Simulation, Optimization and Design of 3D Printed Sand Molds for Cast Metal Parts

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Background – Ongoing Research at VTT

- Simulation, optimization and design for AM – focus on SLM
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- Investigation of ways to simplify and reduced costs of post-processing procedures

In cooperation with:

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- Investigation of ways to simplify and reduced costs of post-processing procedures

- Prediction and identification of defects → defect tolerant design concept

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Lesson Learned

- Geometric freedom that AM provides should be utilized fully in order to see the benefits from this manufacturing approach
  - Innovation
  - Functionally superior
  - Parts consolidation
  - Lightweight structures
- Must understand the manufacturing process (and its limitations)!

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Current Project

MOTIVATION

- Some key limitations in metal AM:
  - Size
  - Material selection
  - Quality assurance
  - Cost
- Typical ‘large’ powder bed fusion build sizes:
  - 400 x 400 x 400 mm³ (EOS)
  - 500 x 280 x 365 mm³ (SLM)

PROPOSED SOLUTION

- 3D printed sand molds for cast metal components → keep much of geometric freedom
- Largest cohesive build space for sand molds 4m x 2m x 1m (Voxeljet)
- Process is suitable for most metals that can be cast with sand casting method (e.g. magnesium, aluminum, steel, brass, etc.)

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Manufacturing Process Description

Example: 3D printing of mold and core for steel manifold (from http://hetitec.com/case-studies/manifold)

Design of mold & core

3D printing sand molds

Assembling the mold

Casting

Cast manifold before cleaning

Final part after machining
Primary Manufacturing Constraints

3D printing of the sand mold
- A wall thickness of 3mm must be maintained in the sand mold
- It must be possible to remove excess sand → Mold must have parting line

Casting
- A minimum wall thickness of e.g. 5mm is recommended (varies with material)
- Long, thin channels are challenging (need long, thin, and fragile cores)

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Case Study – Raute Component

- Raute Corporation is Finnish technology company with customers in wood products industry
- Component description: body of a device for trimming peeled veneer to desired length

- Design Goals:
  - Component consolidation (adapter plus main body component)
  - Improved functionality (integrated air channels)
  - Size reduction for material/energy savings

- Project Goal: establish a work flow and manufacturing network

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FEM Model & Topology Optimization

- Finite element model
  - Material: tin bronze
  - Loads:
    - Forces from knife interaction
    - Forces from hydraulic cylinder controlling component position
    - Bolt preloads
- Topology optimization
  - Studied variations in design space, optimization objective, and constraints

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Design Interpretation

- Smoothing

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Design Interpretation

- Smoothing
- Manufacturability check

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Design Interpretation

- Smoothing
- Manufacturability check
- Air channel integration
  - Formed stainless steel tubes

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Casting Simulation & Mold Design (1/3)

- Runner system (gating) – channels in mold through which molten metal is poured to fill the cavity

- Risers (feeders) – reservoir of molten metal necessary to compensate for losses due to shrinkage when metal solidifies
Casting Simulation & Mold Design (2/3)

Flow-3D Cast: Molten Metal Flow

Solidification

Temperature After Casting
Casting Simulation & Mold Design (3/3)

Key points:
- Sand removal after printing
- Tube insertion and positioning

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Mold Creation

- Voxeljet VX1000 printer
  - Binder jetting (phenolic binder)
  - Build area (1060mm x 600mm x 500mm)
  - Print layer size = 0.3mm
- 4 copies of the molds were printed simultaneously
- Alcohol-based zircon coating

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Tube Forming, Casting & Machining

- Stainless steel tubes were bent with aid of 3D printed guides and inserted into molds

- Casting at Finnish foundry:
  
  Parts will be machined to specified tolerances
  - Bolt holes, key surfaces
  - Nozzles and barbed hose fittings
Result – Workflow Established

FEM Model | Topology Optimization | Design | Reanalysis | Gating Design | Casting Simulation

Mold Design | Mold Creation

Component Ready for Casting
Conclusion

- Understanding of manufacturing techniques during early phases of design is crucial.
- Knowledge sharing between experts helped to ensure the successful design and manufacture of this component.
- Much of the design freedom we expect from AM was maintained using this manufacturing approach.
TECHNOLOGY FOR BUSINESS