GREEN PART PROPERTIES AS DESIGN DRIVER FOR “FIRST TIME RIGHT” WITHIN SINTER-BASED ADDITIVE MANUFACTURING

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PROJECT OVERVIEW

The *SIGNAL*-Project deals with:

- sinter-based Additive Manufacturing (abbr.: SBAM)
- of light metals (titanium and aluminum)
- for use in various mobility sectors (aviation, railway and automotive).

Official (translated) title:

Development of sinter-based generative process routes for aluminum and titanium alloys for topology-optimized lightweight components for the mobility sector

Supported by:

Federal Ministry for Economic Affairs and Climate Action

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The consortium project is funded by the **Federal Ministry for Economic Affairs and Climate Action** (BMWK) in the Lightweight Technology Transfer Program (TTP LB) under the funding code **03LB2060** and supervised by Project Management Jülich (PtJ).

PROJECT OVERVIEW
2/6 PARTNER PROFILES

Hamburg University of Applied Sciences
- Officially founded in 1970
- Approx. 16000 students, around 6000 of whom are enrolled in the Faculty of Engineering and Computer Science

Focus within *SIGNAL*:
- Extrusion-based SBAM processes
- Design Rules for SBAM
- SBAM-specific topology optimization

Element22 GmbH, Kiel
- Founded in 2011 with Ti MIM-expert team
- 50+ employees including 7 working students
- Offers materials, debind and sinter services as well as design and manufacturing of components

Focus within *SIGNAL*:
- Powder-based SBAM processes
- Development of aluminum-feedstock
- Sinter-simulation

MOTIVATION

General Background

- SBAM processes have economic and ecological potential [1,2]
- Realization of “First Time Right” through simulations and knowledge gain will have positive impact on costs [3]
- Parts experience shrinkage during necessary subsequent process-steps
- These process-steps are a risk for undesired distortion or even collapse of respective parts
- Undesired deformation due to anisotropic shrinkage is examined in e.g. [4] for SBAM or [5] for general sintering
- Aspect of collapsing of structural features due to parts’ dead load is addressed in this work

Design for SBAM

- Green part design: guidelines for polymer AM, e.g. [6], are applicable
- For subsequent process steps there are further design requirements as discussed in [7]
- Qualitative design rules in this field are rare

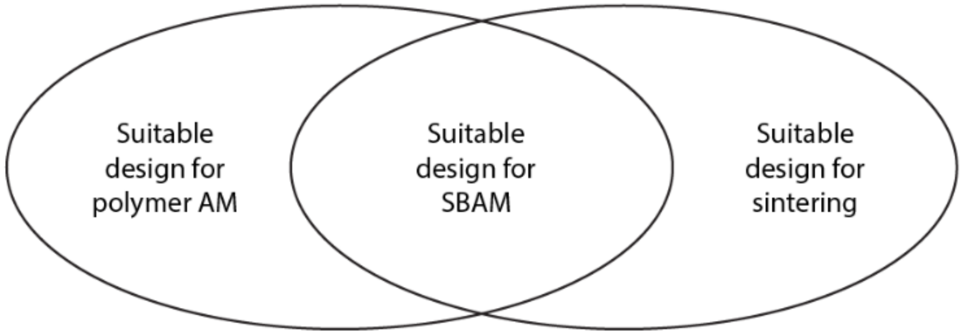


Fig.: Overlap of design requirements

GENERAL PROCESSES

SINTER-BASED ADDITIVE MANUFACTURING

Generally

- A homogenized mixture of metallic alloy and different polymers is processed
- The different polymers fulfil various tasks
- Printed parts then undergo subsequent process steps
- Potentially other process steps have to take place

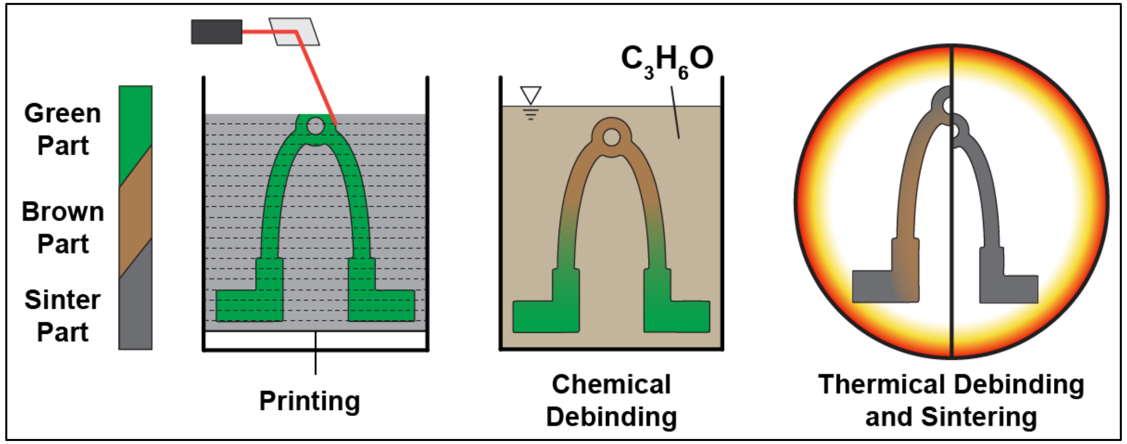


Fig.: Process steps of Cold Metal Fusion

Cold Metal Fusion

- Cold Metal Fusion (CMF) is basically PBF-LB/P
- Compared to direct metal AM processes less energy during printing is required [8,9]
- Resulting residual stresses are of a different order of magnitude [8,9]

Metal Fused Filament Fabrication

- MFFF parts experience anisotropic shrinkage behaviour depending on material and process parameters [10]

METHODOLOGY

Objective

- Gaining insight of failure mechanism
- Identifying critical stress limits w.r.t. components' dead load

Subject of investigation

- 2 different CMF-Feedstocks
- 3 different build directions for MFFF

} **Ti-6Al-4V** (near Grade 5)

Approach

- Specimens are designed with respect to stresses present
- Physical experiments paired with FE-simulations
- Examined geometries are cantilevers
- Failure of (some) cantilevers is the goal

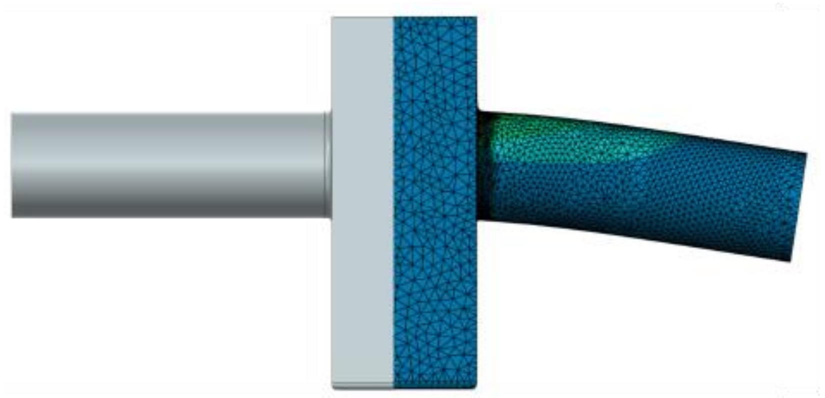


Fig.: Examplary CAD- and FEA-geometry

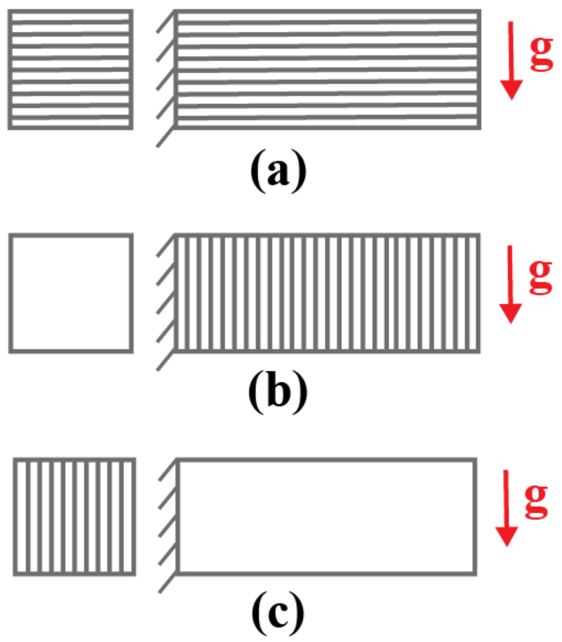


Fig.: Build orientation set-ups for MFFF-specimens

EXPERIMENTAL SET-UP

COLD METAL FUSION AND METAL FFF

- Printing configurations are shown in table on the right
- Processed Material: **Ti-6Al-4V** (near grade 5)
- CMF green parts have to be depowdered manually
- Chemical debinding: aceton bath at 50 °C for several hours
- Thermal debinding (≤400 °C) and sintering (>1000 °C)
  → both steps in the same vacuum furnace

Tab.: Process parameters for CMF and MFFF

	CMF	Metal FFF
Printer Used	Formiga P 110 (*EOS*)	FL300M (*FuseLab*)
Shrinkage (%)	12.3	15.8
Layer height (mm)	0.1	First Layer: 0.2 Other: 0.1
Scan/Print speed (mm/s)	Contour: 2000 Hatch: 3500	40
Laser power (W)	Contour: 20 Hatch: 17	-
Nozzle Temperature (°C)	-	135

RESULTS – PRELIMINARY STUDY

FAILURE MECHANISM - CMF

Point of collapse within the process

- Distortion of the cantilevers in x-y-plane
- Material structure on surfaces show sintered characteristics

→ Failure occurs directly before sintering

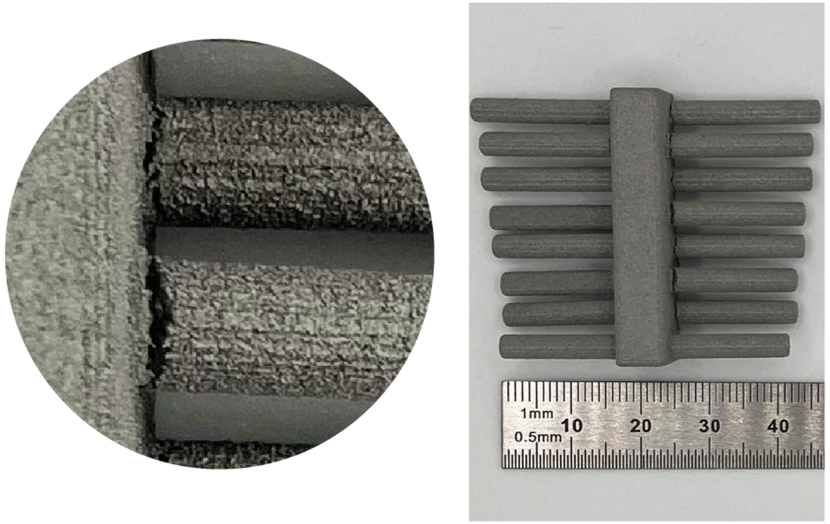


Fig.: Close up of examplary CMF-specimen after sintering

Failure mechanism

- Fracture has no directional characteristics
- Fracture strain is small
- Assumption of quasi-brittle material behavior
- This suits other existing studies [11]

→ Principal stress hypothesis is chosen as target value

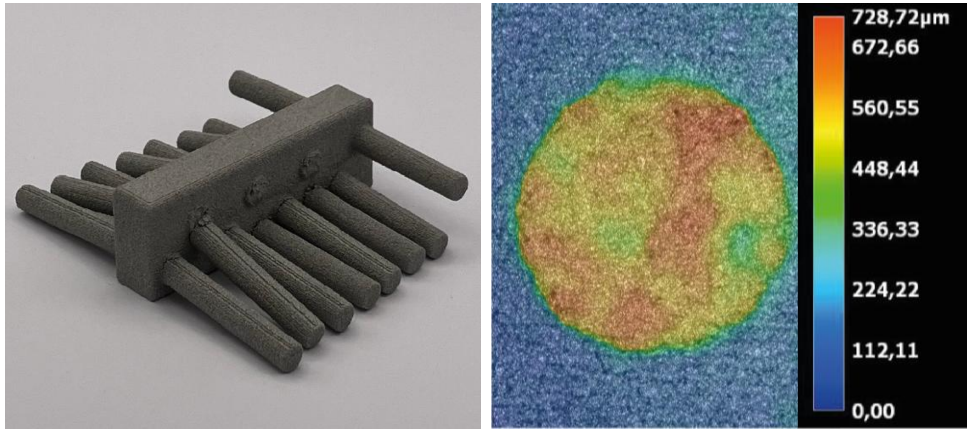


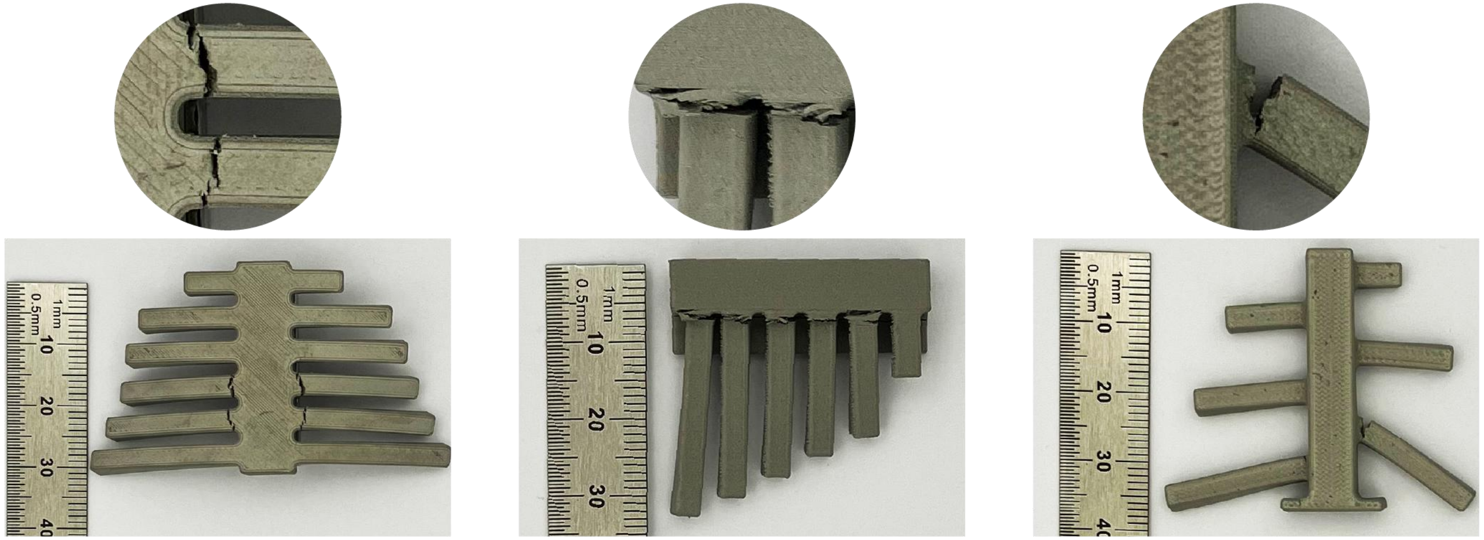
Fig.: CMF-specimen and fracture surface with elevation profile

RESULTS

FAILURE MECHANISM - MFFF

- Quasi-brittle fracture behavior only applicable for one build direction
- Other two examined build directions experience larger deformation
- Principal stress hypothesis doesn’t seem to fit for these two set-ups

Fig.: MFFF-specimens in perspective



(a) (b) (c)

Fig.: MFFF-specimens with close up of fractures

RESULTS
CRITICAL STRESS LIMITS

- **Total of 278 cantilevers** were manufactured (164 via CMF, 114 via MFFF)
- If the stress values in the highlighted lines of the table were adhered to, 100 % of the geometries were manufactured intact
- The critical stress limit was by far the lowest for **FFF** set-up 2, which underlines the influence of **anisotropy**
- The **stress limit** was for all geometries directly **proportional to the density** of the material
- Thus, the stress limit w.r.t. the sintered density is stated as well

Tab.: Critical stress values w.r.t. dead load

Study	$\sigma_{principal,max,green}$ (kPa)	$\sigma_{principal,max,sintered}$ (kPa)	# of manufactured cantilevers	% of cantilevers w/o fracture
CMF - Preliminary study	$\sigma \leq 22.3$	$\sigma \leq 31.7$	24	100 %
	$22.7 \leq \sigma \leq 26.8$	$32.3 \leq \sigma \leq 38.0$	16	75 %
	$29.2 \leq \sigma$	$41.4 \leq \sigma$	12	0 %
CMF - Main study	$\sigma \leq 14.0$	$\sigma \leq 19.9$	38	100 %
	$14.3 \leq \sigma \leq 16.7$	$20.3 \leq \sigma \leq 23.7$	42	26 %
	$17.2 \leq \sigma$	$24.4 \leq \sigma$	32	0 %
FFF - Set-up 1	$\sigma \leq 13.7$	$\sigma \leq 19.5$	30	100 %
	$17.9 \leq \sigma$	$25.5 \leq \sigma$	30	13 %
FFF - Set-up 2	$\sigma \leq 2.7$	$\sigma \leq 3.8$	5	100 %
	$8.1 \leq \sigma$	$11.5 \leq \sigma$	25	0 %
FFF - Set-up 3	$\sigma \leq 17.9$	$\sigma \leq 25.5$	16	100 %
	$22.5 \leq \sigma$	$32.0 \leq \sigma$	8	0 %

CASE STUDY
INSIGHTS APPLIED TO AUTOMATED DESIGN

Optimization for first CMF-feedstock

- Swan neck for a race car receives a redesign via topology optimization (software: *Hexagon MSC Apex GD*)
- The optimization includes 5 **load cases** (4 for the component application, **1 for debinding and sintering**)
- Density as sintered and a stress target of 25 kPa (v. Mises) is used for the debinding-load case

Workflow

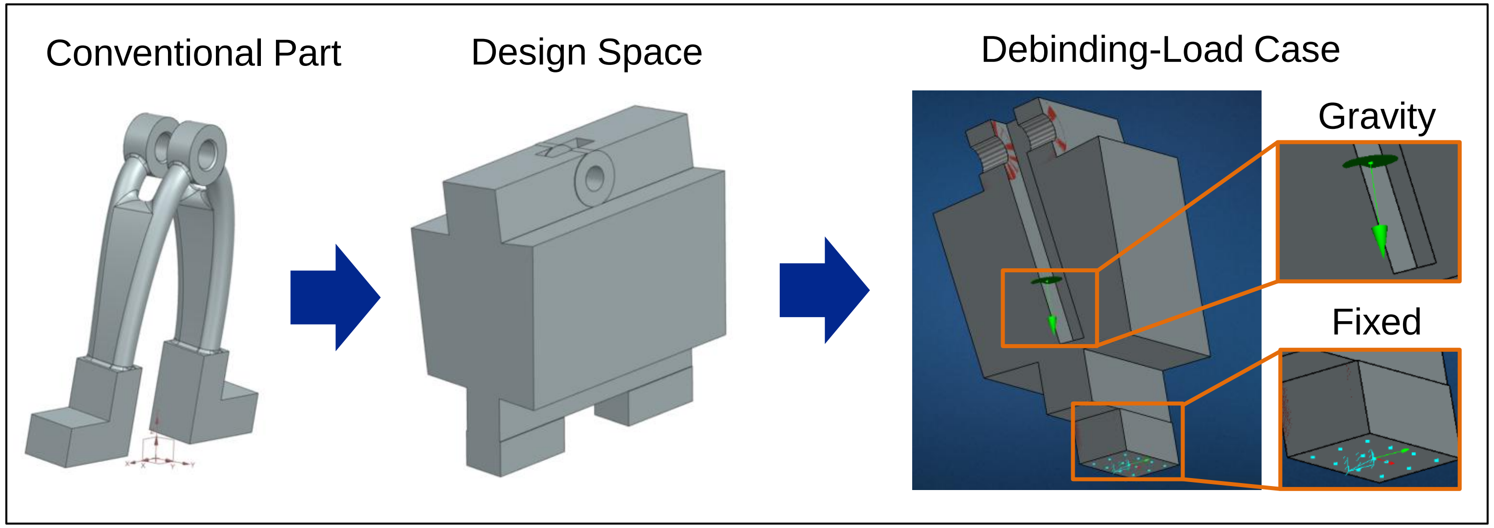


Fig.: Workflow for topology optimization

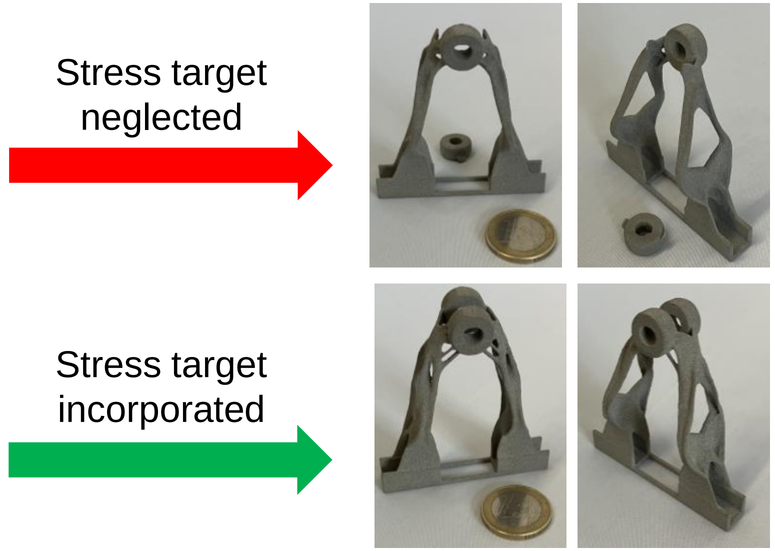


Fig.: Physical results of topology optimization

CONCLUSION AND OUTLOOK

Conclusion

- A “hands-on” approach for evaluating the sinterability of SBAM parts was examined
- This approach enables the phenomenological identification of stress limits regarding parts’ dead load
- Compliance with the stress limit is seen as a mandatory, but not sufficient prerequisite for success
- The stress limit can be implemented as a load case for topology optimization

However

- Sintering behavior of MFFF parts was not investigated to the extent necessary
- Simplistic FEA set-up may be useful for quasi-brittle material behavior, but is in question for geometries with larger occurring deformation
- Material properties after deformation are an unresolved aspect
- The identified stress limits underlie deviations; statistically reliable values are still to be identified

SOURCES

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