cusp height 3μm
$R_a = 1.08 \ \mu m$

After 3D Printing and milling at Cusp height 0.6μm
$R_a = 0.71 \ \mu m$
### Lead Time (Working days)

<table>
<thead>
<tr>
<th></th>
<th>Conventional</th>
<th>3D Printed Honeycomb structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Punch</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Puller</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>8</strong></td>
<td><strong>3.7</strong></td>
</tr>
</tbody>
</table>

### Cost (SEK)

<table>
<thead>
<tr>
<th></th>
<th>Conventional</th>
<th>3D Printed Honeycomb structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Punch</td>
<td>10 500</td>
<td></td>
</tr>
<tr>
<td>Puller</td>
<td>15 500</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>26 000</strong></td>
<td><strong>31 000</strong></td>
</tr>
</tbody>
</table>

Based on a depreciation period (for the 3D-printing machine) of 5 years (incl. a 5 years long warranty)
### Punch and Puller Made in a Metallic Material
Conventional Procedure Compared to 3D Printing

<table>
<thead>
<tr>
<th></th>
<th>Lead Time (Working days)</th>
<th>Cost (SEK)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Conventional 3D Printed</td>
<td>Honeycomb structure</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Punch</strong></td>
<td>8</td>
<td>10 500</td>
</tr>
<tr>
<td><strong>Puller</strong></td>
<td>6</td>
<td>15 500</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>8</td>
<td>26 000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>3.7</td>
<td>29 000</td>
</tr>
</tbody>
</table>

Based on a depreciation period (for the 3D-printing machine) of 10 years (incl. a 10 years long warranty)
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Conclusions

- 3D printing enables a significant lead time reduction for stamping tools & dies.
- The 3D printing costs are somewhat higher but reasonable and are expected to be reduced during the coming years.
- So long there are only 1-2 relevant materials for 3D-printing of stamping tools & dies. These materials need to be tested from different perspectives.
- The possibilities provided by 3D printing need to be explored further.
- The current limitations (size, few relevant materials, quality assurance issues...) need to be addressed.
THANK YOU
FOR YOUR ATTENTION