Advanced modeling techniques for the optimization of powder bed fusion additive manufacturing processes

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Agenda

1. Simufact Company and Product Lines
2. Challenges of Metal Powder Bed Fusion Processes
3. Simulation of Metal AM
4. Case Study and Software Demo
Simulating Manufacturing - The Manufacturing Division of simufact

- Supporting the optimization of metal-based manufacturing processes
- Manufacturing oriented process simulation
- Technology based on MSC MARC and MSC DYTRAN solvers
Global MSC Product Portfolio - Materials to Systems

- Materials
  - Digimat
  - Digimat-VA
  - MaterialCenter
  - Simufact Additive
  - Simufact Additive
- Fabrication
  - MSC Apex
  - Marc
- Parts
  - Simufact Welding
  - Simufact Joining
- Assembly
  - SimManager
  - sc/Tetra
  - Patran
  - scFLOW
- Systems
  - Adams
  - AdamsCar - Realtime
  - Nastran
  - Actran
Simulating Manufacturing - The Manufacturing Division of Simufact
Powder Bed Fusion AM
Challenges in Design of Metal AM Parts

Main pain points

◆ **Distortion**  → Part out of Tolerances  
    → Collision with Recoater

◆ **Residual Stresses**  → Part or Support Failure during Manufacturing

◆ **Support Structures**  → Wrong location or design

◆ **Consequences**  → Possible Build Job Abortion  
    → Iterative Trial & Error

Finally: Wasting Time & Money 😞
Objectives

Objectives of AM process simulation

◆ Objective #1
  ▪ Prediction of final shape (distortions)
  ▪ Determination of support structure strategy
  ▪ Identification of risks of job abortion
  ▪ Prediction of residual stresses

◆ Objective #2
  ▪ Microstructure, durability, surface quality.

Source: Renishaw
Analysis Scales

◆ **Macro Scale**
  - Element layer (> powder layer) analysed in one step
  - Inherent Strains - pure mechanically, extremely fast
  - Delivers Distortion & Stress ✓

◆ **Meso Scale**
  - Element layer analysed in one step or by hatching segments
  - Thermal, mechanical or thermo-mechanically coupled
  - Able to deliver approximate thermal history and derived results

◆ **Micro Scale**
  - Moving heat source on solid
  - Transient fully thermo-mechanically coupled
  - Delivers thermal history and derived results like microstructure

◆ **Nano Scale**
  - Moving energy beam - absorption & reflection at powder level
  - Heat transfer, radiation, convection, fluid dynamics
  - Detailed basic investigations

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Macro-Scale: Mechanical Approach

**Inherent strains**

- **Comprise**
  - Plastic strains
  - Thermal strains
  - Creep strains
  - Phase transformation strains

- **Reflect**
  - Material
  - Manufacturing parameters
  - (Individual) machine

**Calibration to determine inherent strains**
Meso-Scale : Thermo-Mechanical Approach

Macro to meso scale thermal / thermo-mechanical

- Element layer- to segment wise activation
- Application of thermal loads
- Optional thermo-mechanical coupling
- Enables to predict
  - Distortion of Part, Supports & Base Plate
  - Stress
  - Peak temperatures
  - Heat Fluxes
  - Simplified thermal history
  - Derived results (tbc)
AM process chain simulation

Stress relief heat treatment

- Temperature curve
- Temperature dependent material properties
  - Elastic modulus
  - Stress-Plastic strain flow curves
  - Conductivity, Specific heat capacity
- Creep laws
  - \[ \dot{\varepsilon} = A \sigma^n A \exp\left(-\frac{Q}{RT}\right) \]
  - \[ \dot{\varepsilon} = A \left[ \sinh(\alpha \sigma) \right]^n \exp\left(-\frac{Q}{RT}\right) \]
AM process chain simulation

Hot isostatic pressing

- Temperature + pressure curve
- Temperature dependent material properties
- Creep laws
- Densification acc. to power law

\[ \rho = 1 - (1 - \rho_0) e^{-\frac{3P}{2\sigma_{\text{yield}}}} \]
Simufact Additive Automatic Geometry Compensation

- Simufact Additive provides an active **compensation strategy** to get rid of initial, process depending distortions
- Geometry compensation is the key for a controlled, robust AM process to meet the required tolerances
- After running a compensation based on simulation (might happen in several iterations) the real build will deliver valid parts with the first shop-floor build job

*First Time Right*
Case Study

Additively manufactured lightweight engine hood hinge
LightHinge+

Additively manufactured lightweight engine hood hinge
LightHinge+ project partners

- Initiator of project
- Independent engineering company of the automotive industry
- Experts for lightweight construction and additive manufacturing
- Concept and component development

- Austrian metal material, metal parts & engineering supplier
- Prototype production and application know-how

- German software company focused on manufacturing simulation
- AM Process simulation with Simufact Additive
- Distortion compensation by pre-deformation
Active Hood System

2018 REGAL ACTIVE-HOOD TECHNOLOGY

BUICK
Context

Current system

◆ Active hood systems vs. conventional hood closure cause significant increase in weight
◆ Active hood complex kinematics leads to many issues with assembly and tooling cost

Targeted segment: small and sports car

◆ Current active hood system not applicable to small and sports car segment (too heavy, too bulky)
◆ Small series (80 – 30.000 p. a.) cannot be operated efficiently with technologies from mass production
LightHinge+ - The Concept

Goal for the small series and sports car segment

- Ultra lightweight
- Maximum component and function integration
- Tool-less and update-capable production
Additive manufacturing only works economically if the highest degree of functional integration in the component is achieved.

- Topology analysis without consideration
  - a) of the functional integration
  - b) of the manufacturing concept
leads the design engineer on a "wrong mechanical track".

**Concept of "breakaway structure" instead of "kinematics"**

⇒ Success factor for weight minimization

- Designers must think out of the box (creative and experience-based solution)
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**Concept of "breakaway structure" instead of "kinematics"**

➡ Success factor for weight minimization

- Designers must think out of the box (creative and experience-based solution)
LightHinge+ - The Design

- **Ultra lightweight**
- **Maximum component and function integration**
  Integrated pedestrian protection function
- **Tool-less and update-capable production**

Wiping water hose guide

Fragile structure

Connection point gas spring

Collar screws guide

Hood hinge function + Pedestrian protection function

Comparison:
- 19 parts
  - 1.49 kg
  - 51% reduction to 0.72 kg
- 6 parts
  - 0.72 kg
  - 68% reduction to 0.24 kg

Lightweight construction potential
Function integration
Cost impact
Sustainability & resource efficiency
LightHinge+ - The Outcome
Some Details
AM Process Design

Virtual Tryout
Support Structure Optimization

Experience based knowledge

Simulation based knowledge

> 50 % of whole material usage required for support

< 18 % of whole material usage required for support
Calibration of AM Process Simulation

- Cantilever specimens with different scanning strategies have been printed by voestalpine.
- The cantilevers have been cut and the deformation measured.
- Deformations have been input into simufact additive.
- The inherent strains that reflect the manufacturing process loads have been calibrated.
Model setup for AM simulation

- Import part geometry
- Import support structure geometries
- Select material from database – 316L steel
- Define process chain to be simulated (build part, cut from plate, remove supports)
- Mesh geometries with voxels
AM simulation of single parts

Simulation of
- Building the part
- Cutting from plate
- Removing support structures

Calculation times
- Lower bracket
  - ~ 20 hrs on 16 cores
- Upper bracket
  - ~ 4.5 hrs on 8 cores
AM simulation of real-life build space

- Actually six parts are manufactured simultaneously
  - 3 lower brackets
  - 3 upper brackets

- Simulation of
  - Building the parts
  - Cutting from plate
  - Removing support structures
Simulation results – Residual stresses

- Effective stresses shown
- Stresses are calculated based on non-linear elastic-plastic material model with realistic stress-strain relationship (flow curve)
- Yield stress at 585 MPa
  - Plastification leads to permanent deformation = distortion
- Ultimate strength is 685 MPa

=> No failure expected
Simulation results – Distortion

- Total displacement shown

- Other results available:
  - Residual stresses
    - Risk of tearing
    - Support separation
  - Layer-Z displacement
    - Risk of wiper collision
Distortion of manufactured part vs. CAD

→ Parts out of tolerance (distortions > 1 mm)
Validation by optical measurement

With kind support from

...AICON
3D Systems

Hexagon Manufacturing Intelligence
AM Process Design

Optimization
Pre-deformed shape for distortion compensation

- Simulated distortion is inverted
- Inverted distortion is mapped on surface STL
- Pre-distorted STL is exported
- Exported STL was used for optimized AM of distortion compensated parts

NB: shown distortions are overscaled by a factor of 10 for better visualization
LightHinge+ Distortion Compensation

- Required tolerances could be achieved within the first print job
- Reduction of the initial distortion in one step by approx. 50% - 80%
- Production time and costs reduced

Distortion NOT compensated
Shape deviations up to 1.5 to 2.0 mm

Iteration „zero“

Distortion compensated
Shape deviations < 0.75 mm

Optimized after simulation

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Iteration „zero“

Distortion compensated
Shape deviations < 0.75 mm

Optimized after simulation
Conclusion
Conclusion

- Realizing a new, innovative hood hinge
- Combining ultra lightweight by bionic approach with additively manufactured breakaway structure (pyrotechnically triggered)
- Significant reduction of initial distortion based on simulation based compensation strategy
- Cost efficient production due to minimized support structure and optimized printing strategy
LightHinge+: Summary

**Traditional sheet metal part**
- appr. 6-20 €/piece (only mass production)
  - not small series capable
  - punching, riveting, sheet metal forming
- 1.490 g
- 19 parts (incl. norm parts)
- high fixed capital
- Significant package space required

**Innovative AM part**
- Appr. 500 - 1.000 €/piece
  - in small series
  - tool-free, updateable
- 720 g
- 6 parts (incl. norm parts)
- very low fixed capital
- Small package space
Innovative Simufact

German Innovation Award 2018

German Stevie Award in Gold

Best of 2017

Best of Industry Award 2018

Materialica Design + Technology Gold Award 2018

Nominee in the category Additive Manufacturing