

VI. Strength, Durability, and Noise Performance of Binder Jetting and L-PBF Gears –

Guilherme Guimarães, M.Sc. (ITA)/ Emil-Elias Breuer, M.Eng. (WZL)

Additive manufacturing (AM) emerges as a promising alternative for gear production, offering advantages such as design flexibility, reduced material waste, and faster prototyping cycles. However, the fatigue strength of AM gears is unclear in literature. This study presents a comparative analysis of gears produced using two prominent AM technologies, Binder Jetting (BJT) and Laser Powder Bed Fusion (LPBF), against their conventionally manufactured counterparts. For Binder Jetting, 17-4PH BJT gears were evaluated against 17-4PH gears produced through the conventional chain of hobbing and profile grinding. In the case of LPBF, 20MnCr5 LPBF gears were compared with conventionally manufactured 20MnCr5 gears that underwent hobbing, carburizing, and profile grinding. The load-carrying capacity was assessed through tooth bending fatigue tests using the staircase method to determine strength, followed by contact fatigue tests at fixed torque levels to capture Weibull failure probabilities. The experimental results indicate that, while AM gears currently exhibit a performance gap compared to wrought steel gears, their mechanical behavior is promising for a range of applications. These findings provide valuable insights into the potential of AM for efficient and customized gear production.

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The Brazilian Gear Conference ITA-WZL 2025

Strength, Durability, and Noise Performance of Binder Jetting and L-PBF Gears

Guilherme Guimarães, M.Sc. (ITA)

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São José dos Campos, August 13th & 14th, 2025

Agenda

1. Future Mobility versus Gear Requirements
2. What about Performance?
3. Challenges & Limitations
4. Conclusion & Outlook



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Future of Mobility Translated to Gear Requirements

Ford Opens Cologne EV Center, Home Of Europe's Electric Explorer SUV

Production of the electric Explorer starts this year, followed in mid-2024 by a second MEB-based EV dubbed a "sports crossover"

One shared car 'replaces ten private cars' in Flanders

[The Brussels Times, 2023]

[InsideEVs, 2023]

Uber is taking its car-sharing service to North America

Kirsten Korman, @kirstenkorman1 • 6:02 AM GMT+1 • June 9, 2023

Electric cars demand in Europe grows as over 1 million passenger EVs registered in Q1, 2023

[InsideEVs, 2023]

[Techcrunch, 2023]

San Francisco is a postcard from a driverless car future. Here's what it's like.

[Washington Post, 2023]

Chinese EV maker Xpeng expands self-driving capability to streets of Beijing as it bids for autonomous car leadership

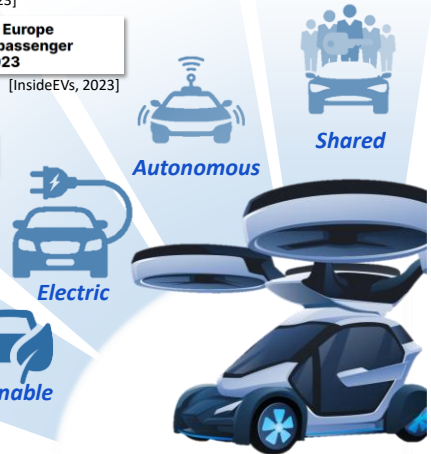
[South China Morning Post, 2023]

EU Climate Policy Reforms Set Conditions for Large Global Manufacturers to Decarbonize

[EnvironmentLeader, 2023]

SKF announces five-year, \$278m decarbonisation investment

[Power Technology, 2023]



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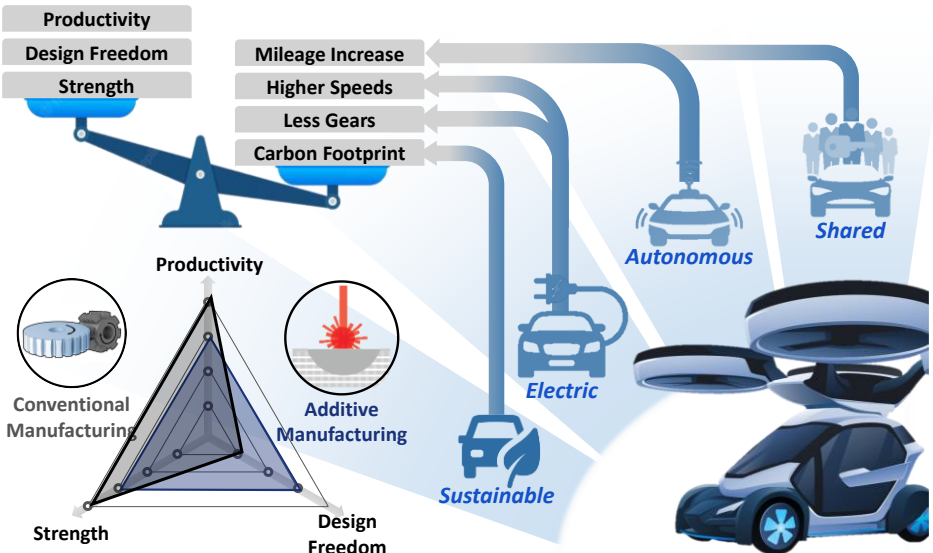
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Future of Mobility Translated to Gear Requirements



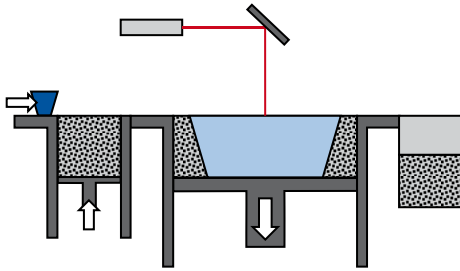
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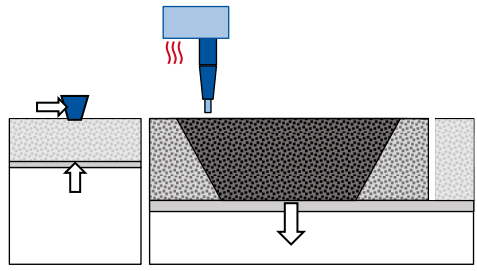
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Laser Powder Bed Fusion [L-PBF]

Process Type	=	Direct Process
Material	=	20MnCr5
Machine	=	Alkimat Laser Funde 200
Laser Power	=	250 W
Scan Speed	=	550 mm/s
Layer Height	=	0.045 mm

[KLEE22]



Binder Jetting [BJT]

Process Type	=	Indirect Process
Material	=	17-4PH
Machine	=	Digital Metal DMP2500
Binder Level	=	Dark 1
Scan Speed	=	200 mm/s
Layer Height	=	0.042 mm

[KLEE22]



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Testing Geometry and Test-Rigs

ITA Gear



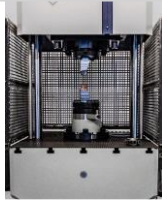
Material: 20MnCr5



$m = 2.85 \text{ mm}$
 $z = 23$
 $\alpha = 17.5^\circ$
 $b = 15 \text{ mm}$
 $d_a = 70 \text{ mm}$

WS VS LPBF

Bending



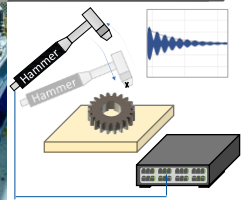
Rumul 150 Testronic

Contact



ITA's Test Rig

NVH



Hammer Testing

WZL Gear



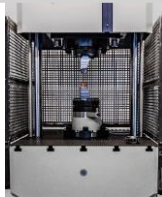
Material: 17-4PH



$m = 3.17 \text{ mm}$
 $z = 20$
 $\alpha = 20^\circ$
 $b = 18 \text{ mm}$
 $d_a = 72 \text{ mm}$

WS VS BJT

Bending



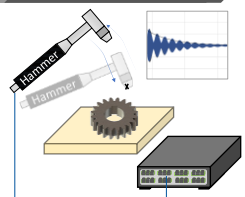
Rumul 150 Testronic

Contact



FZG Test Rig

NVH



Hammer Testing



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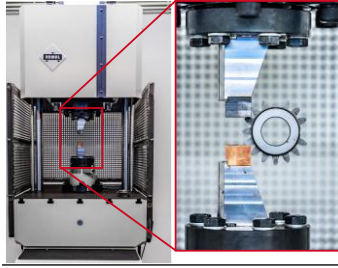


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Bending Strength: Binder Jetting vs Wrought Steel



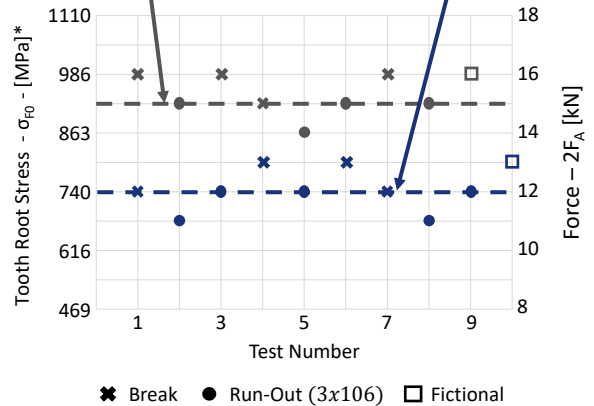
Test Parameters

Test Rig	= Rumul Testronic 150
Gear	= WZL GSM
Material	= 17-4PH
Z_{clamp}	= 4
F_0	= -0.5 kN
Frequency	= 147 Hz

*Stress calculated based on ISO 6336-3

Wrought Steel
 $\sigma_{F_0 mean} = 945 \text{ MPa}$
 $2FA_{mean} = 15 \text{ kN}$

Binder Jetting
 $\sigma_{F_0 mean} = 710 \text{ MPa}$
 $2FA_{mean} = 12 \text{ kN}$



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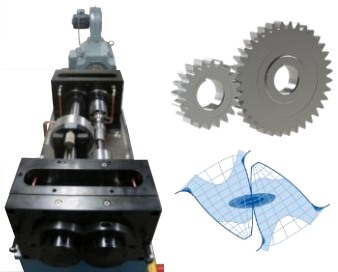


WZL

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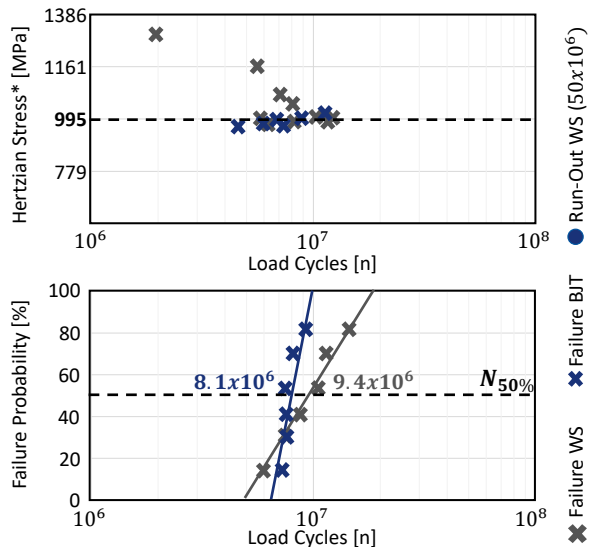
Contact Fatigue: Binder Jetting vs Wrought Steel



Test Parameters

Test Rig	= FZG Test Rig
Gear	= WZL GSM
Material	= 17-4PH
Center Distance	= 91.5 mm
Rotation	= 5400 rpm
T_{oil}	= 90°C

*Theoretical Value Calculate based on ISO 14635-1



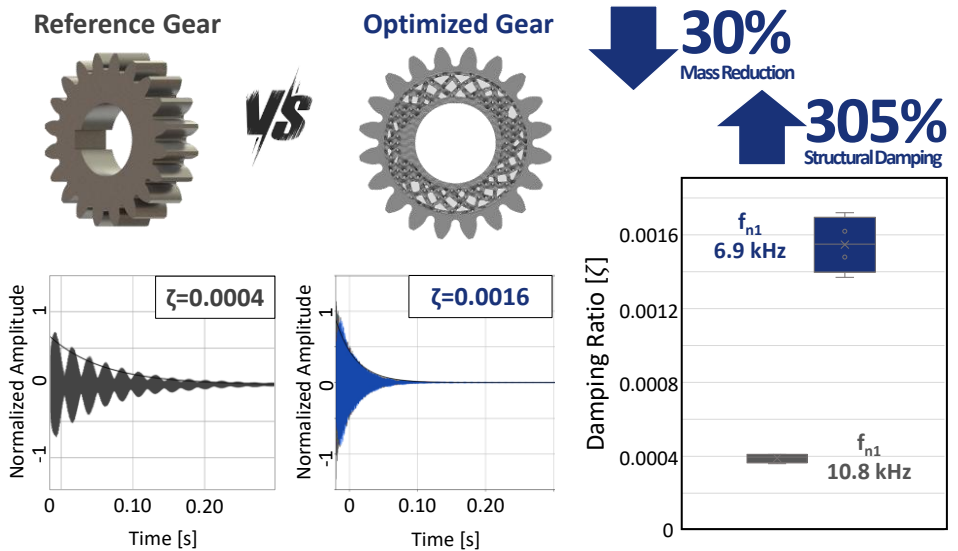
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WZL

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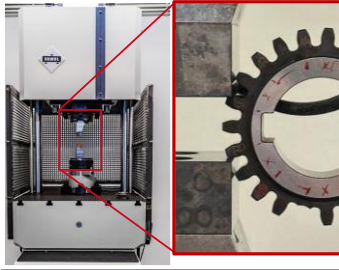


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Bending Strength: Laser Powder Bed Fusion (LPBF) vs Wrought Steel



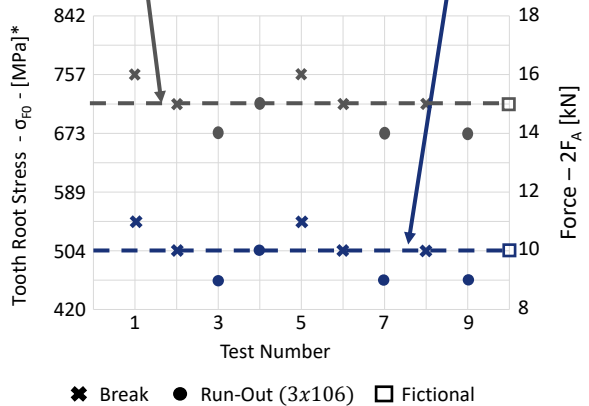
Test Parameters

Test Rig	= Rumul Testronic 150
Gear	= ITA HPD
Material	= 20MnCr5
Z_{clump}	= 4
F_0	= -0.5 kN
Frequency	= 147 Hz

*Stress calculated based on ISO 6336-3

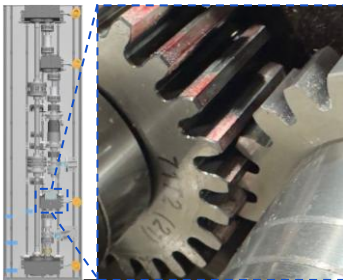
Wrought Steel
 $\sigma_{F_0 mean} = 715 \text{ MPa}$
 $2FA_{mean} = 15 \text{ kN}$

LPBF
 $\sigma_{F_0 mean} = 504 \text{ MPa}$
 $2FA_{mean} = 10 \text{ kN}$



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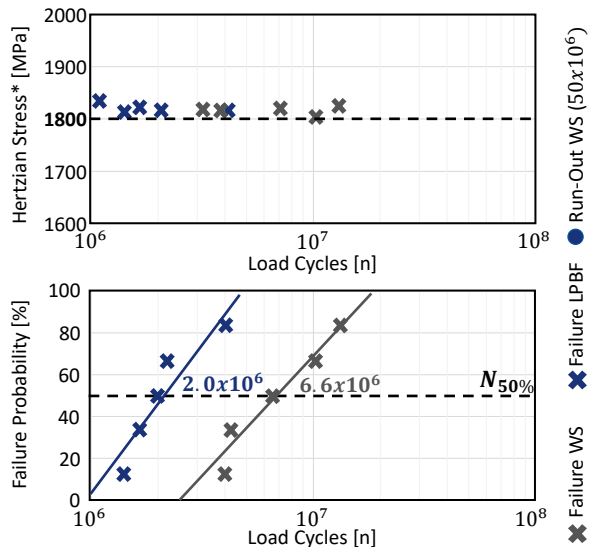
Contact Fatigue: Laser Powder Bed Fusion (L-PBF) vs Wrought Steel



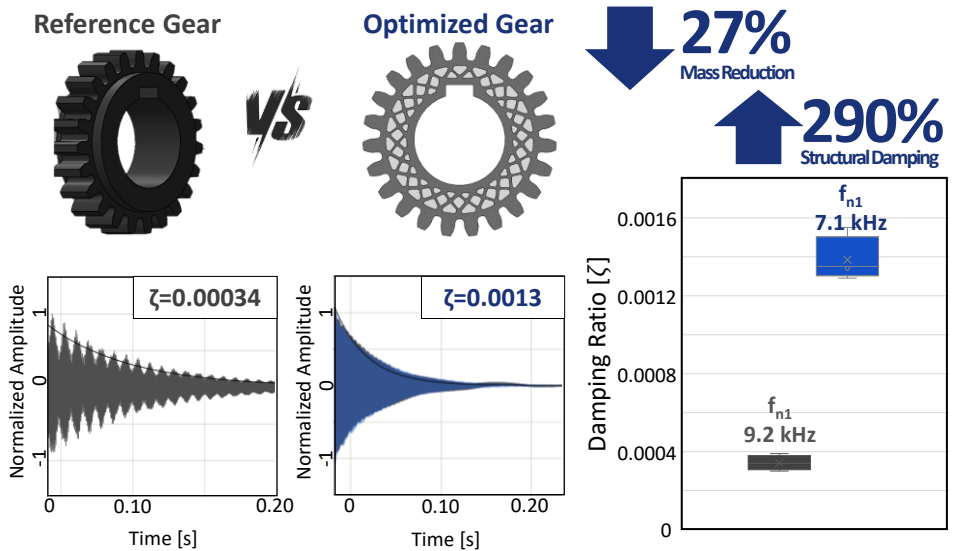
Test Parameters

Test Rig	= ITA Test Rig
Gear	= ITA HPD
Material	= 20 MnCr5
Center Distance	= 71 mm
Rotation	= 4000 rpm
T_{oil}	= 90°C

*Theoretical Value Calculate based on ISO 14635-1



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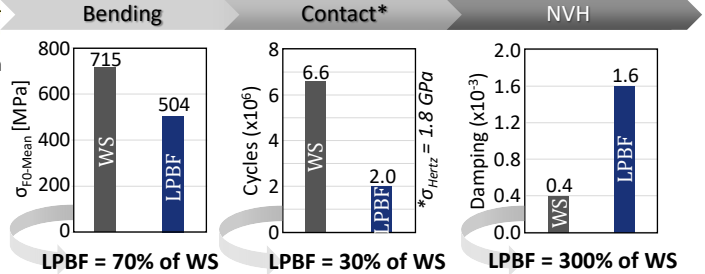
Summary of Results

ITA Gear



$m = 2.85 \text{ mm}$
 $z = 23$
 $\alpha = 17.5^\circ$
 $b = 15 \text{ mm}$
 $d_a = 70 \text{ mm}$

Material: **20MnCr5**

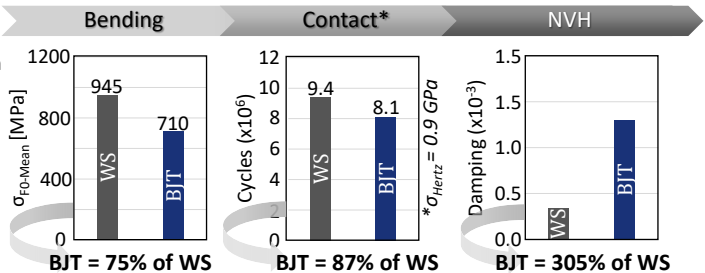


WZL Gear



$m = 3.17 \text{ mm}$
 $z = 20$
 $\alpha = 20^\circ$
 $b = 18 \text{ mm}$
 $d_a = 72 \text{ mm}$

Material: **17-4PH**

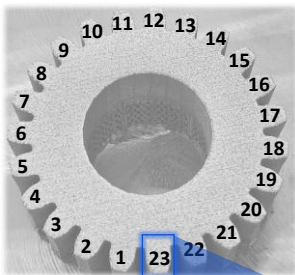


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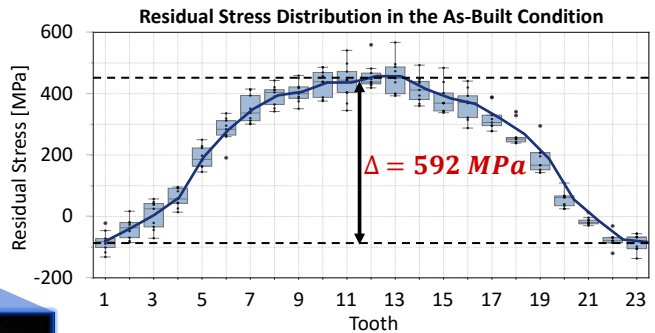
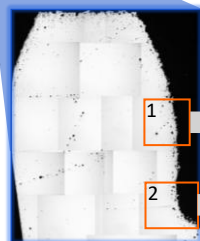


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Challenges: Porosity & Residual Stress



Tooth Porosity



1. Flank Porosity



2. Tooth Root Porosity



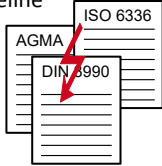
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Process

- Lack of standards and qualification procedures for critical sectors
- No standardized calculation method or design guideline



- Shrinkage of 15–20% occurs during sintering due to the low density of the green part



Materials

- Many industrially established alloys are not yet qualified, especially for demanding applications like gears
- Process relies on spherical powders with a narrow particle size distribution, which are cost-intensive



- Material development and qualification remain key challenges for broader application of BJT



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Conclusions and Outlook

There is no right technology.
There is just **the most suitable** for each application...



70%

In overall the Additive Manufactured gears reached 70% of the bending strength when compared to conventionally manufactured gears.

80%

In overall the Additive Manufactured gears reached 80% of the Conventionally manufactured in contact fatigue.

300%

The design freedom in Additive Manufactured allowed an increase of 300% in damping properties.

50%

The use of Additive Manufactured reduced in 50% the material used for manufacturing the gears.



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Conclusions and Outlook

There is no right technology.
There is just **the most suitable** for each application...



- New **Finishing Routes** are required for attending the additive manufacturing challenges.



- Porosity
- Residual Stresses
- Roughness

- The development of **new alloys** is required for further development of binder jetting.

- Development of **standards and qualification** procedures for critical sectors.

- Incorporation of AM in gear design guidelines and standards.



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