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

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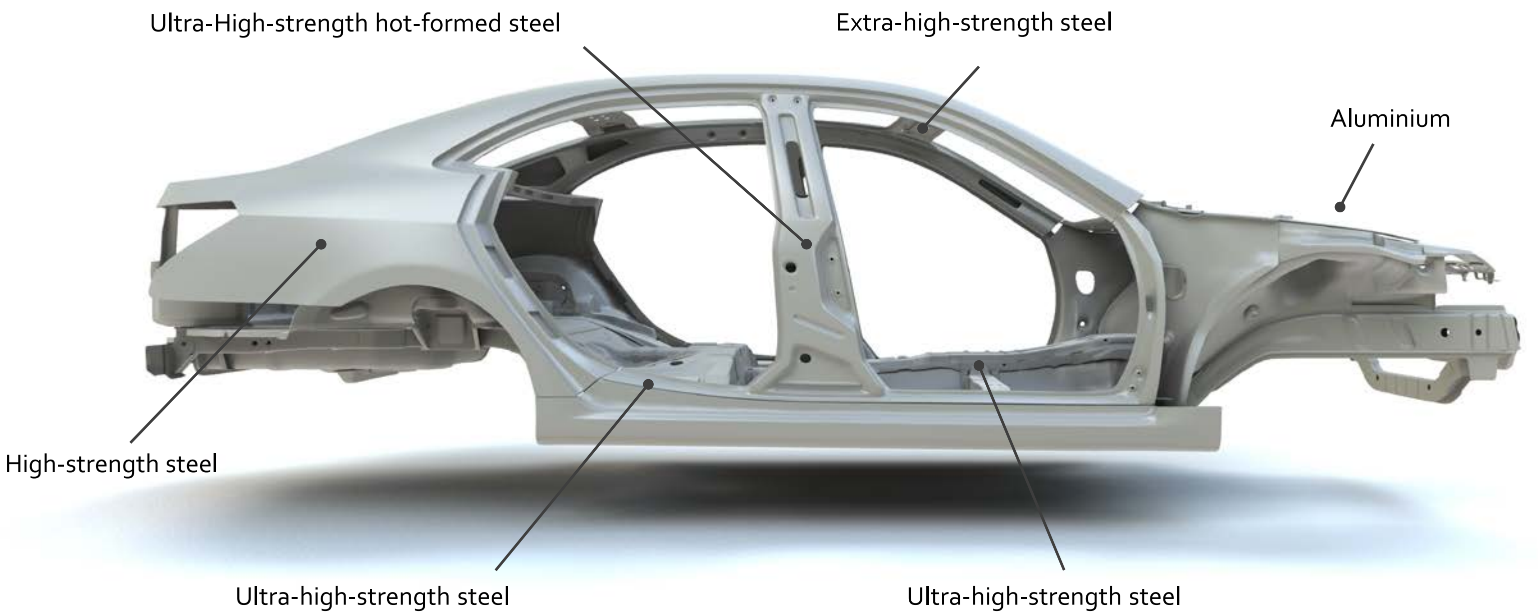
Car Production

Focus in this presentation

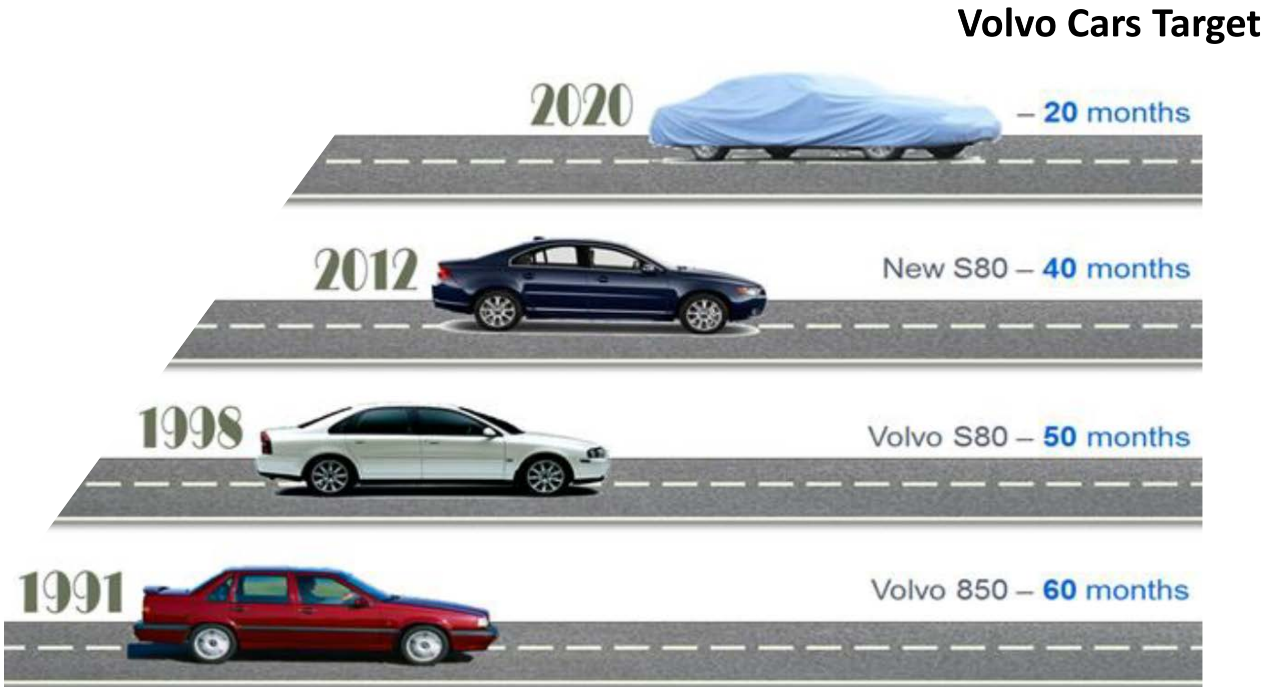
Tools and Dies for Car Body Components Production



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



Courtsey of Volvo Cars

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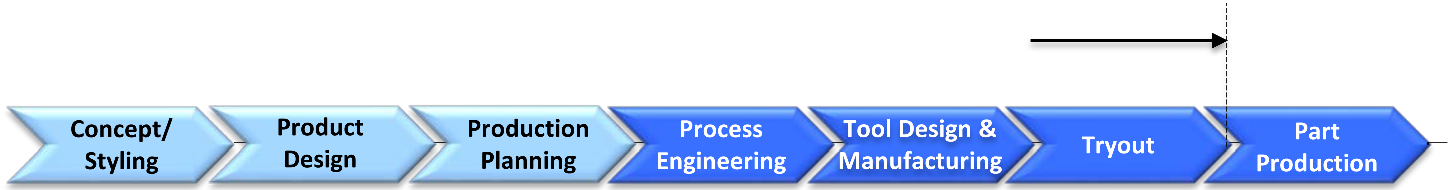
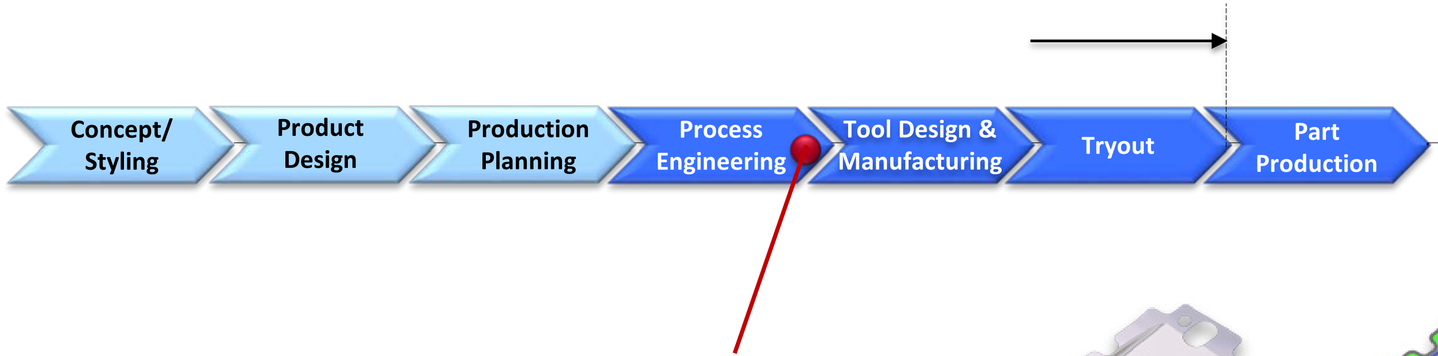
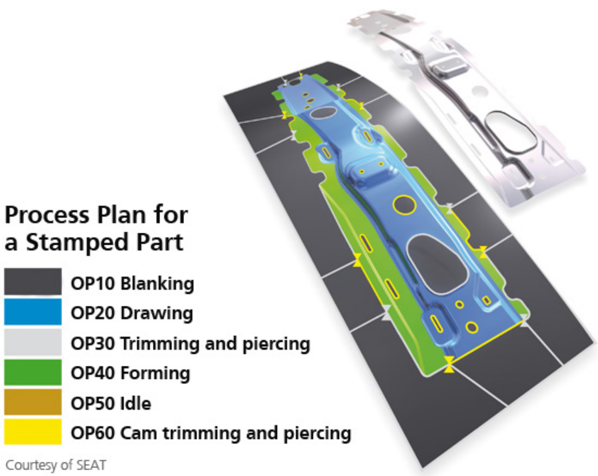
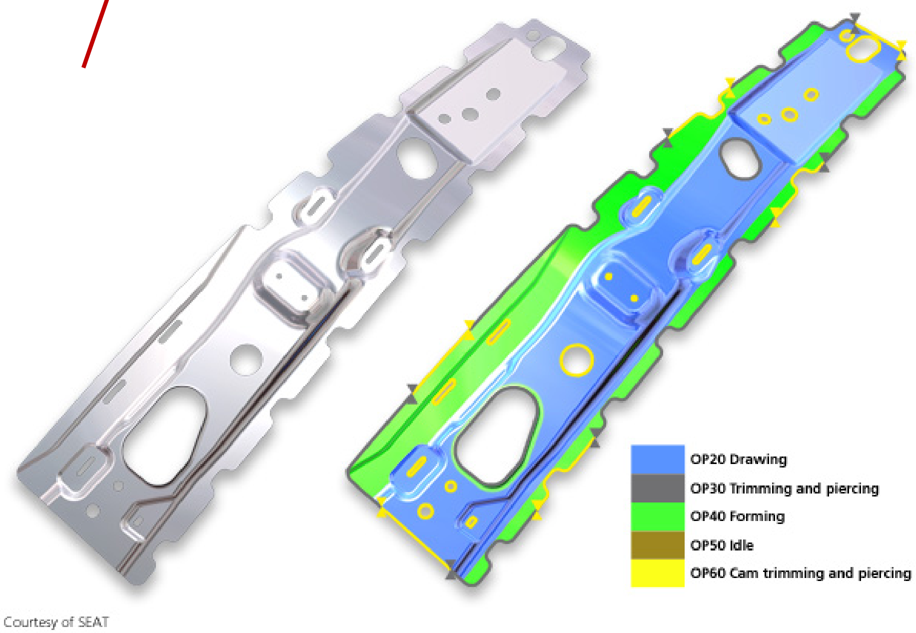
Product Development



Product Development

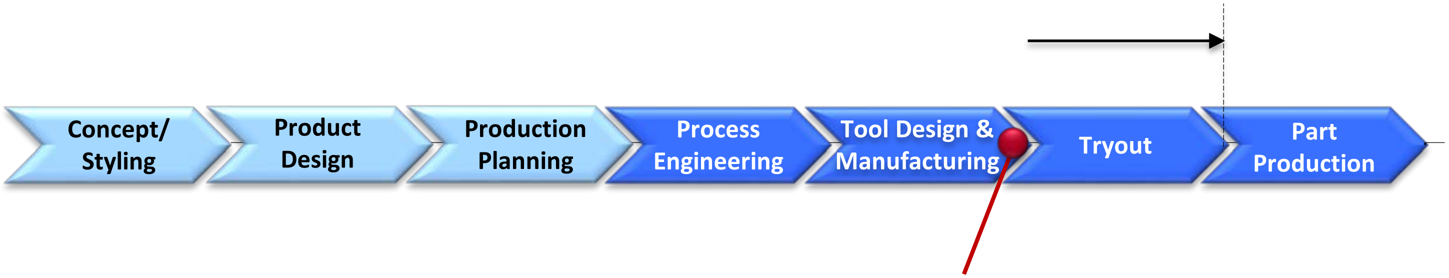




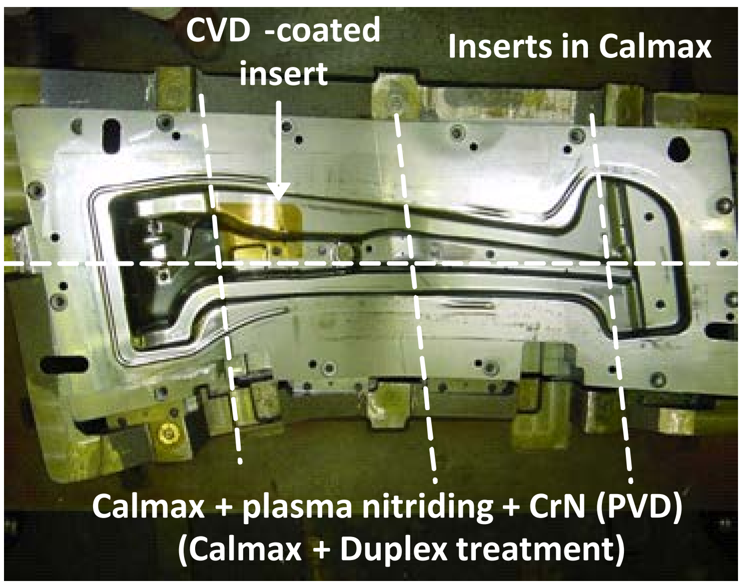


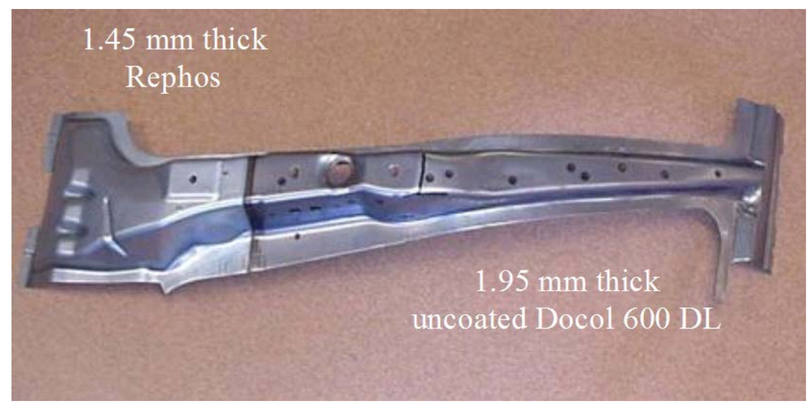
Source: *Autoform Engineering, www.autoform.com*

Product Development



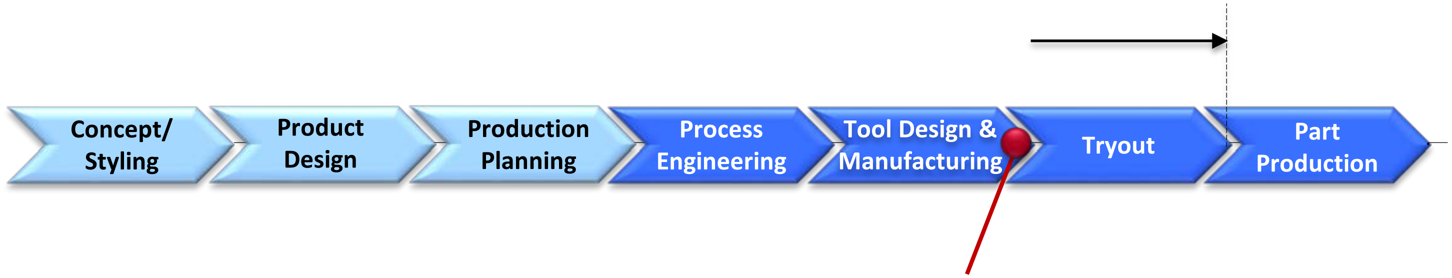
Forming die - B-pillar, Volvo Cars



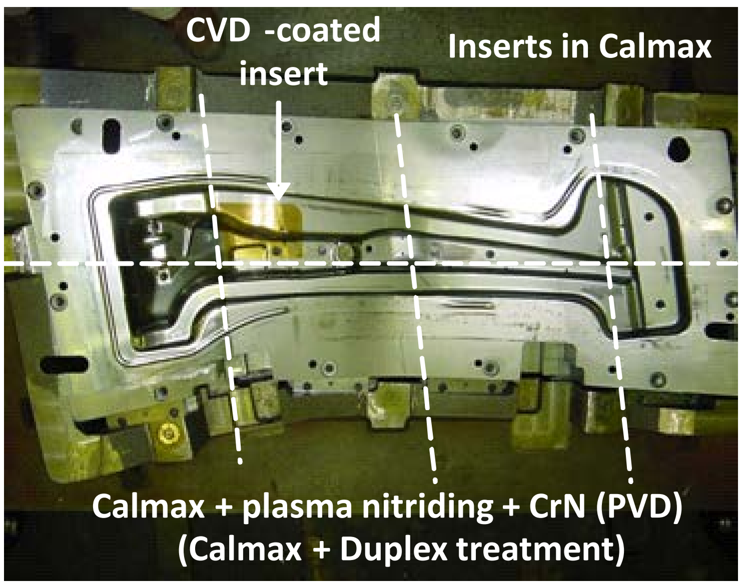


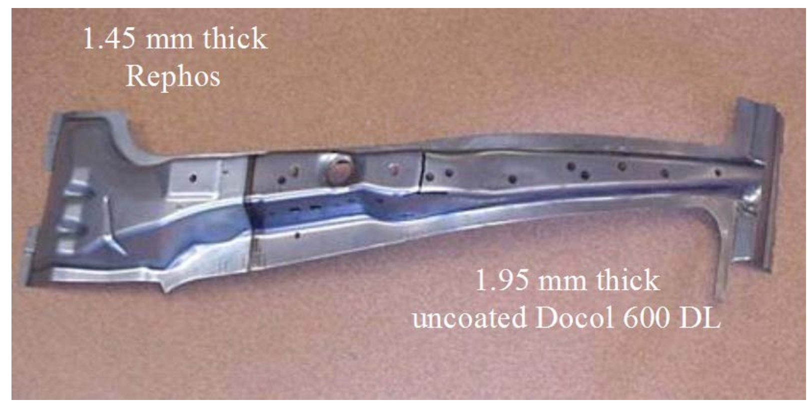
Source:
Nader Asnafi: ”Tooling and Technologies for Processing of Ultra High Strength Sheet Steels”, Conf. Proc. of *Tools and Technologies for Processing Ultra High Strength Materials*, Sept 19-21, 2011, Graz, Austria, At Graz, Austria

Product Development



Forming die - B-pillar, Volvo Cars

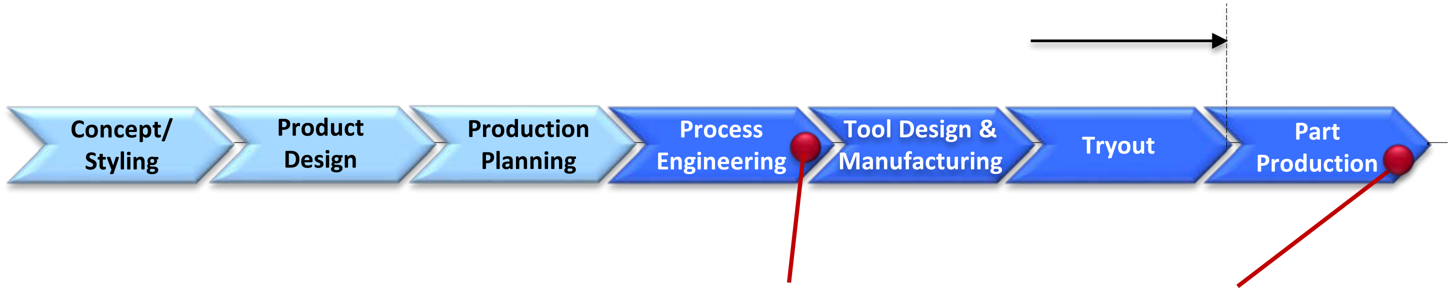




Is it possible to 3D print these die segments?

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

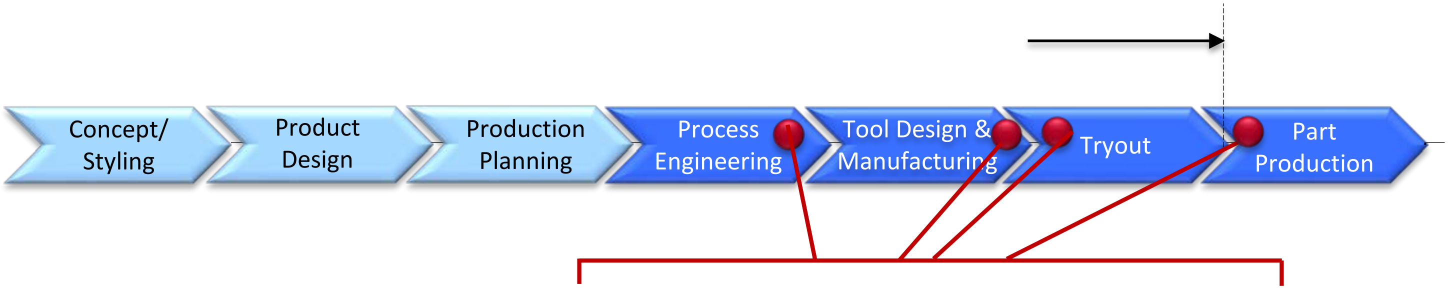


Cold work tool/die failure mechanisms

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



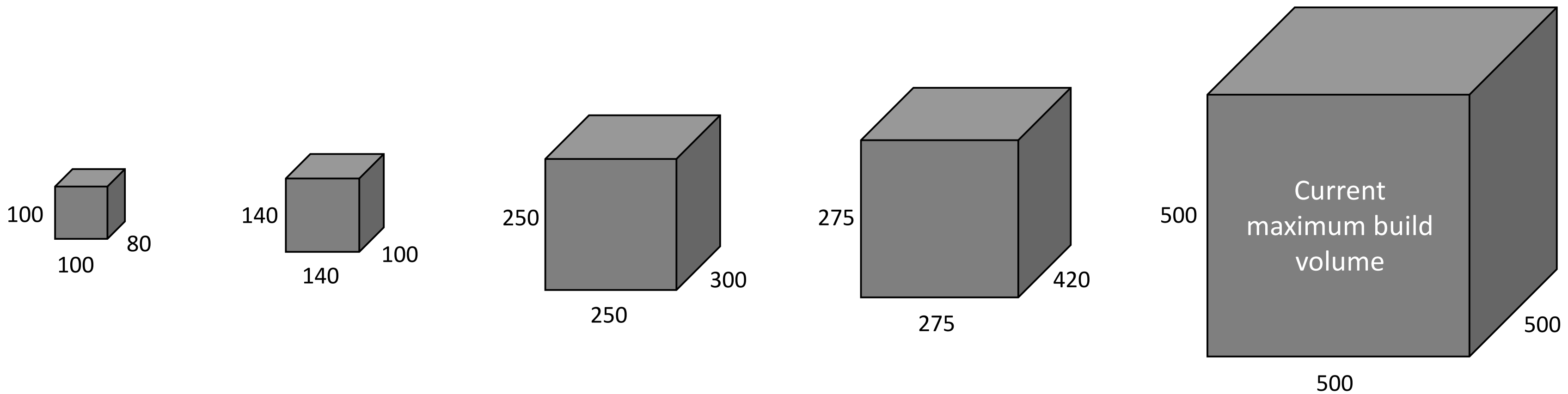
	Forming dies	Trim dies	Restrike/Flange dies
Sheet materials	X	X	X
Operational severity	X	X	X
Lubrication	X	X	X
Production volume size	X	X	X
Tool/die			
Materials	X	X	X
Strength	X	X	X
Machinability	X	X	X
Polishability	X	X	X
Surface roughness	X	X	X
Hardness (initial & after hardening)	X	X	X
Wear	X	X	X
Chipping	X	X	X
Cracking	X	X	X
Galling	X	X	X
Weldability	X	X	X
Hardenability	X	X	X
Coating	X	X	X

Contents

3D metal printing: current possibilities & limitations

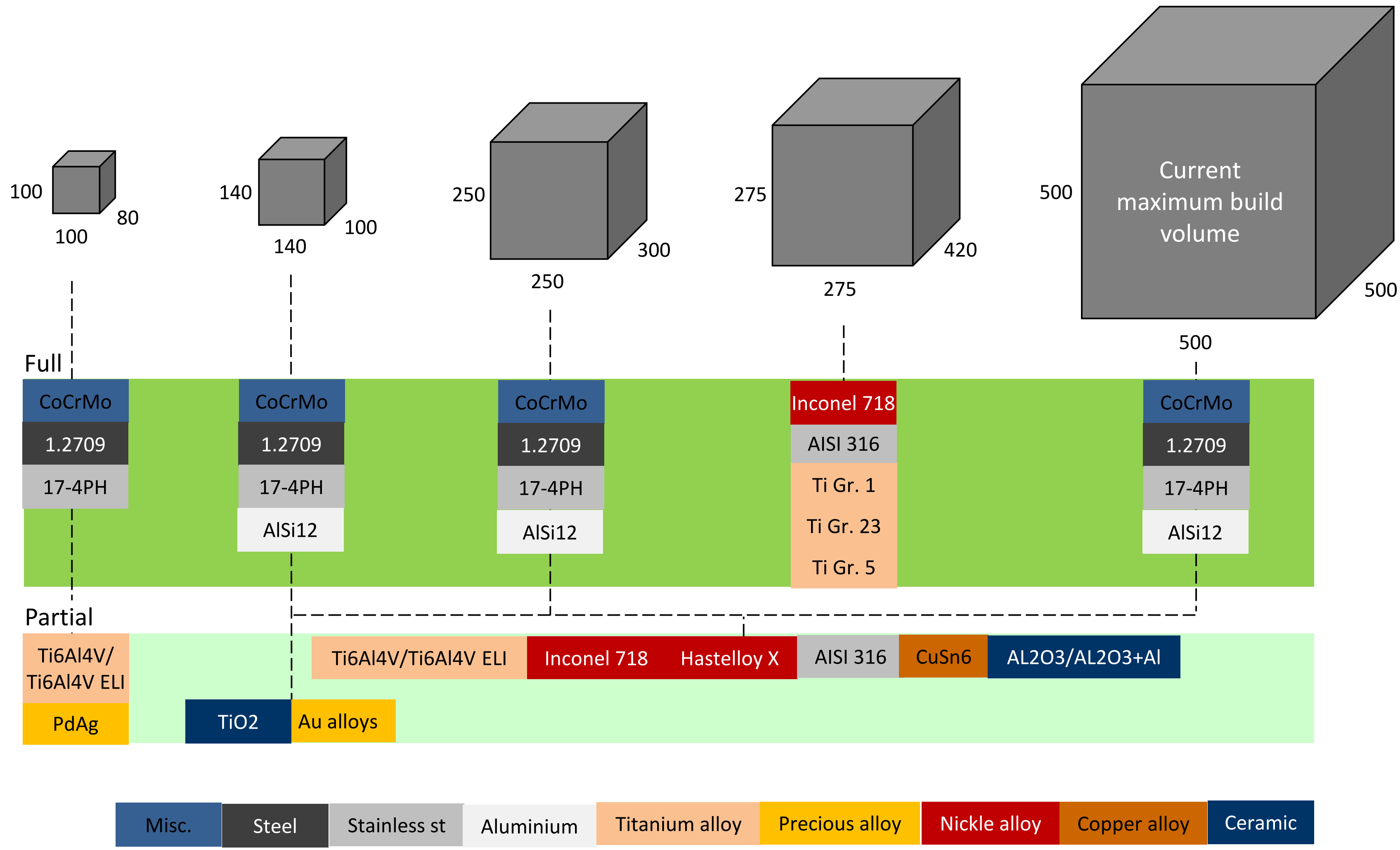
- The current maximum size of the metal piece to 3Dprint?
- The metallic materials that can be printed?
- Tool/die weight/design: Solid structure vs hollow honeycomb structure?
- The strength of the printed metallic material?
- Surface roughness of the printed metal piece?
- Hardness of the printed metal 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?



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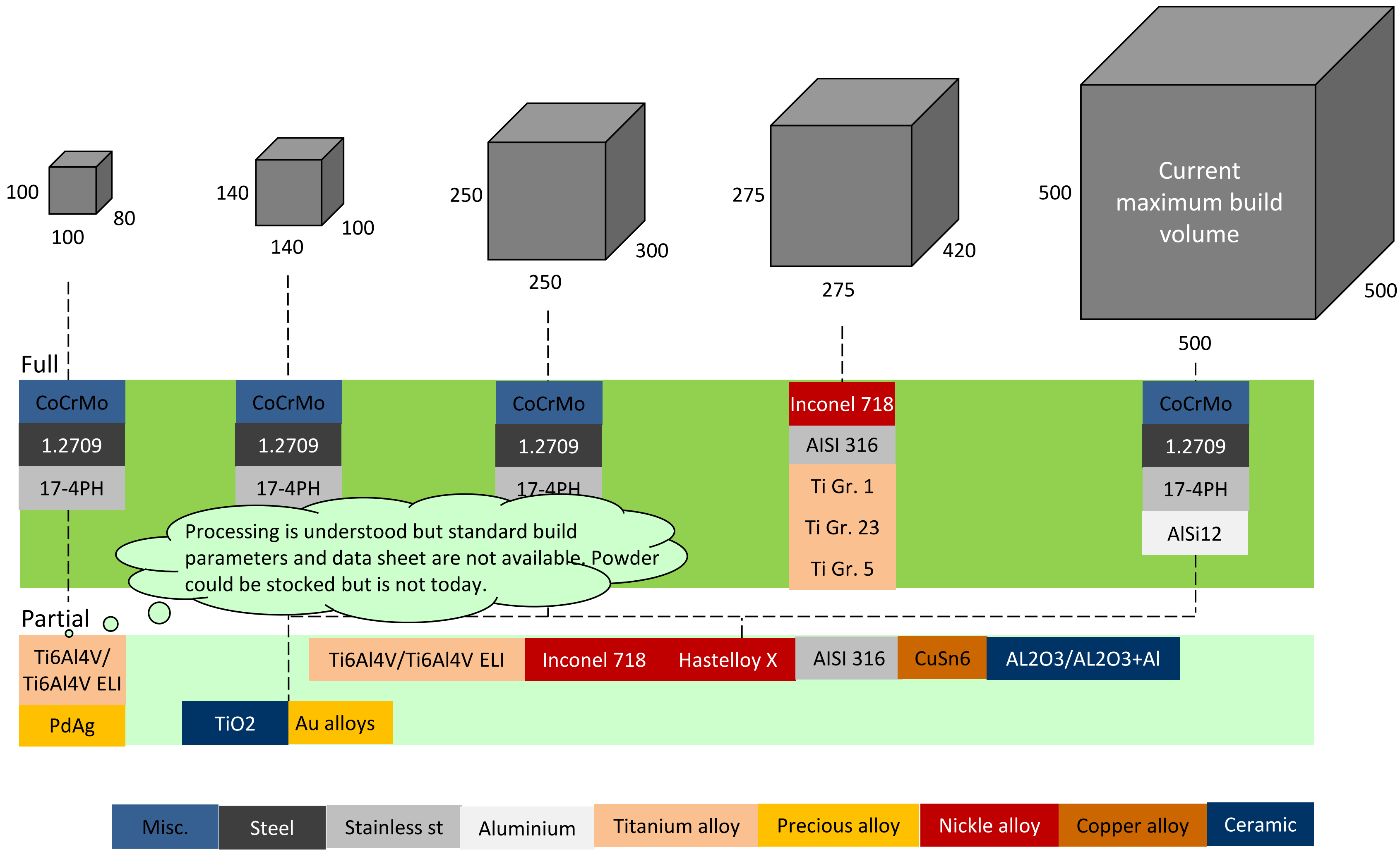
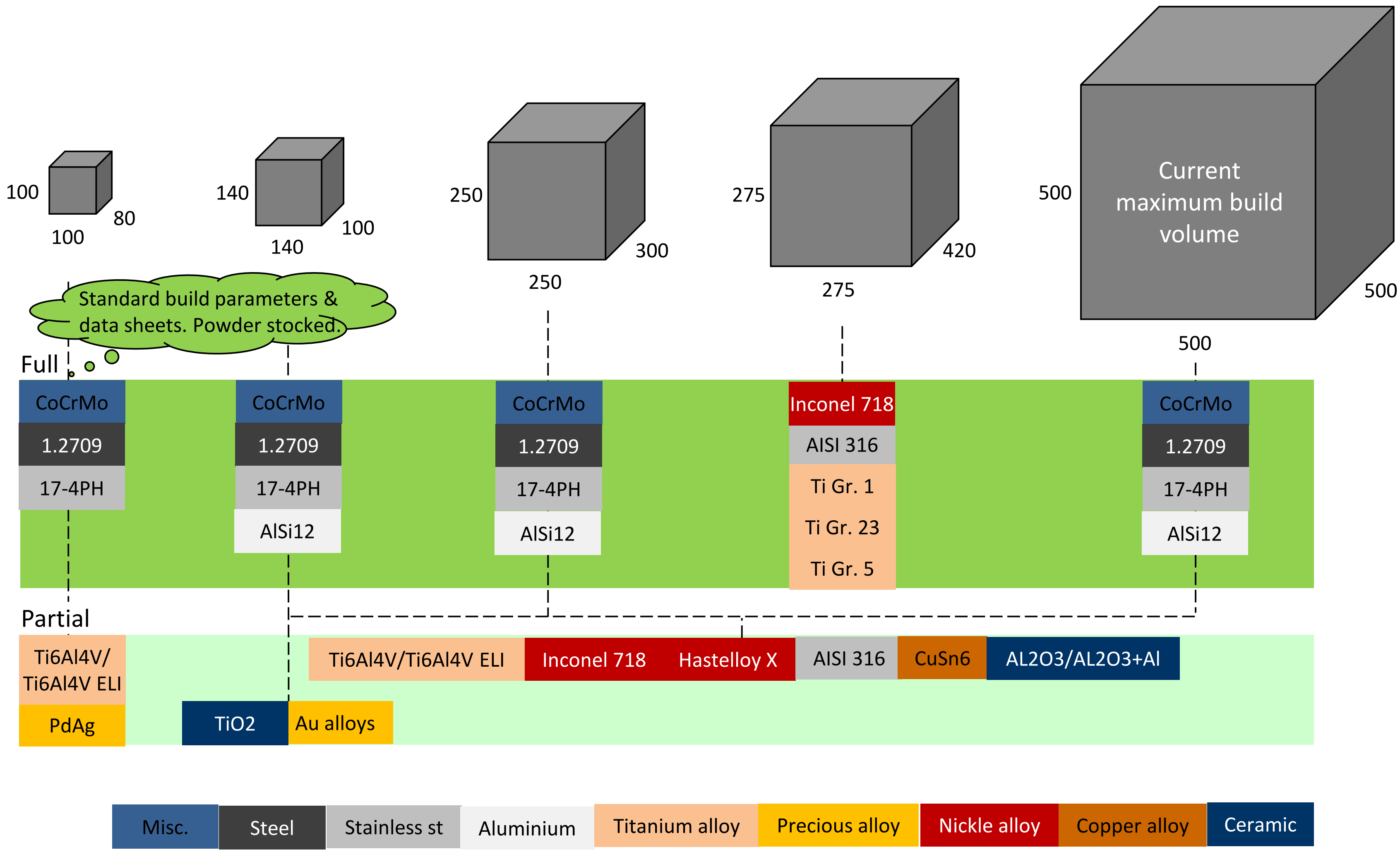
The metallic materials that can be printed?



Source: 3D Systems, http://www.3dsystems.com/

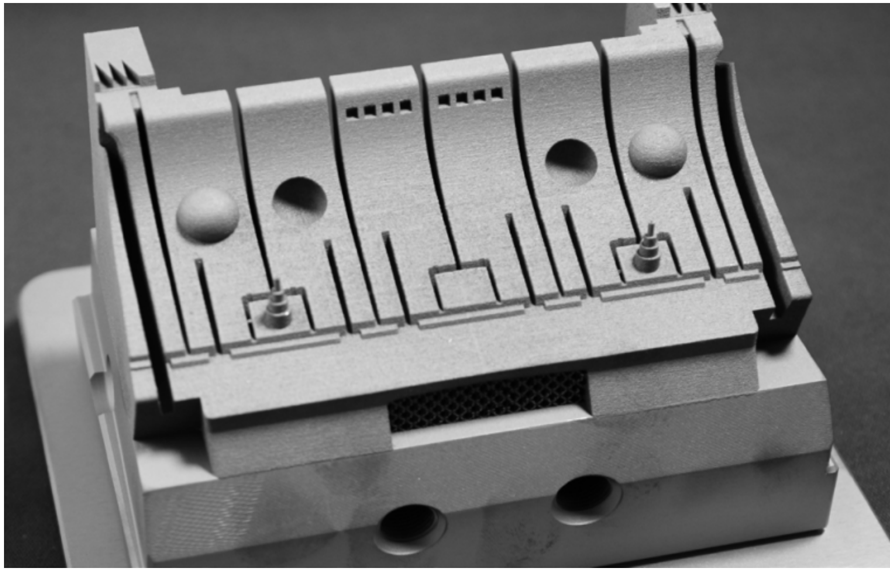
The metallic materials that can be printed?



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[1]

	Condition	As-built[2]	After post heat treatment[3]
Ultimate Tensile Strength, MPa	ASTM E8	1110 ± 50	2000 ± 50
Yield Strength, MPa	ASTM E8	860 ± 50	1930 ± 50
Elongation at break, %	ASTM E8	11 ± 3	~ 1
Hardness		37 ± 2 HRC	55 ± 2 HRC
Density		approx. 100%	

[1] Parts built on a ProX 200 Direct Metal Production Printer

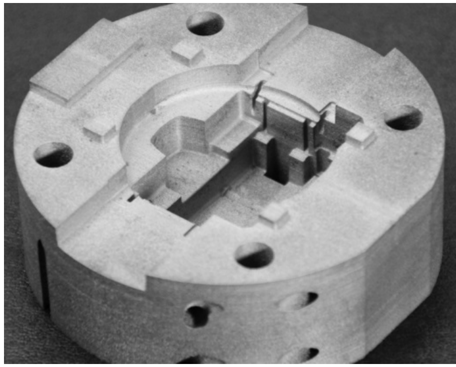
[2] As-built refers to the state of components built on the ProX 200 Direct Metal Printer before any post processing except removal from the build platform

[3] Recommended post heat treatment at 490 °C for 6 hours (exact time dependent on part volume)

Chemical Composition

Maraging Steel (like 1.2709)

Element	% of weight
Fe	Balance
Ni	17.0 - 19.0
Co	9.0 - 11.0
Mo	4.0 - 6.0
Ti	0.9 - 1.0
Si	≤ 1.0
Mn	≤ 1.0
C	≤ 0.03



Source: 3D Systems, http://www.3dsystems.com/

Comparison: AISI D2/DIN 1.2379 vs Maraging Steel

	As delivered/built		After post heat treatment	
	AISI D2/ DIN 1.2379*	Maraging steel (1.2709)	AISI D2/ DIN 1.2379*	Maraging steel (1.2709)
Yield strength	350-550 MPa	860 MPa	1900 MPa**	1930 MPa
Ultimate tensile strength	706-870 MPa	1110 MPa		2000 MPa
Fracture elongation	>11% & <20%	11%		1%
Hardness	210-255 HB (18-26 HRC*)	37 HRC	55 HRC***	55 HRC

* 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.

Adobe Acrobat Document

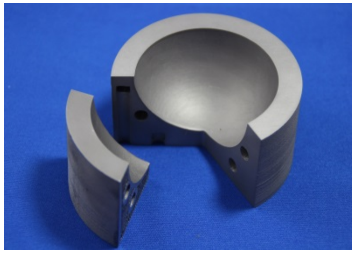
Maraging Steel (1.2709)

Output quality

Feature resolution: ≈150 um

Surface roughness, R_a:
Controlled.
In many regions ≈10-25 μm.
Smallest after printing, R_a = 5 μm.
Can be polished as usual to lower R_a.

Tolerances: ≈ 50-100 μm
Repeatability: ≈ 30 μm

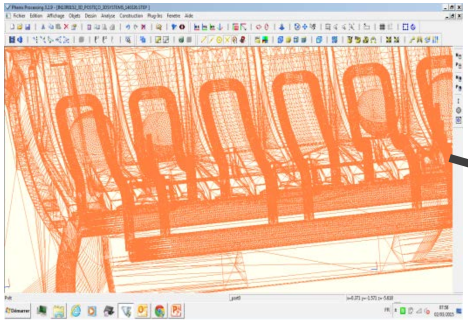


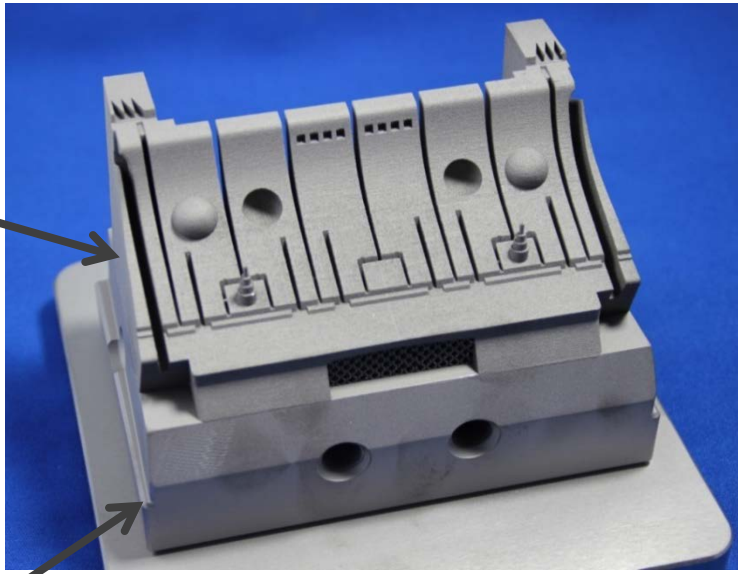
Facade on hollow structures:
1.5-2 mm
Can be machined/milled as usual.

How could 3D metal printing be included in the tool/die manufacturing process/production system?

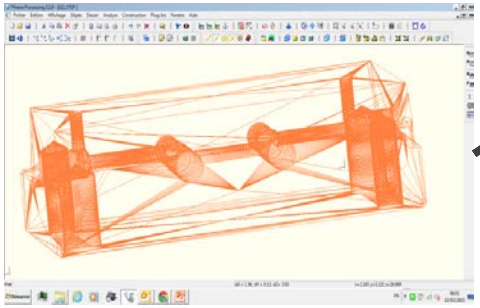
Combine milling with 3D printing:

<u>3D printed section</u>:
- Complex external shape
- Difficult internal conformal cooling channels



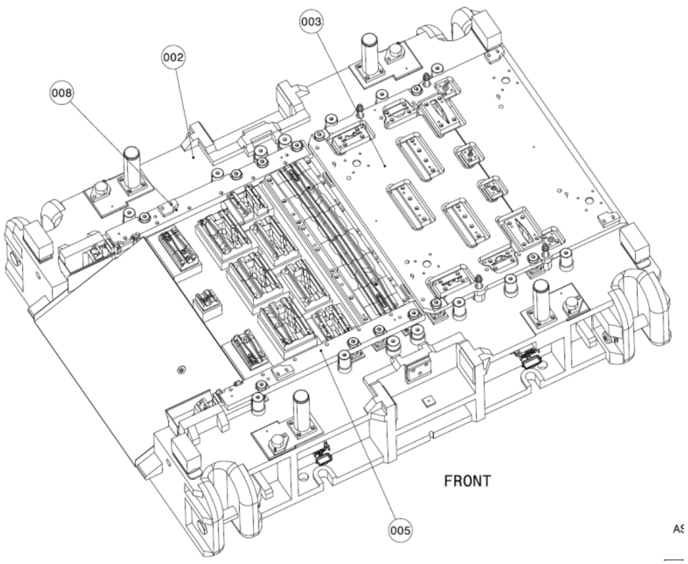


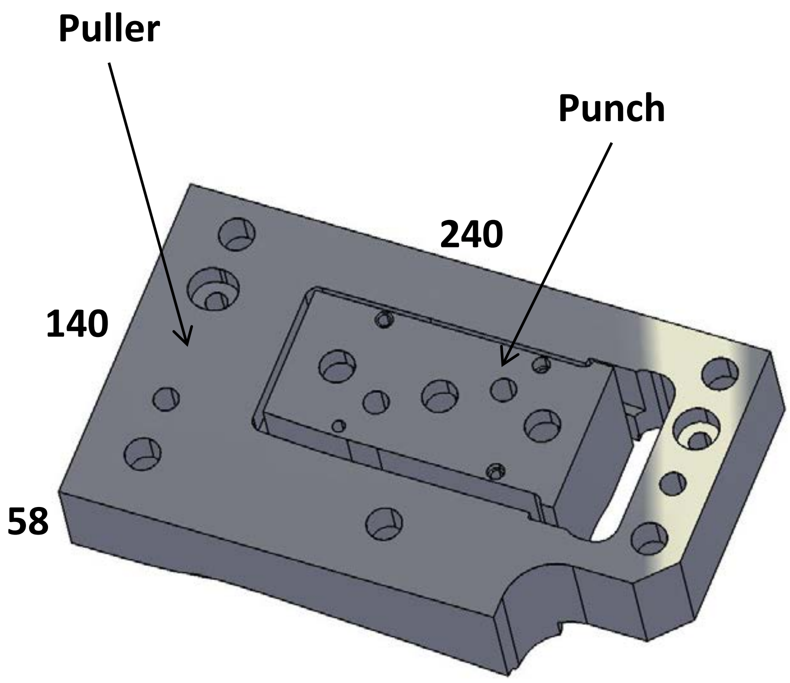
<u>CNC machined section</u>:
- Massive and simple structure
- Crossing channels straightness



Contents

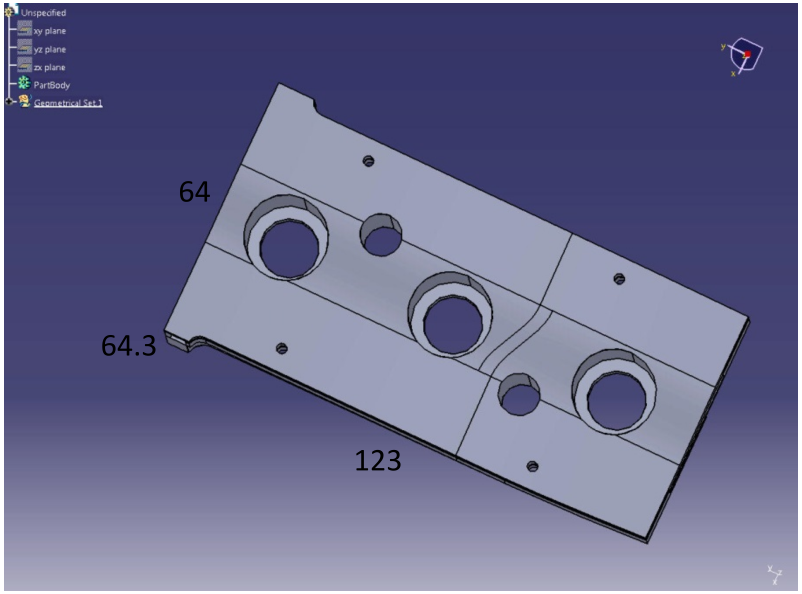
C-Bow Lower Progressive Die



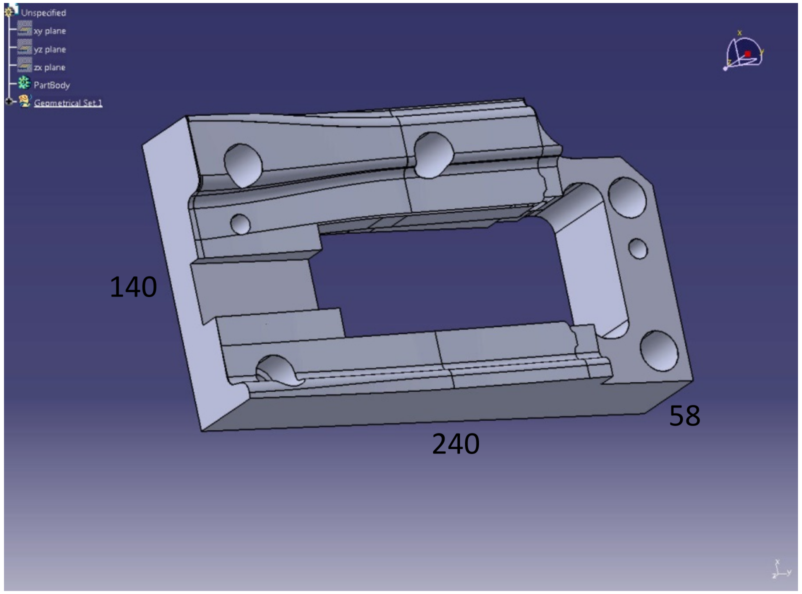


Punch and Puller Made in a Metallic Material

Punch



Puller



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 μm

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 μm

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 μm

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 μm

Polishing of the working area to Ra = 0.8 μm

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

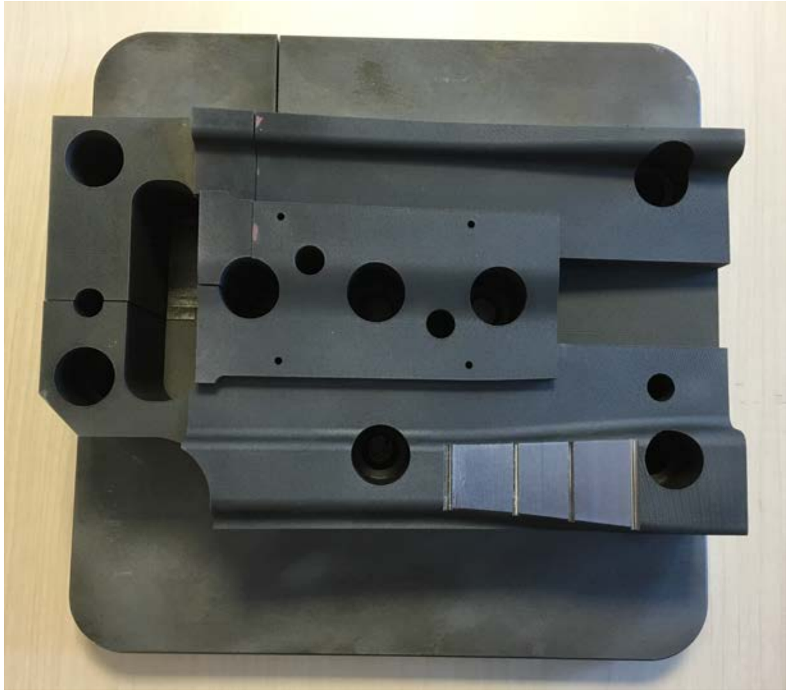
3: Hardening of the punch

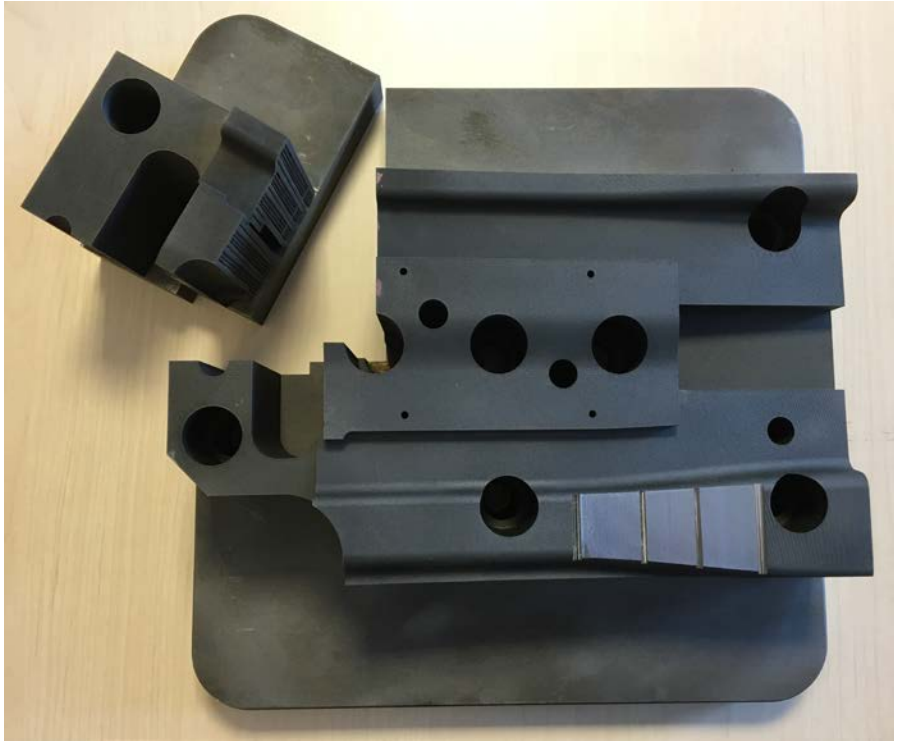
4: Polishing of the punch

Total lead time (both punch & puller) = 3.7 days

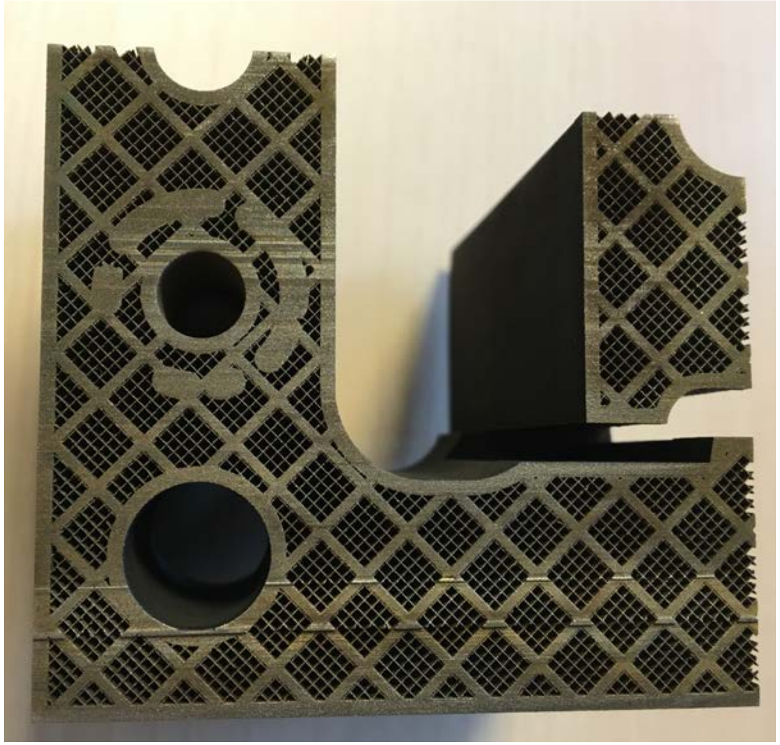
Total cost (both punch & puller) = 31000 SEK (based on a depreciation period of 5 years)

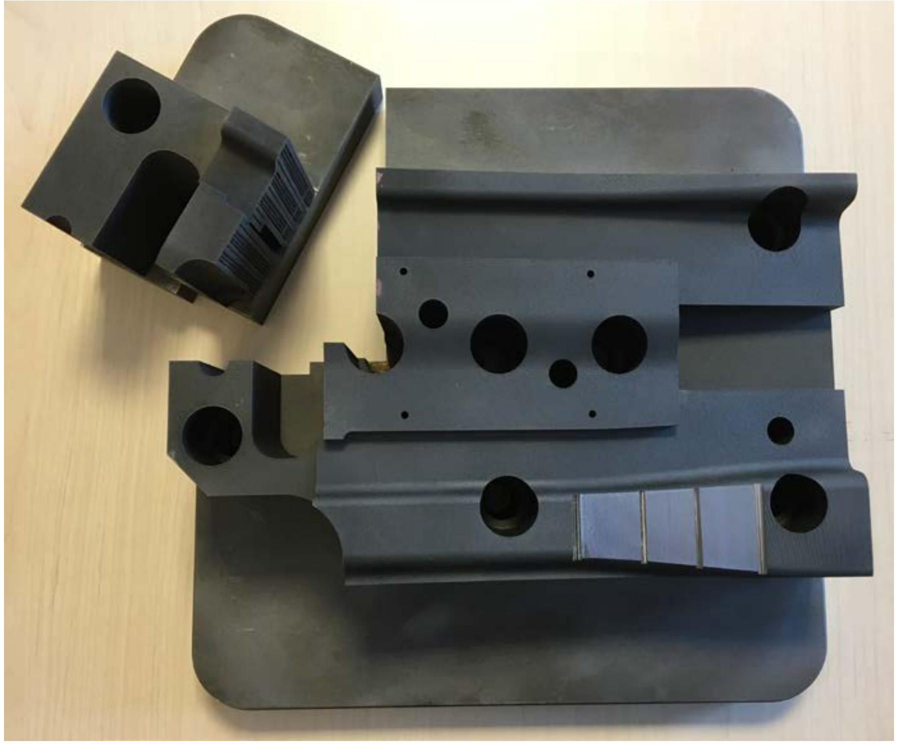
Punch and Puller Made in a Metallic Material
Conventional Procedure Compared to 3D Printing



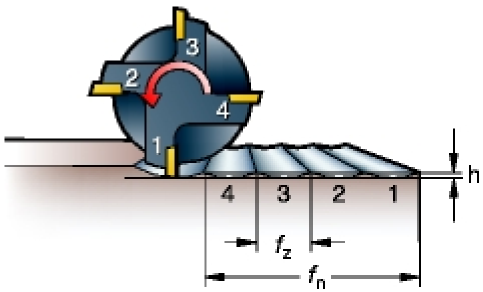


Punch and Puller Made in a Metallic Material
Conventional Procedure Compared to 3D Printing

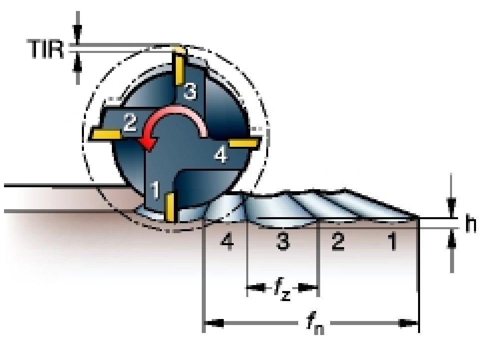




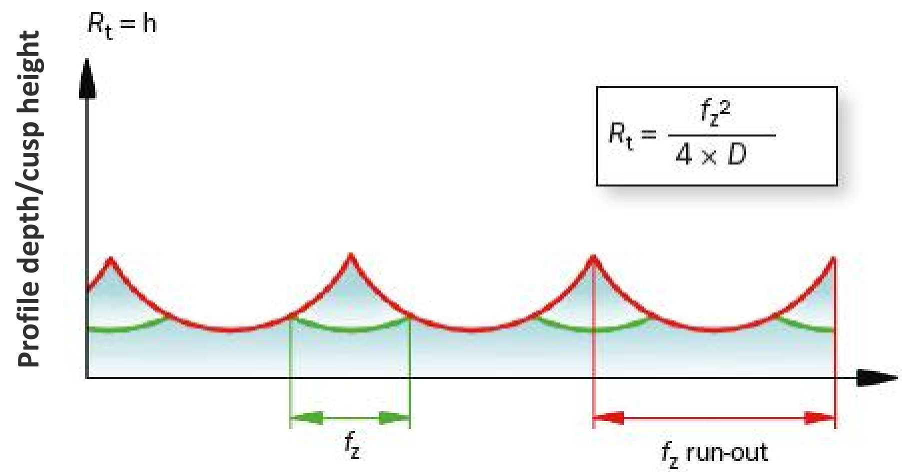
Surface texture – radially generated



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:



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



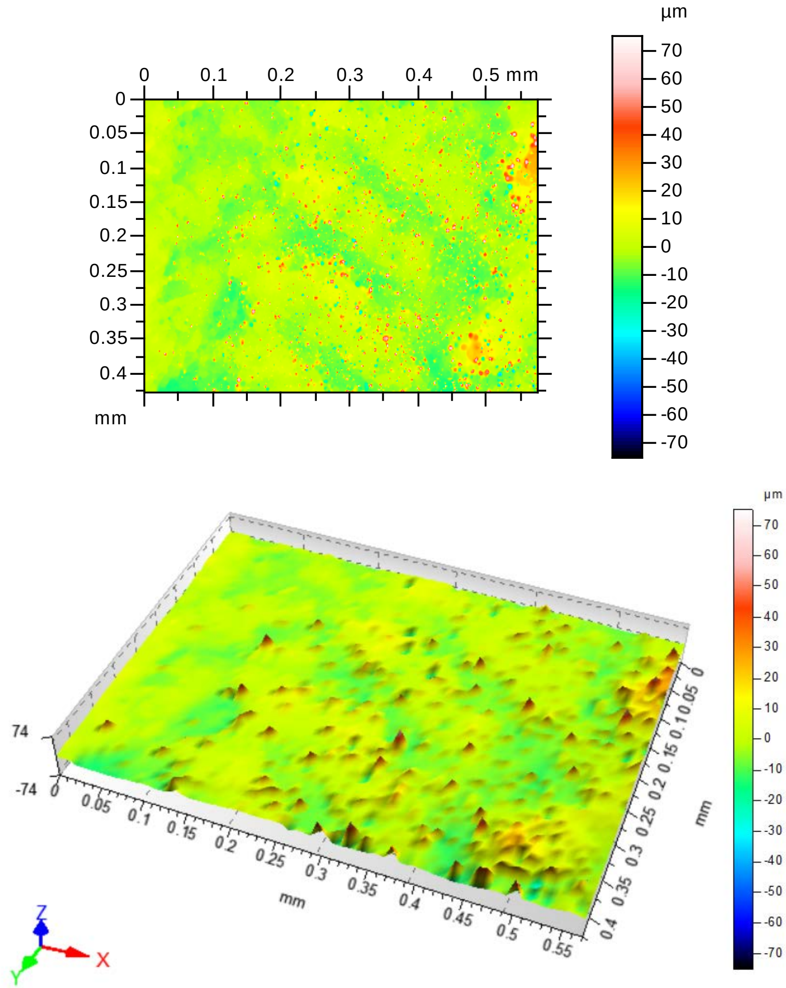
As mentioned, surface texture and climbing tendencies may limit the feed rate, especially when the radial depth of cut is small.

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, Dc
- Feed per tooth, fz
- Tool indicator reading of the run-out, TIR.

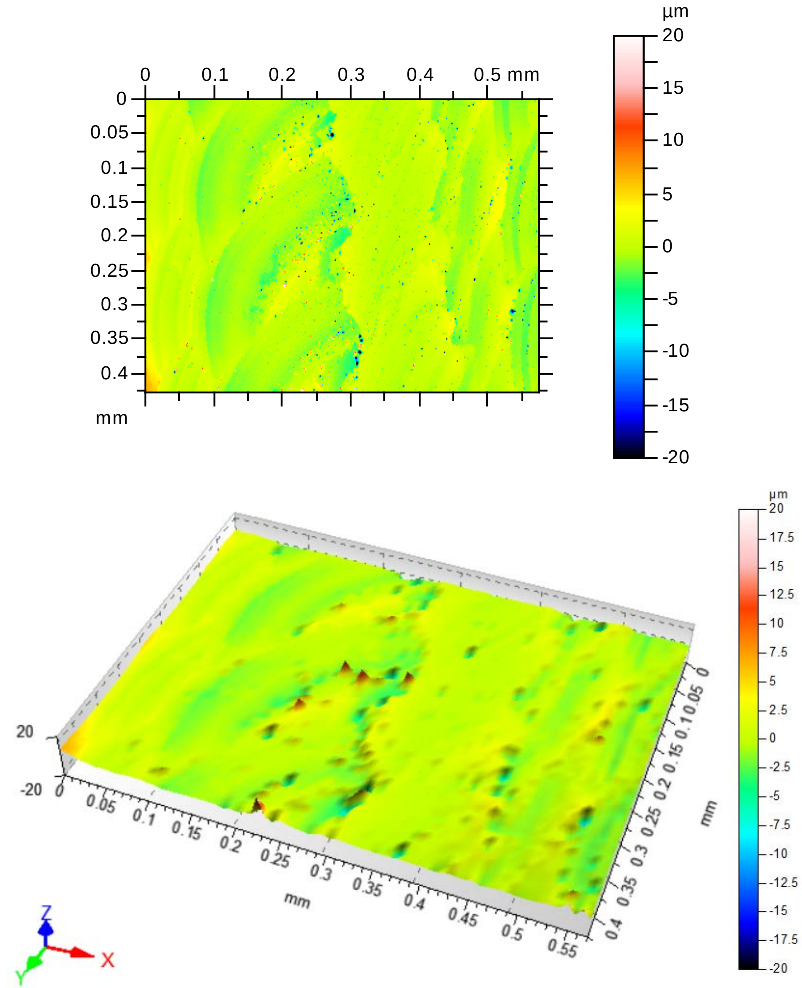
Source: Sandvik Coromant

Surface roughness



Directly after 3D Printing

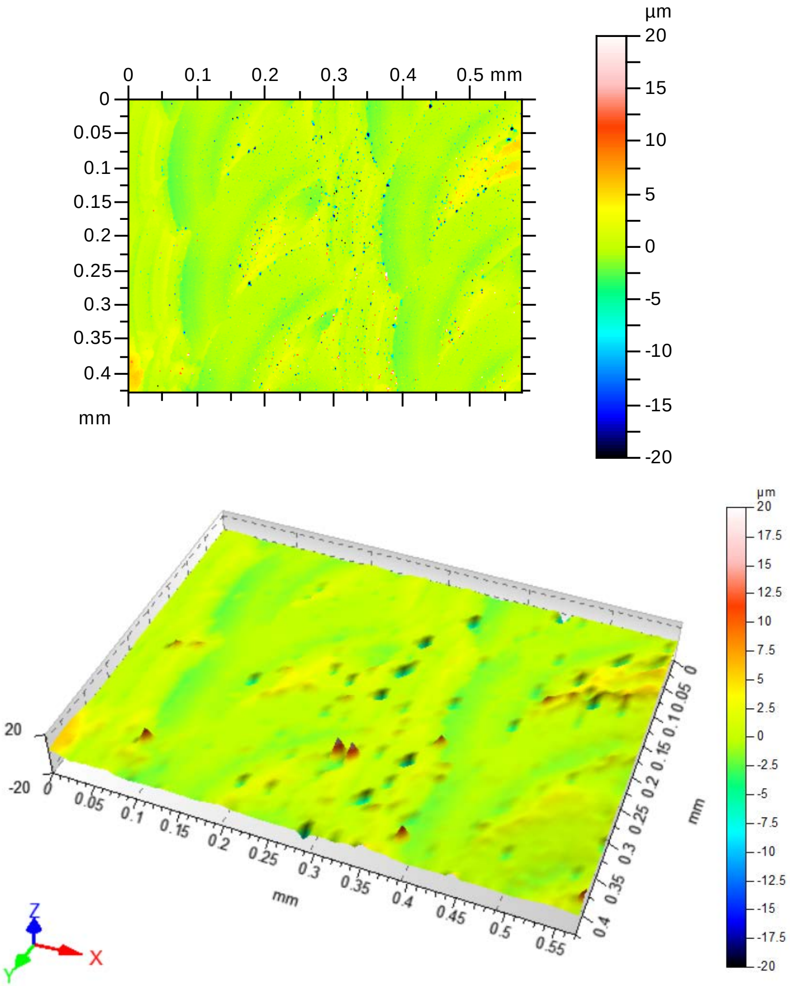
R_a = 4.92 µm



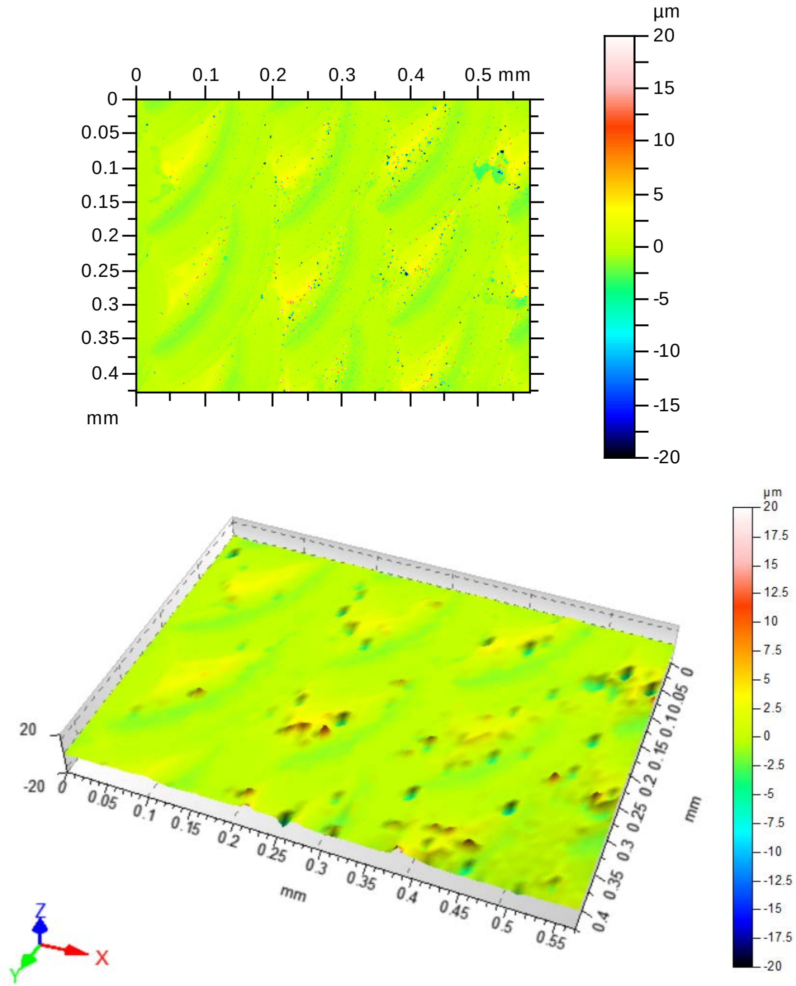
After 3D Printing and milling at Cusp height 6µm

R_a = 1.08 µm

Surface roughness



After 3D Printing & milling at Cusp height 3µm
R_a = 1.08 µm



After 3D Printing and milling at Cusp height 0.6µm
R_a = 0.71 µm

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

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	Lead Time (Working days)	
	Conventional	**3D Printed** Honeycomb structure
Punch	8	
Puller	6	
Total	**8**	**3.7**

	Cost (SEK)	
	Conventional	**3D Printed** Honeycomb structure
Punch	10 500	
Puller	15 500	
Total	**26 000**	**31 000**

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

	Lead Time (Working days)	
	Conventional	**3D Printed** Honeycomb structure
Punch	8	
Puller	6	
Total	**8**	**3.7**

	Cost (SEK)	
	Conventional	**3D Printed** Honeycomb structure
Punch	10 500	
Puller	15 500	
Total	**26 000**	**29 000**

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

Contents

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