# Mechanical Properties Prediction with MAGMASOFT®

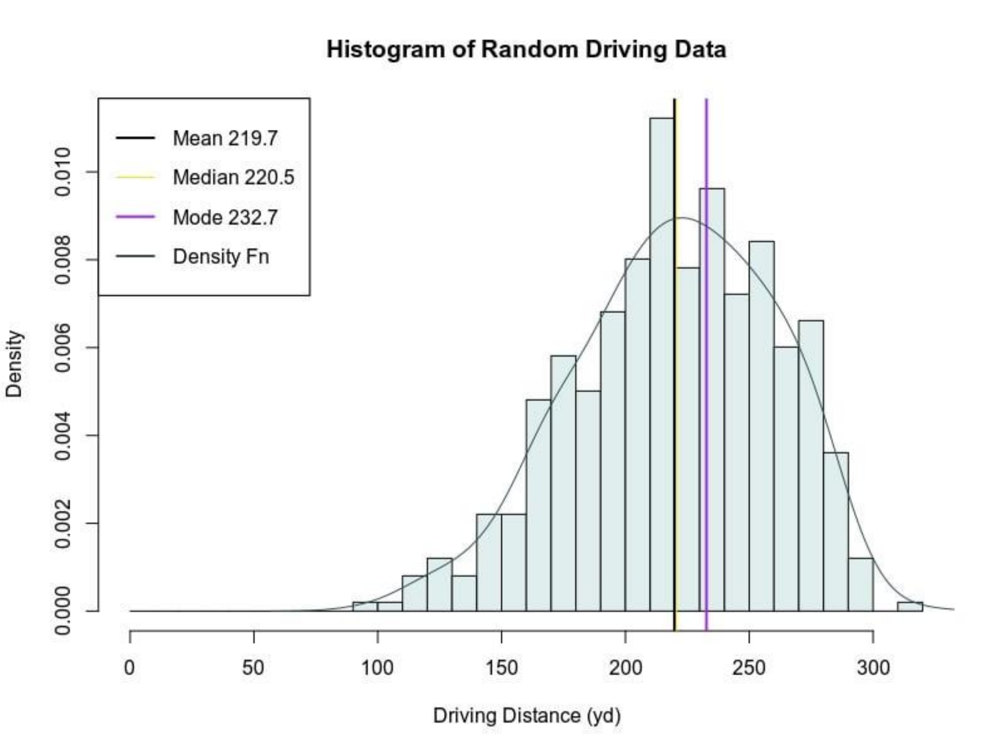
## From Deterministic to Probabilistic Modeling


Vanessa Glück Nardi

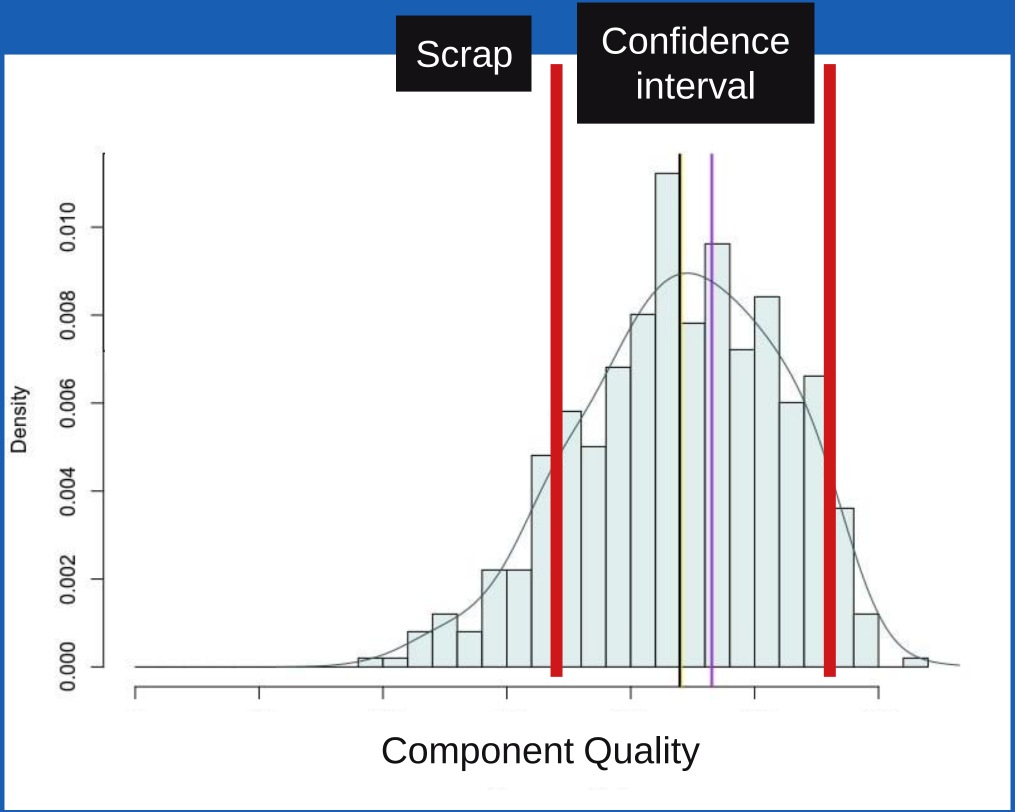
**Frankfurt**


Histogram of Random Driving Data
Mean 219.7
Median 220.5
Mode 232.7
Density Fn
Density
0.000
0.002
0.004
0.006
0.008
0.010
0
50
100
150
200
250
300
Driving Distance (yd)

# HIGH-QUALITY PERFORMANCE IS TO REACH FAR WHILE STAYING ON THE FAIRWAY!



# HIGH-QUALITY PERFORMANCE IS TO REACH COMPONENT QUALITY



# How well do your castings perform?

# Challenges in Casting Design


Photo credit: Huisman

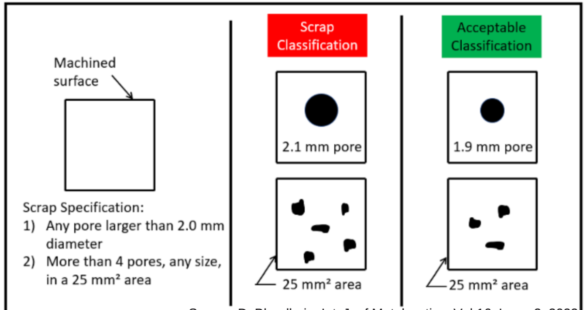
- Stiffness
- Ductility
- Tensile strength
- Toughness
- Fatigue strength

# Challenges in Casting Design

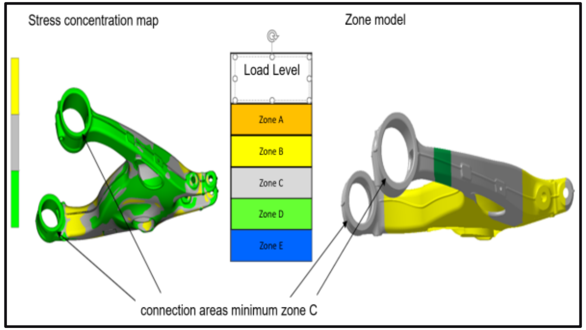
## How are „casting properties“ considered?

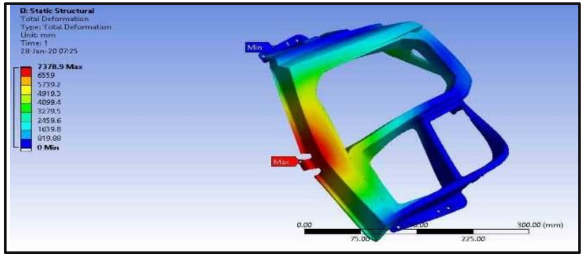
- Specific material performance depending on local loads
- Different types of casting specifications subject to customer requirements
  - Defect classification
  - Local requirements (zone model)
  - Global requirements (crash requirements in CAE)
- Durability and crash simulations often assume homogeneous material properties

**→ Specifications are driven by risk management resulting in significant safety margins and over-dimensioning**



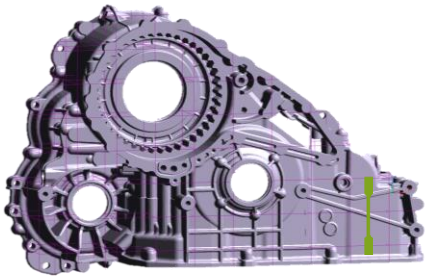
Source: D. Blondheim Int. J. of Metalcasting, Vol 16, Issue 2, 2022



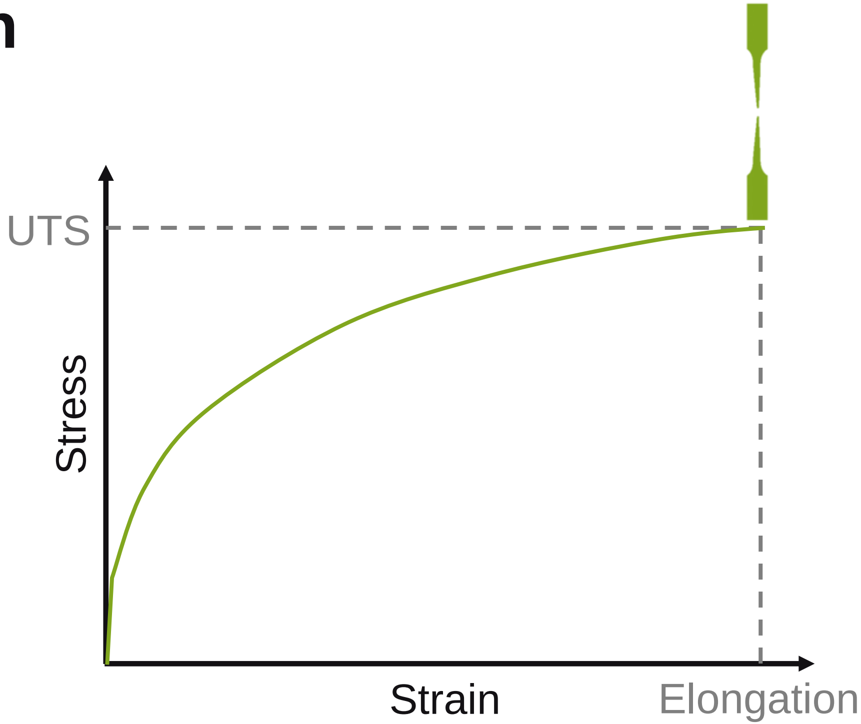



# Challenges in Casting Design

## Materials fail!

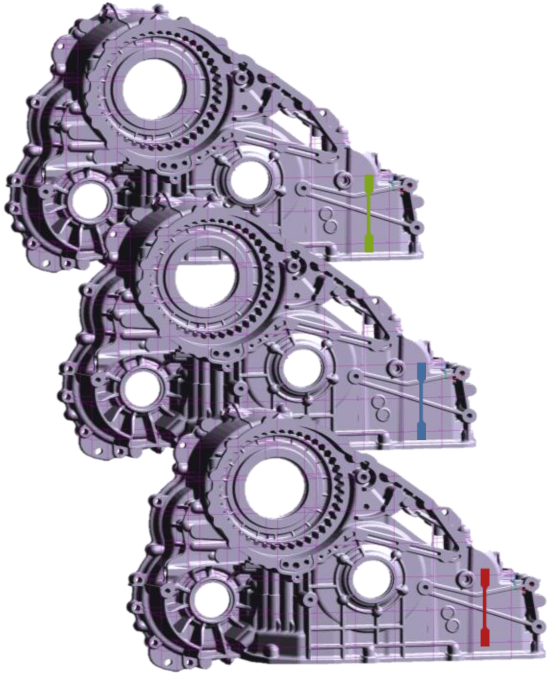


Tensile test

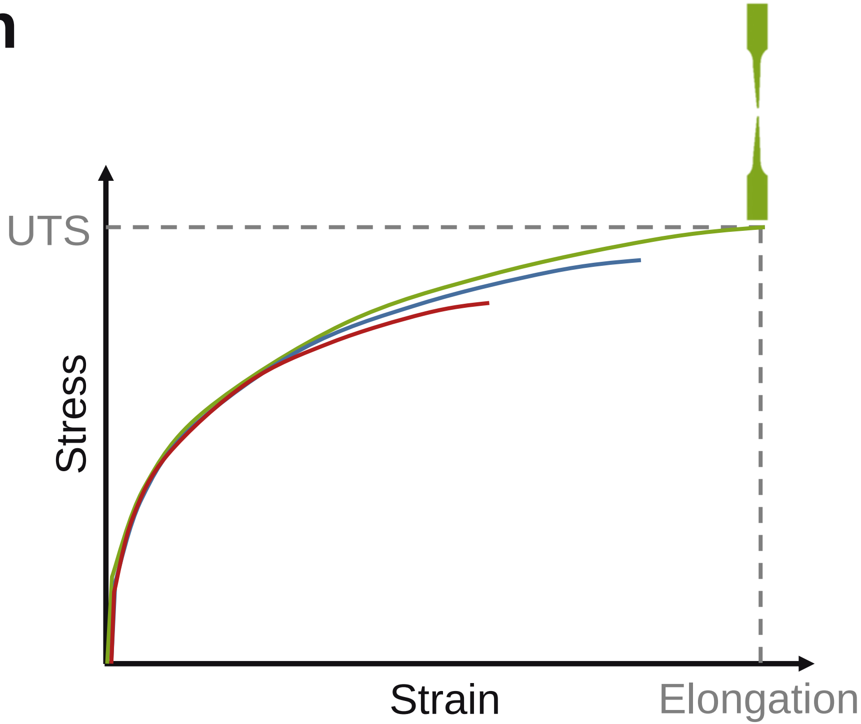


# Challenges in Casting Design

## Materials fail!



Tensile test

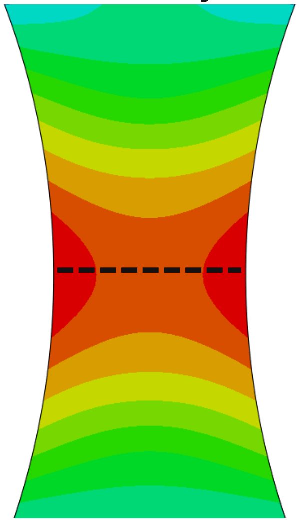


# Challenges in Casting Design

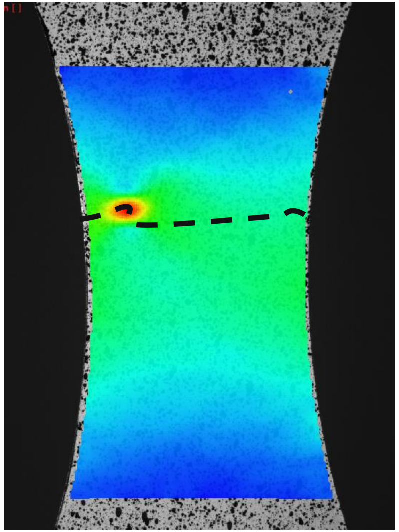
No
pores

## Why do materials fail?

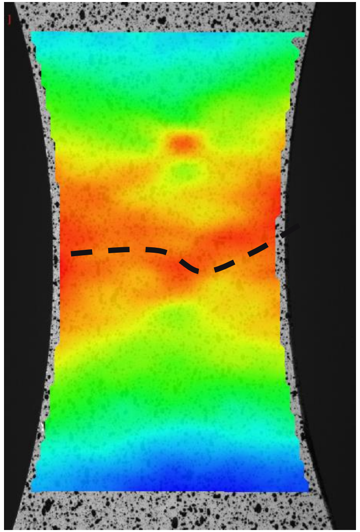
Theory



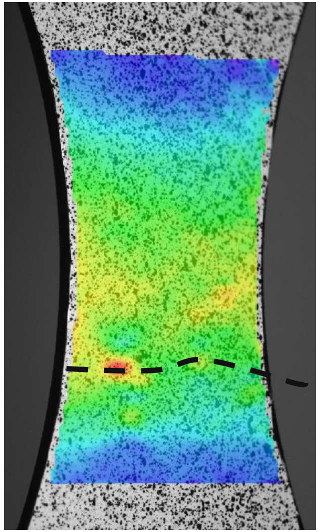
Reality 1



Reality 2



Reality 3



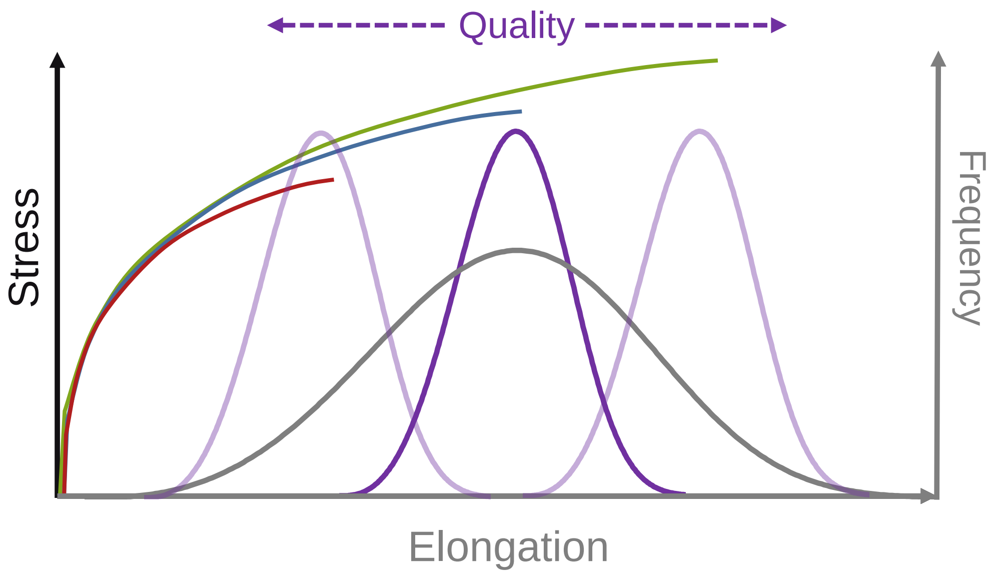
- Repeated tests with seemingly identical material
- Competition between defects, fracture finds the weakest link

**Ref:** J. Olofsson, T. Bogdanoff, M. Tiryakioglu, *Materials Characterization*, 2024

# Challenges in Casting Design

## Sources of variability → Variability in results

Lower process variability → Lower results variability




- **Inherent variability** in the casting process itself.
  - related to melt quality, melt processing, etc.

  Shown as frequency plot!

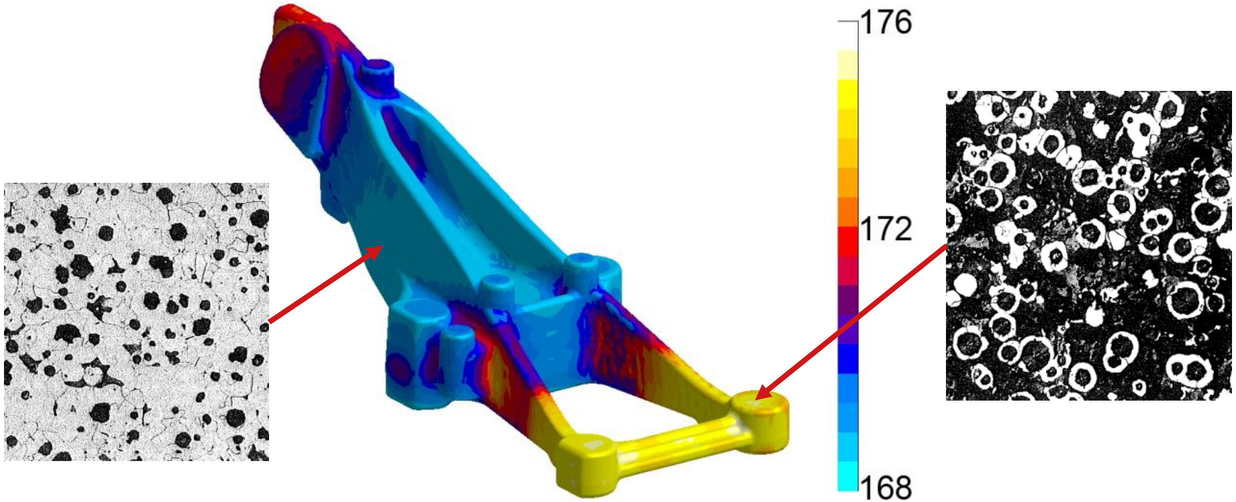
- Failure follows a **weakest-link** failure mode → Well described by **Weibull distribution.**
  - **It takes two parameters:**
    - Shape → Process variability
    - Position → Quality

# How does MAGMASOFT® predict mechanical properties?

# HISTORY

## 1990‘s

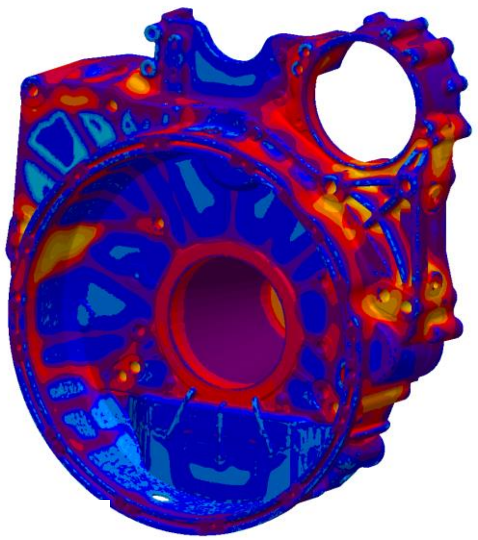
- **MAGMAiron:** Microstructure modeling and microstructure-based material properties

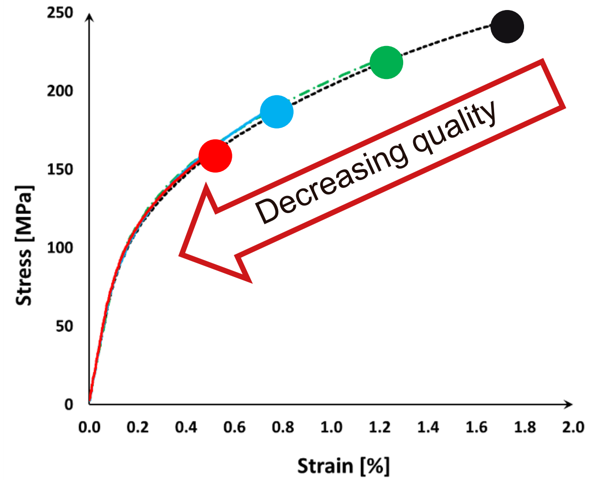


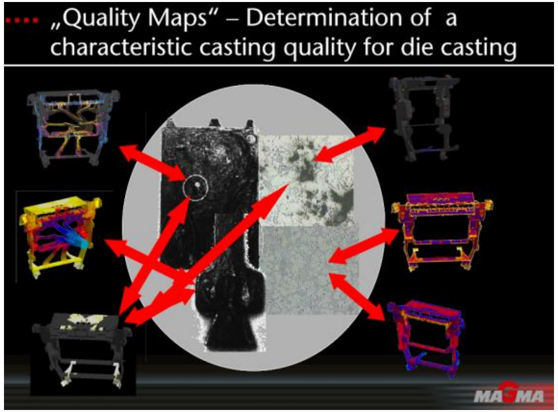
# HISTORY

## 2000‘s

- **MAGMAnon-ferrous:** Modeling of microstructure-based non-linear tensile curves.
- *Optimal quality parameter* and influence of porosity on local material performance
- Quality maps and local casting quality



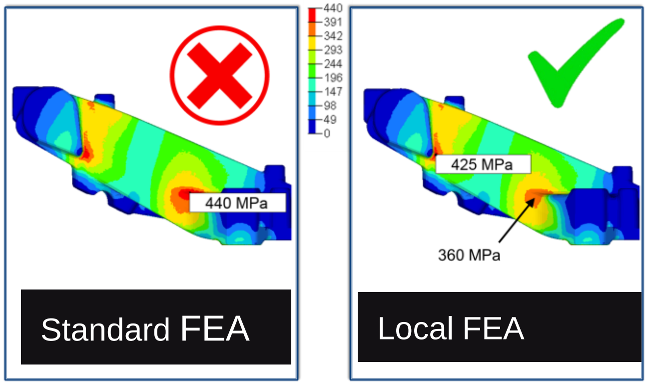


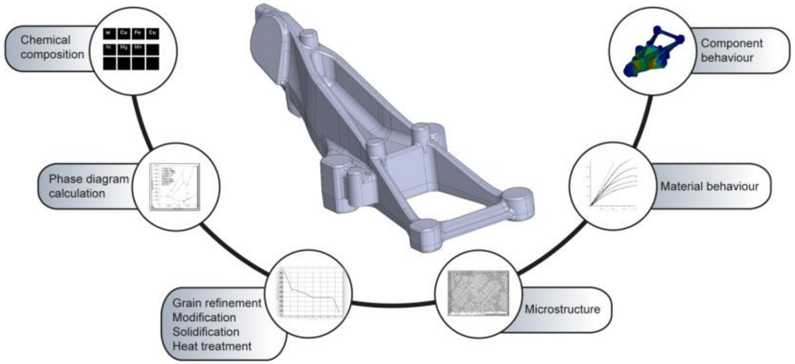



# HISTORY

## 2010's

- Coupling between MAGMASOFT and FEA (MAGMAlink)
- Predict static behavior, fatigue life and fracture properties
- Local properties are needed in order for FEA to correctly identify failure regions



# MICROSTRUCTURE-BASED PROPERTIES

## Deterministic approach

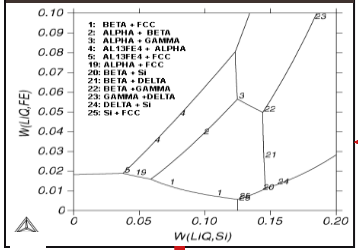
Process

Alloy composition

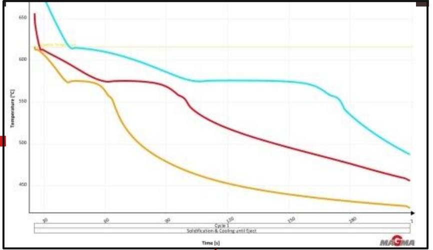
| Aluminum Composition | | |
|---|---|---|
| Cr (Chromium) | 0.0 | % |
| Cu (Copper) | 0.03 | % |
| Fe (Iron) | 0.5 | % |
| H (Hydrogen) | 0.0 | ml/100g |
| Mg (Magnesium) | 0.4 | % |
| Mn (Manganese) | 0.3 | % |
| Na (Sodium) | 0.0 | % |
| Ni (Nickel) | 0.1 | % |
| P (Phosphorus) | 0.0 | % |
| Sb (Antimony) | 0.0 | % |
| Si (Silicon) | 7.0 | % |
| Sr (Strontium) | 0.0 | % |
| Ti (Titanium) | 0.15 | % |
| Zn (Zinc) | 0.1 | % |

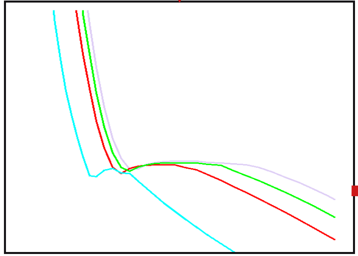
Metallurgy

Thermal equilibrium

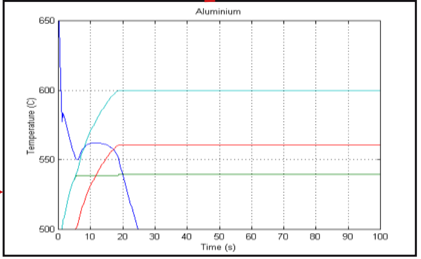



Latent heat and solidification



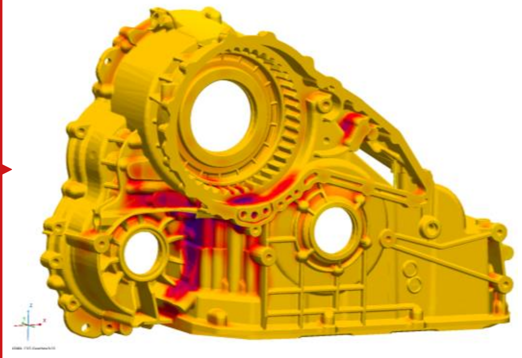


Kinetics




Segregation

Microstructure-based properties



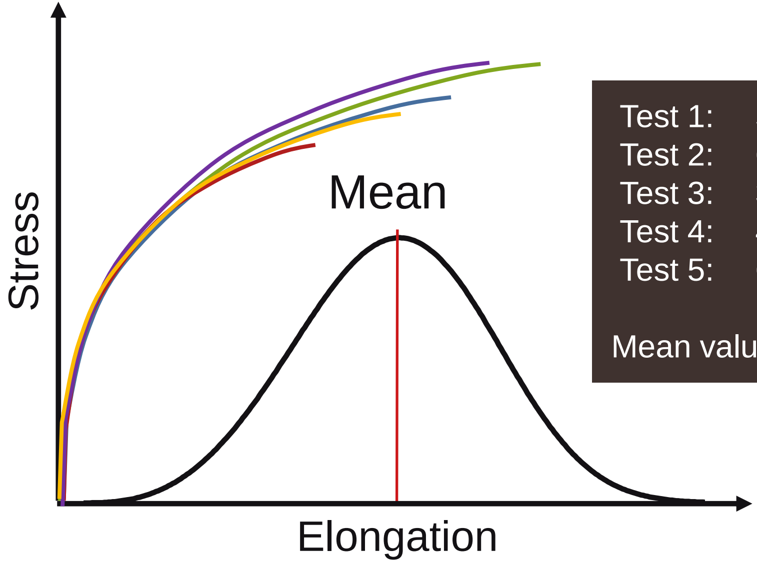
Only provides mean values

# Do the simulations match reality?

# Do the simulations match reality?

Repeated “identical” tests from 5 castings in serial production

- Same geometry, same settings, same melt, same position




| | |
|---|---|
| Test 1: | 5.1 % |
| Test 2: | 6.9 % |
| Test 3: | 3.6 % |
| Test 4: | 4.7 % |
| Test 5: | 6.4 % |

Mean value: **5.3%**

- Experimental mean value matches simulation results.
- None of the tests corresponds to the predicted mean value.
- Simulation is right but something is missing…

There is a variability to consider

# THE CHALLENGE

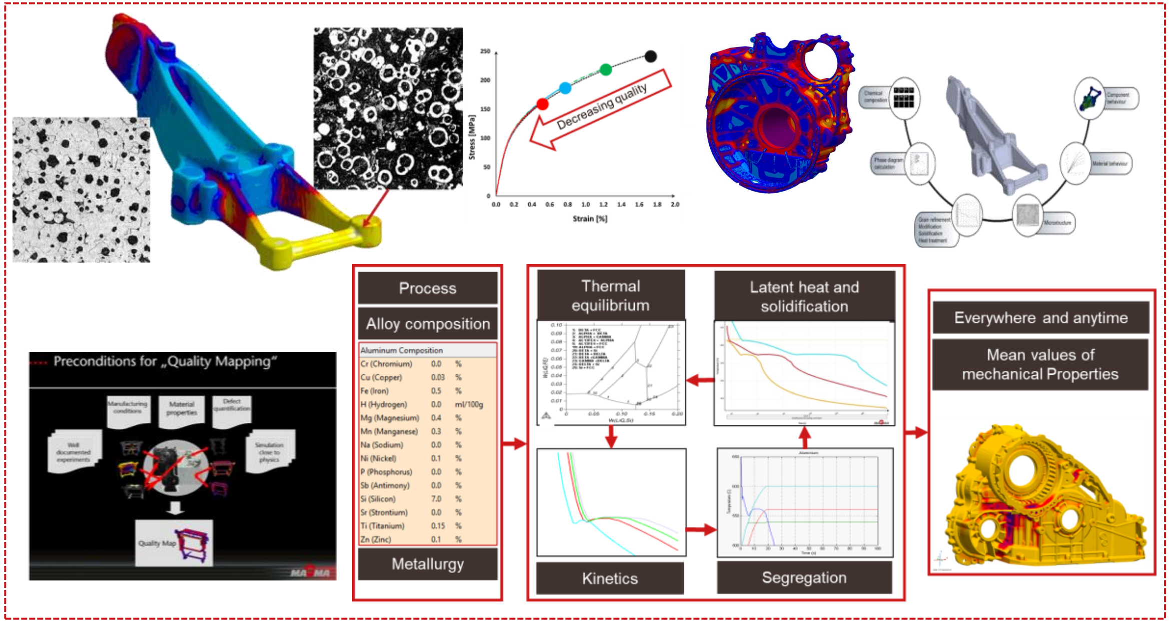
## Properties do not always end up on the same spot

- The physics of material performance is probabilistic
- Deterministic mean values don’t tell you how often you “end up in the rough”
- If you’re lucky, “ending up in the rough” causes scrap. If not, your casting might fail on service…

# New methodology in development

# PROBABILISTIC PROPERTY PREDICTIONS

Based on more than 30 years of microstructure-based properties prediction development and on real world variability

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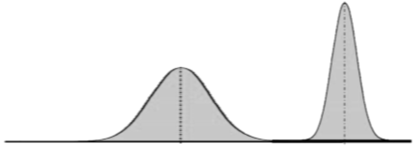
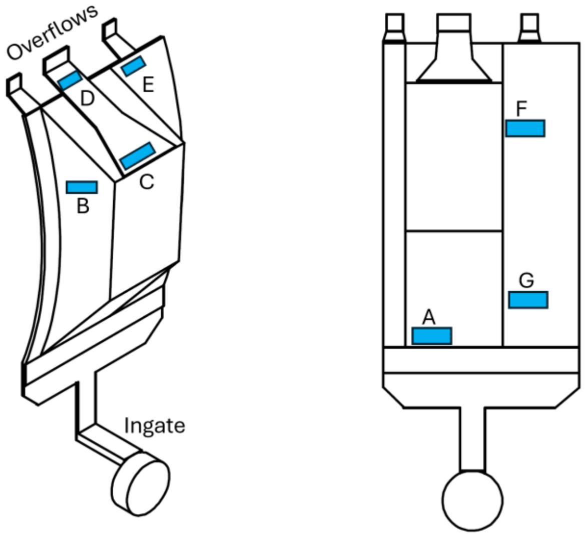
PROBABILISTIC PROPERTY PREDICTIONS

Using process variability



One simulation provides both the mean value and **insight into expected property variations.**

# REAL LIFE EXAMPLE




Schematic geometry

HPDC aluminum casting in serial production

- DOE with four different trials with different process parameters
- Five castings per trial
- Seven positions per casting

**140 tensile tests**

- Evaluated using µ-CT, optical microscopy, SEM analysis, Digital Image Correlation (DIC)

- **GOAL**: Evaluate if elongation shows a statistically significant change in different locations and with different casting parameters

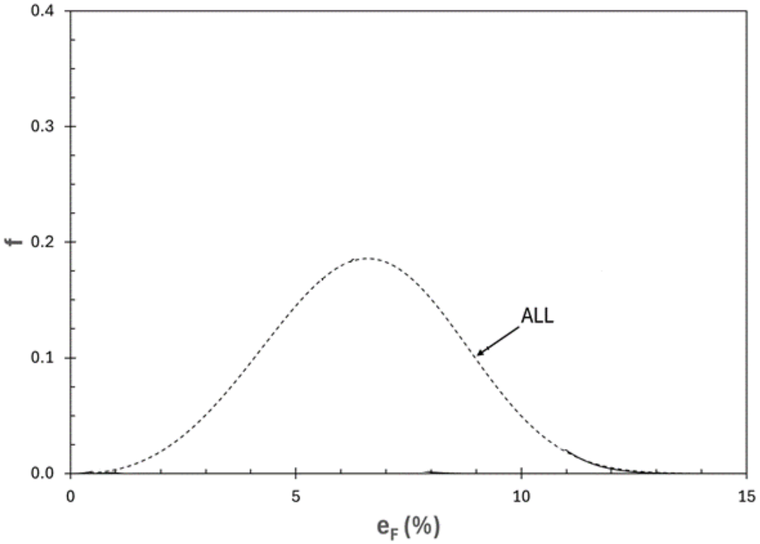
**Ref:** J. Olofsson, T. Bogdanoff, M. Tiryakioglu, H. Bramann, J. Sturm, Submitted publication

# REAL LIFE EXAMPLE

Experimental findings:

1

- No statistically significant effect of the investigated process parameters on elongation
- The variability is quantitatively described by the Weibull shape parameter




**There is a general process variability that describes the distribution of elongation values throughout the casting**

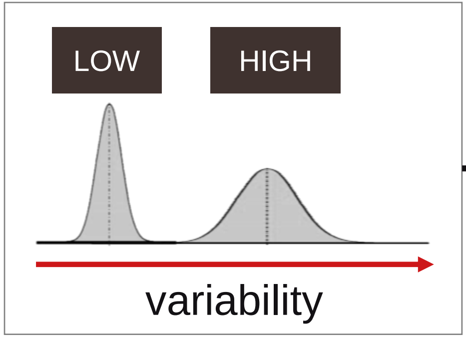
**Ref:** J. Olofsson, T. Bogdanoff, M. Tiryakioglu, H. Bramann, J. Sturm, Submitted publication

# PROBABILISTIC PROPERTY PREDICTIONS

## General process variability concept

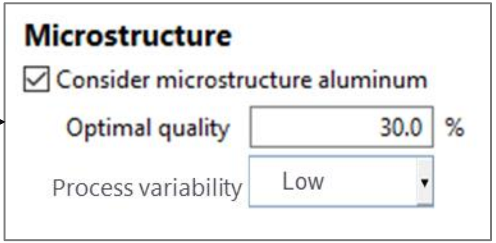
- This understanding of **general process variability** serves as input for the simulation

The level of variability you reach in your foundry




Based on measurements and knowledge about your process

INPUT



# REAL LIFE EXAMPLE

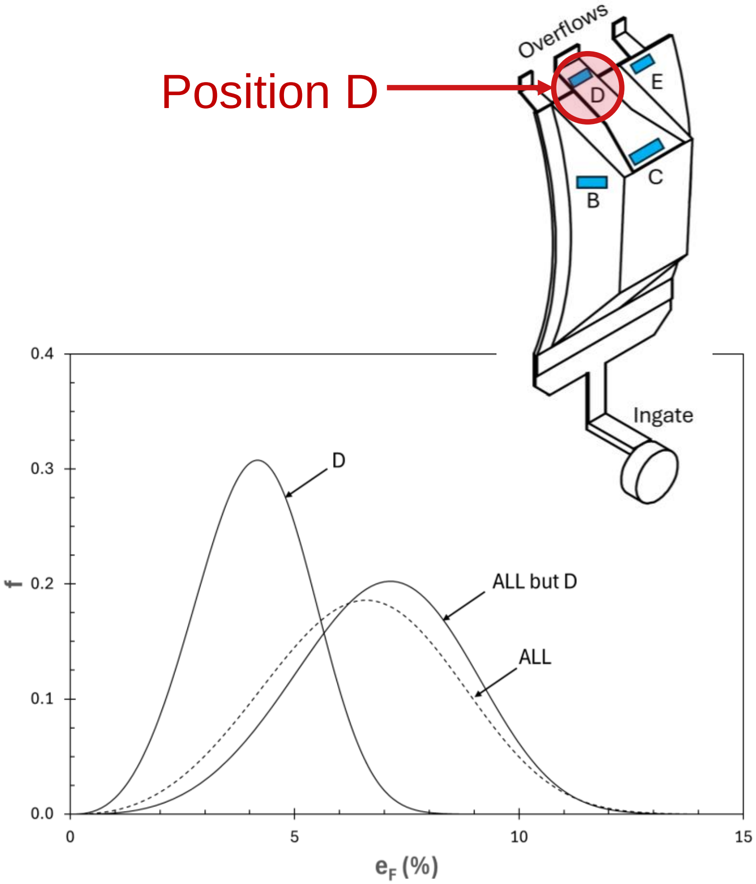
Experimental findings:

1

- No statistically significant effect of the investigated process parameters on elongation
- The variability is quantitatively described by the Weibull shape parameter

2

- One position stands out as different: Position D

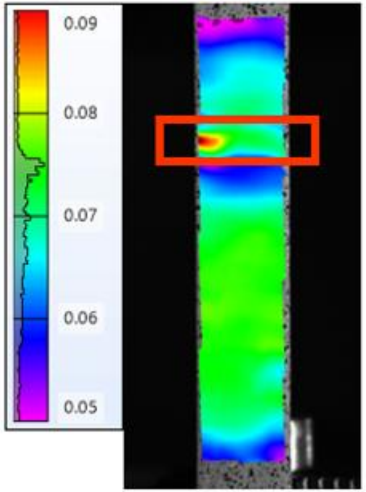


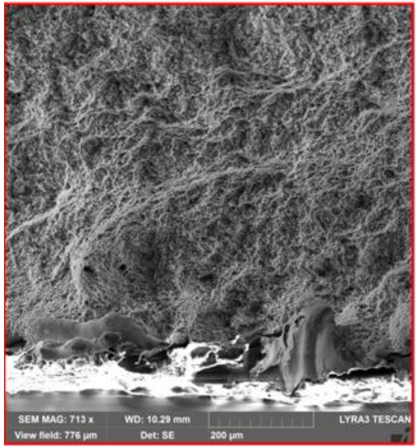

**Ref:** J. Olofsson, T. Bogdanoff, M. Tiryakioglu, H. Bramann, J. Sturm, Submitted publication

# REAL LIFE EXAMPLE

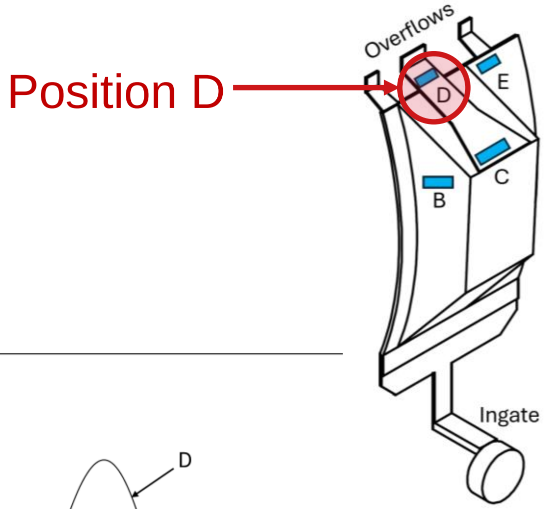
Experimental findings:

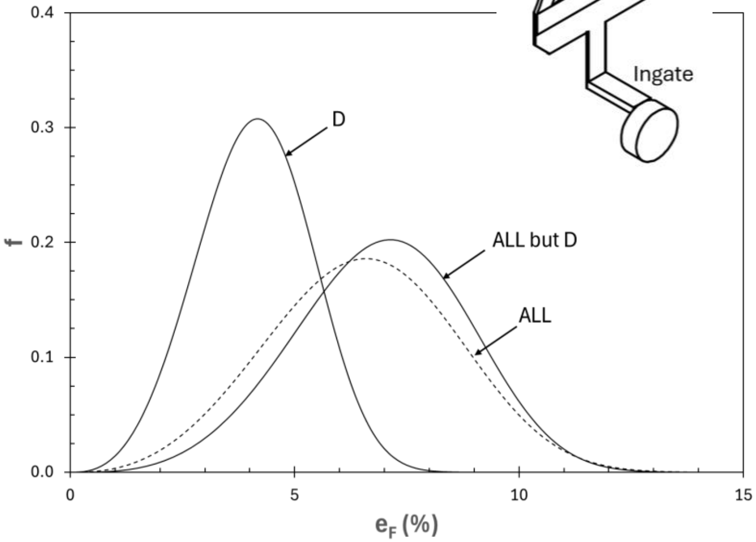
- What happens in Position D?



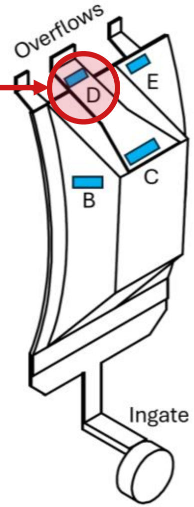

**Large amounts of oxides**



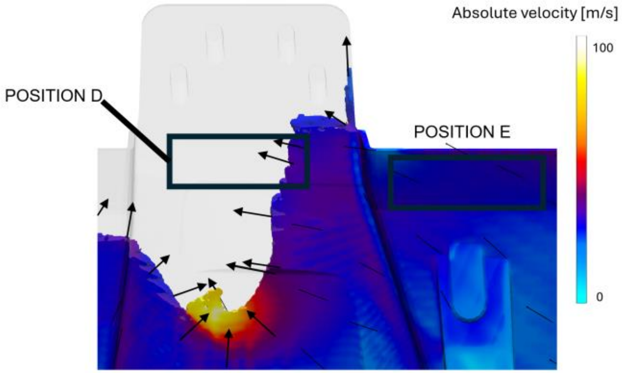

**Ref:** J. Olofsson, T. Bogdanoff, M. Tiryakioglu, H. Bramann, J. Sturm, Submitted publication

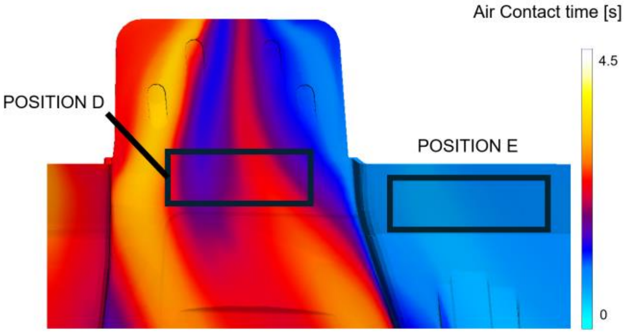
# REAL LIFE EXAMPLE




Experimental findings:

- What happens in Position D?
  - MAGMASOFT simulations reveal a violent **collision between melt fronts** and **high air contact** time.



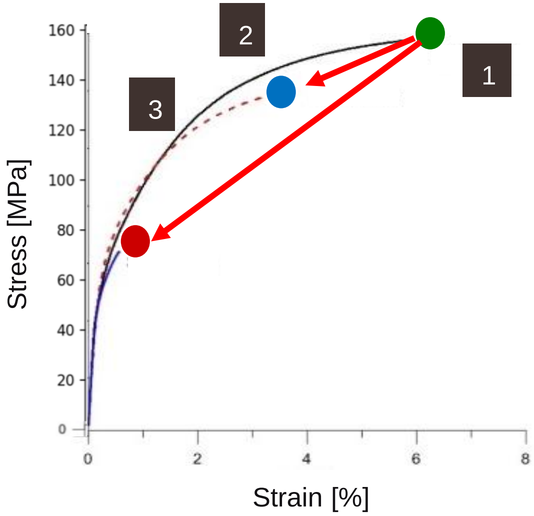

**There is a local effect that changes the mean value and the variability**

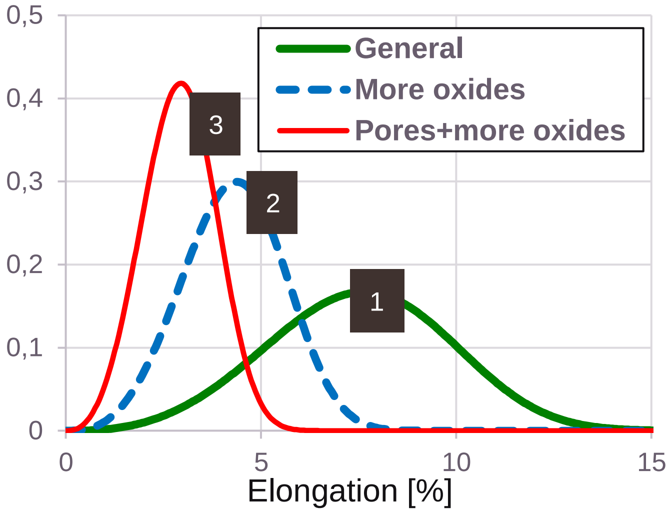
**Ref:** J. Olofsson, T. Bogdanoff, M. Tiryakioglu, H. Bramann, J. Sturm, Submitted publication

# PROBABILISTIC PROPERTY PREDICTIONS

**Local variability concept**

- The “Process variability” is applied with local microstructure, porosity, air entrapment, turbulence, etc., to determine **local performance and variability**.
- Example: oxides reduce the elongation but also affect the local variability. If combined also with porosity it becomes even worse.

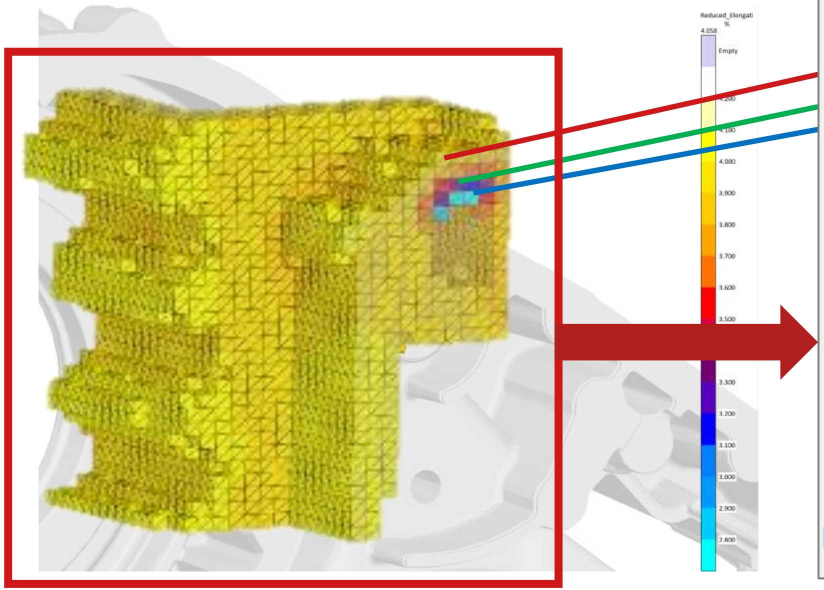


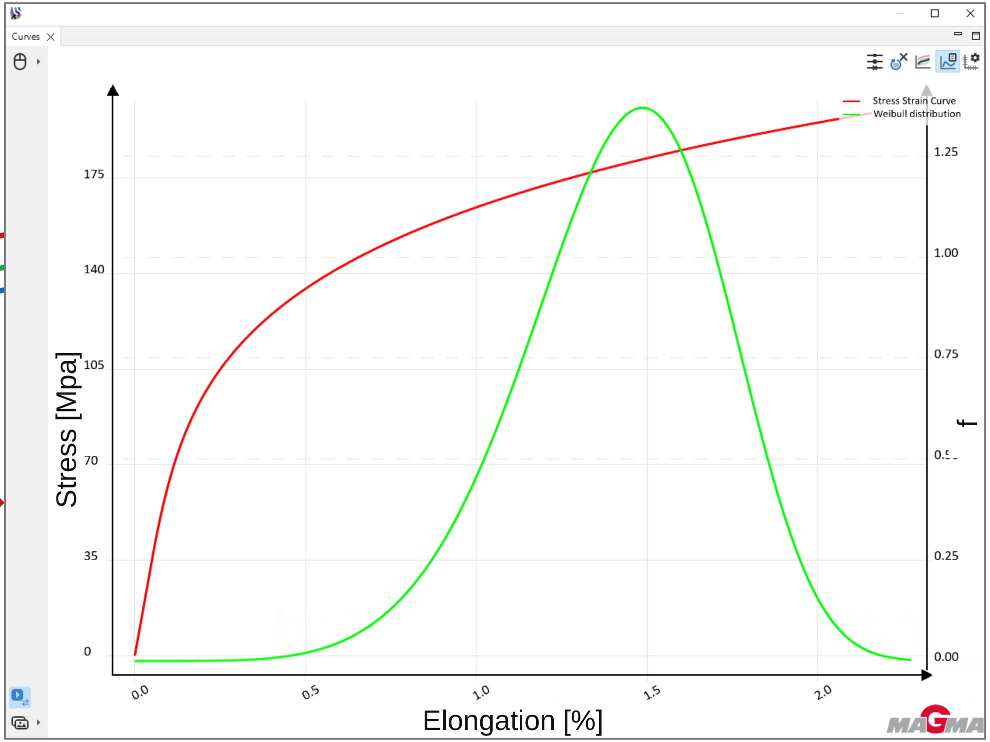



# PROBABILISTIC PROPERTY PREDICTIONS

## Application to a „Virtual test area“

Thousands of cells → Thousands of results !!!



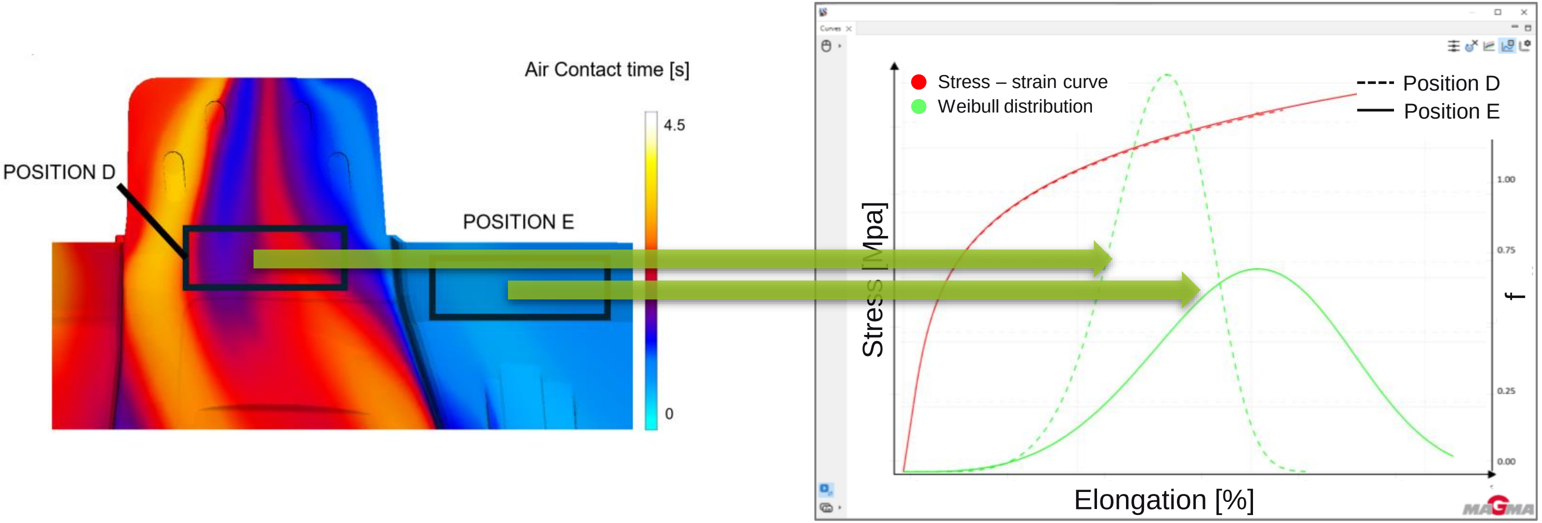



MAGMA

# PROBABILISTIC PROPERTY PREDICTIONS

## Application to a „Virtual test bar“

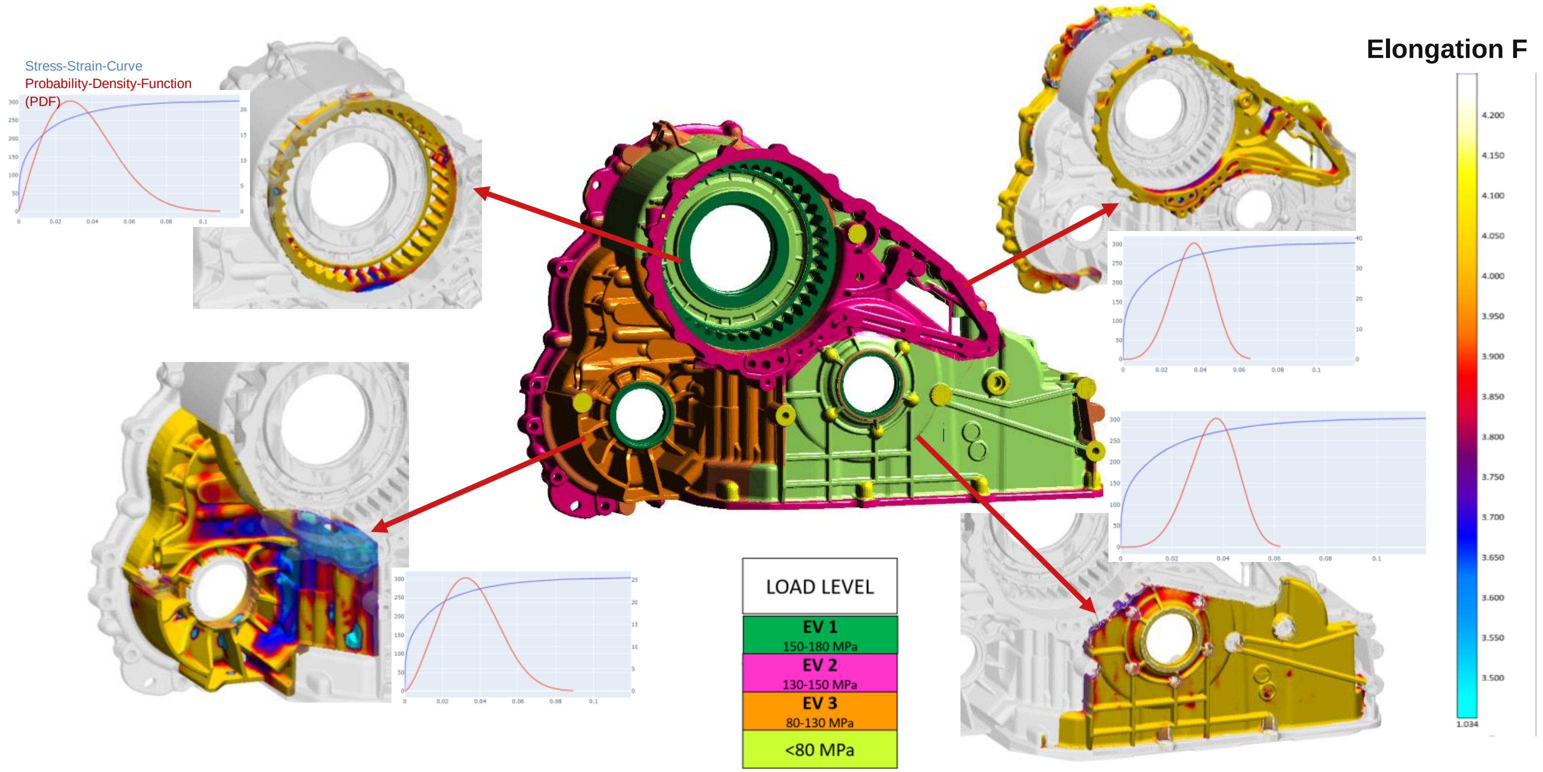
- Select areas to compare their performance
- Local tensile curves and elongation frequency plots are displayed




**The probabilistic approach captures the variation in elongation to failure in one simulation**

# PROBABILISTIC PROPERTY PREDICTIONS

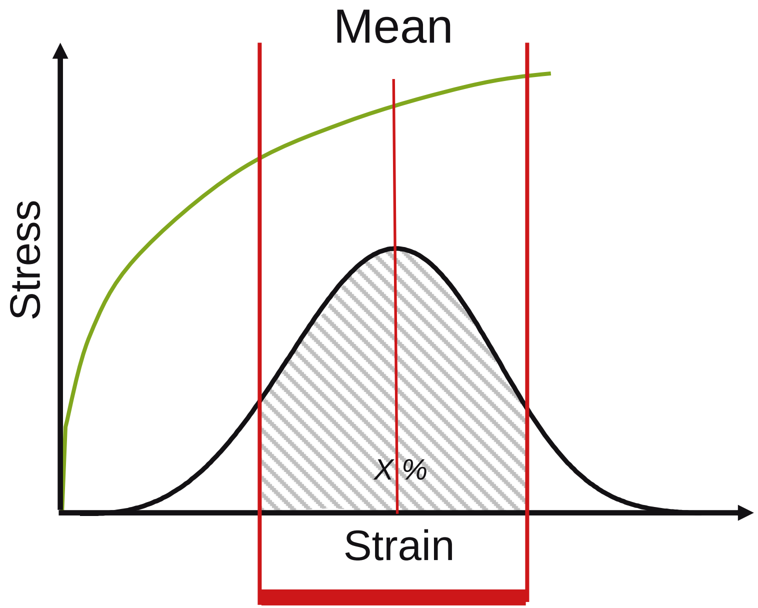
## Application to „Evaluation Zones“



# PROBABILISTIC PROPERTY PREDICTIONS

## Advantages – From deterministic to probabilistic

→ Simulations provide a **mean value** along with a **frequency plot** to visualize the **expected variation in properties** due to process variability in the foundry




→ Opportunity to give **design limits** and **confidence intervals** on what performance range can be expected

*X % of the castings exceeds the minimum requirement*

# FROM DETERMINISTIC TO PROBABILISTIC

## Summary

- A new methodology to provide confidence in predicted material performance
- Builds on 30 years of research in the modeling of mechanical performance of castings
- Developed in collaboration with customers and research partners at **Jönköping University**
- Patent applications filed
- Scientific publications (Giesserei, International Journal of Cast metals Research, etc.)

Available to you in the .zip folder

1

INTEGRATED VIRTUAL PRODUCT AND PROCESS DESIGN FOR CASTING COMPONENTS

TECHNICAL FIELD

The disclosure relates to processes that involve casting an object in a cavity in a mould. In particular, the disclosure relates to improving such casting processes by predicting local properties of the casting through integrated casting process simulation for optimizing cast object design during design phase and applying statistical analysis for optimizing mould and tool design and casting process conditions during production.

2/5

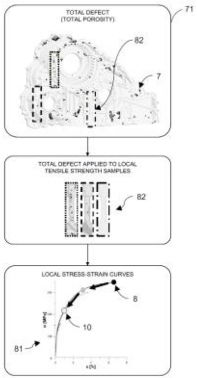



FIG. 3

# FROM DETERMINISTIC TO PROBABILISTIC

## Summary

- Applicable to all types of cast materials and processes
- Being developed and implemented for HPDC/MegaCasting in cooperation with customers

We aim to help you stay on the fairway

**Aim to be available for HPDC in MAGMASOFT 6.2**

# Thank you for your attention.

MAGMA Gießereitechnologie GmbH

Acknowledgements:
Jakob Olofsson, MAGMA research partner & Associate professor at Jönköping University
Toni Bogdanoff, Assistant Professor, Jönköping University