2nd Czech-German Business Meeting, 10.04.2025

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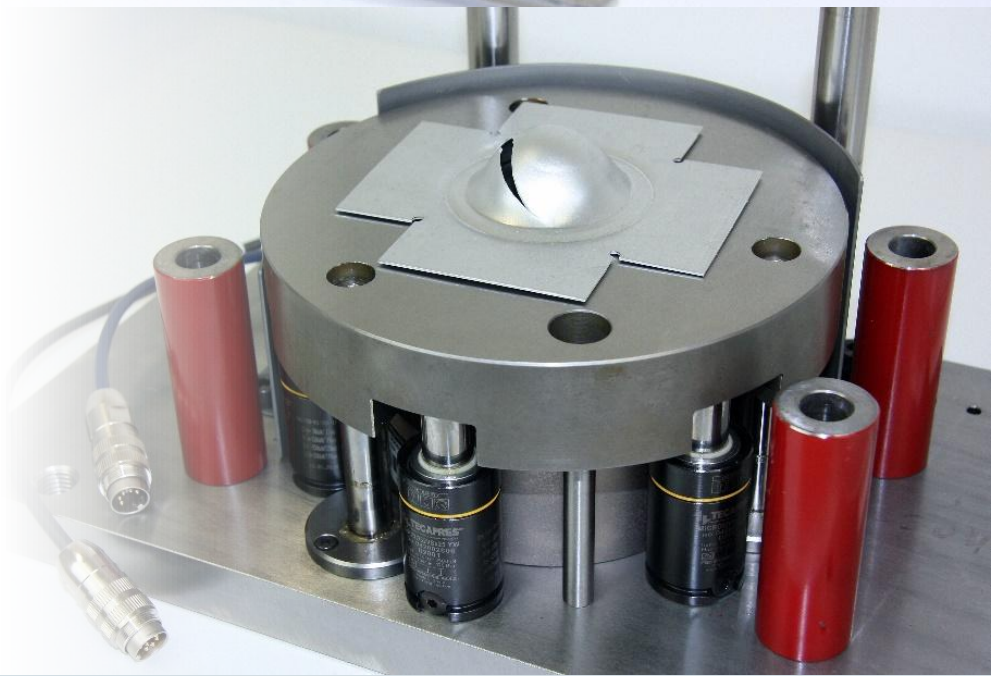
Process Specific Material Characterization: Theory and Practical Implementation

Jakub Korenek, Fraunhofer IWU

Agenda

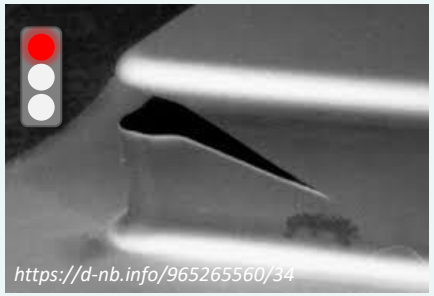
1. Motivation
2. Theoretical Background
3. IWU-Materialtester
4. Conclusion



Motivation

Forming process

challenge:
Fluctuating material properties cause problems in series production



Material

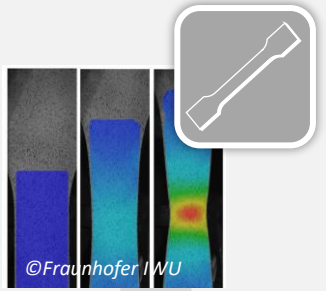
Material as a changing process input variable

Findings hardly transferable

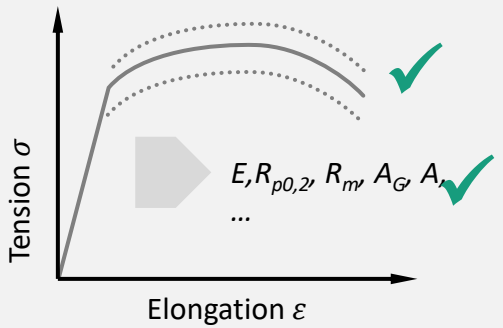
demand:
Forecast of the process capability before the creation of value!

- Statement about forming & failure behaviour under process-related conditions
- for each part individually before it goes into the process

Material characterization based on the tensile test



Provides standardized mechanical parameters for uniaxial load



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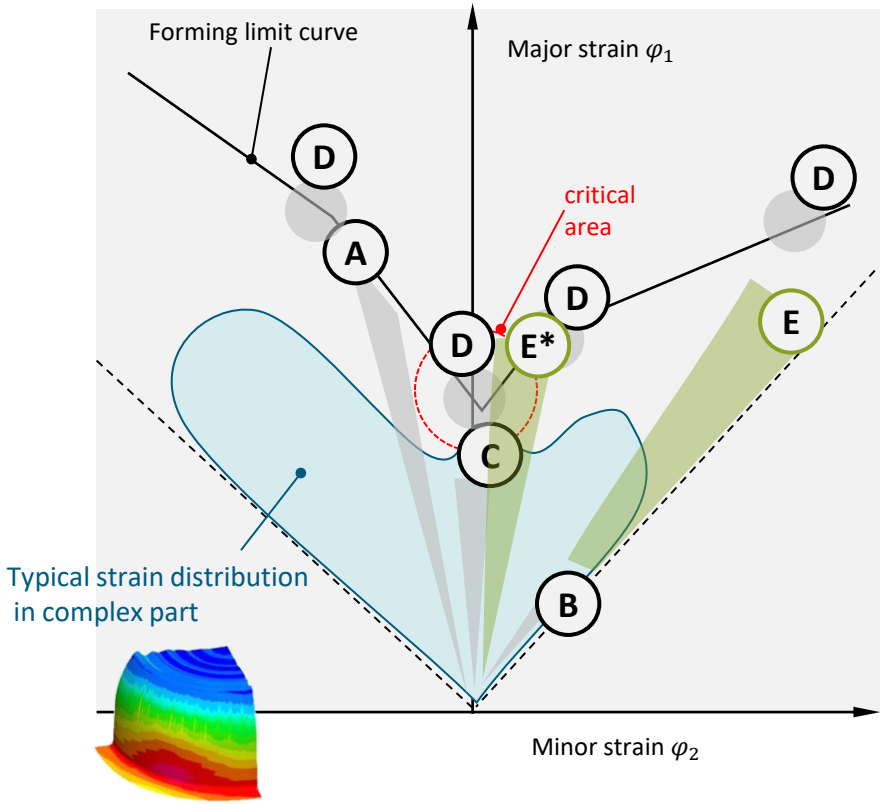
Theoretical background

Laboratory methods

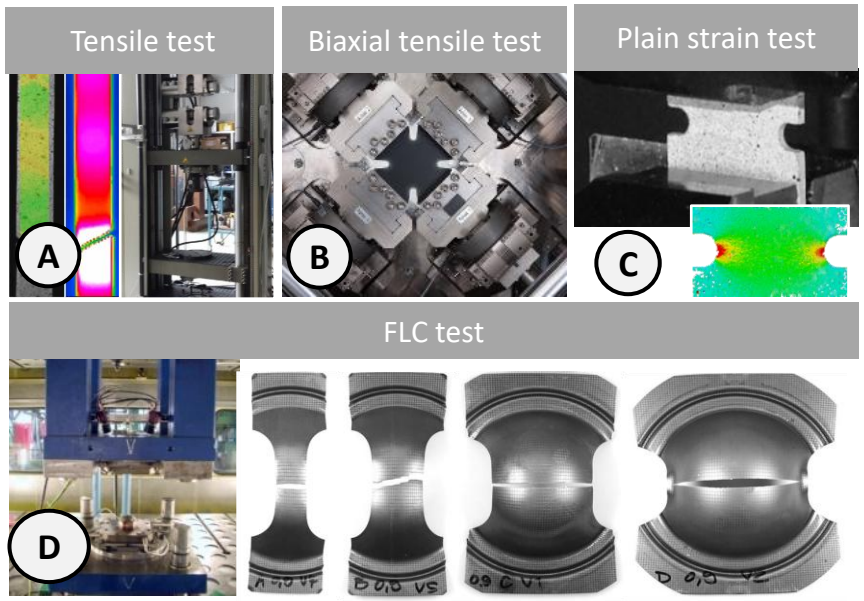
Material testing under process relevant conditions:

- Testing under process relevant strain conditions
- Testing under relevant strain rates



Laboratory methods:

- High information density
- Derivation of multiple material properties
- Database for forming simulation



Cons:

- time consuming
- expensive

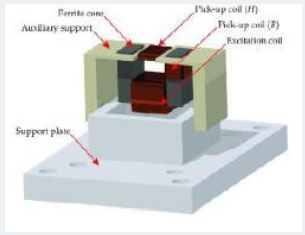
not suitable for testing of a large number of batches

Theoretical background

Alternative testing methods

non-destructive methods:

- electro-magnetic methods (3MA, eddy current, IMPOC)



Pros:

- contactless measurement
- non-destructive
- In-line capability

Cons:

- partly only ferromagnetic materials
- complex calibration
- measurement of the current state

destructive methods:

- adapted instrumented forming tests (Erichsen Test, miniaturized cupping test, IWU-Materialtester)

Pros:

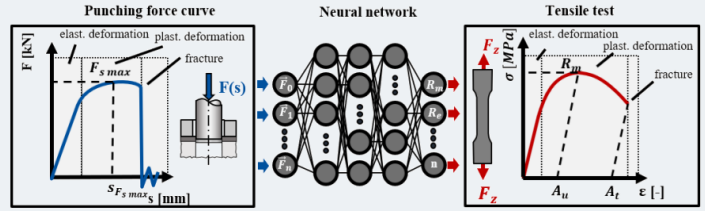
- direct recording of the deformation behavior
- easy to integrate into the production environment

Cons:

- destructive
- data-driven analysis algorithms

indirect testing:

- Use of process variables (e.g. forces) during the processing of materials to evaluate material quality



Pros:

- No additional testing process necessary
- In-line testing of every semi-finished product

Cons:

- Other (partly unknown) influencing variables on the measurement signals (e.g. tool condition)

IWU-Materialtester

Concept

Challenge:

- How can characteristic parameters be derived?
- Currently, the experiment can only be evaluated to a very limited extent:

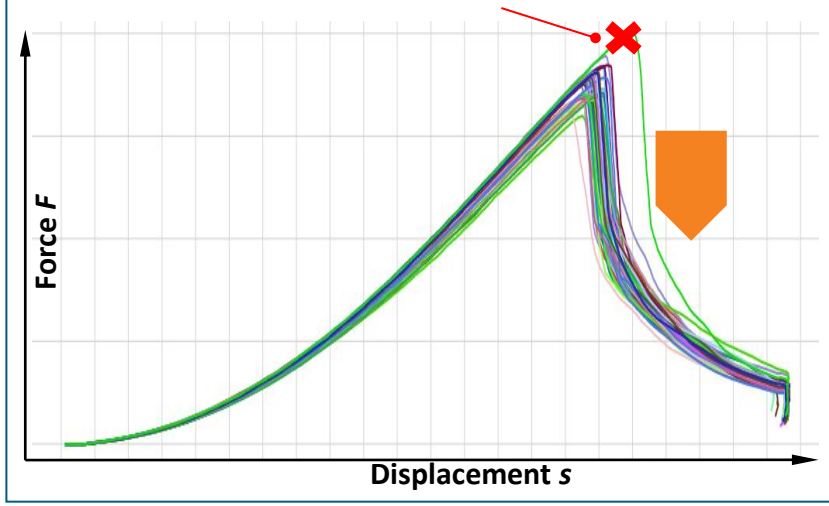
Opportunity: The material provides much more information about itself than just the pure cupping value -> has so far been unused!

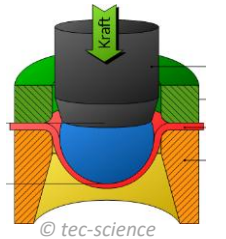
Approach

- Integration of force and displacement measurement in test tool
- Realization of a compact testing device and development of a easy to use test software
- Extraction from specific process relevant material parameters from force-displacement curves by the use of methods of machine learning (ML)

Basis: Erichsen cupping test

Cupping value I_E provides limited information about the formability





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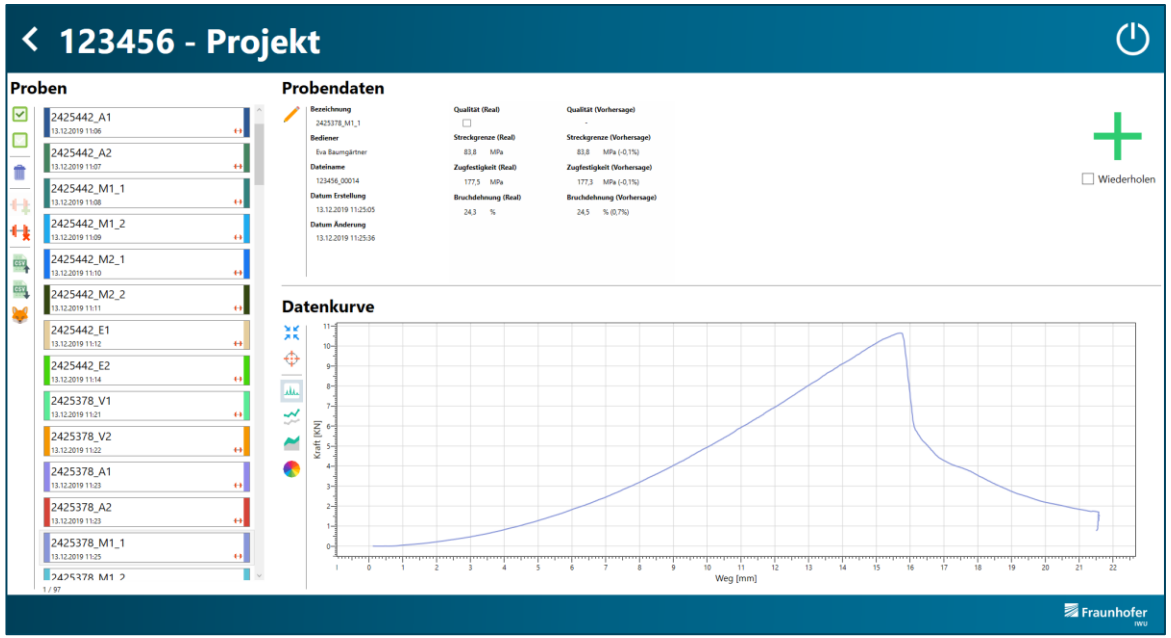
Further development to the 'IWU-Materialtester'

IWU-Materialtester

Implementation

Tool and testing machine



Software

IWU-Materialtester

Implementation

IWU-Materialtester

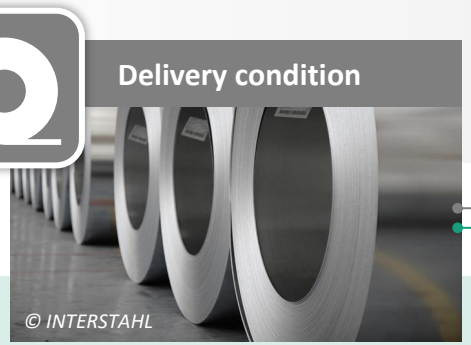
ML-based evaluation

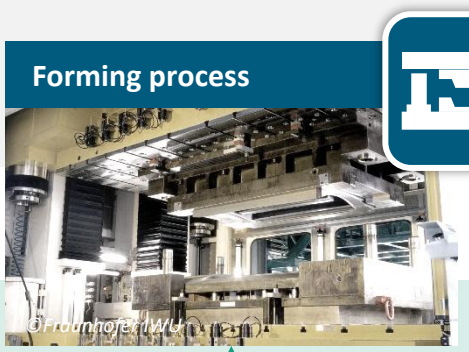
Training phase

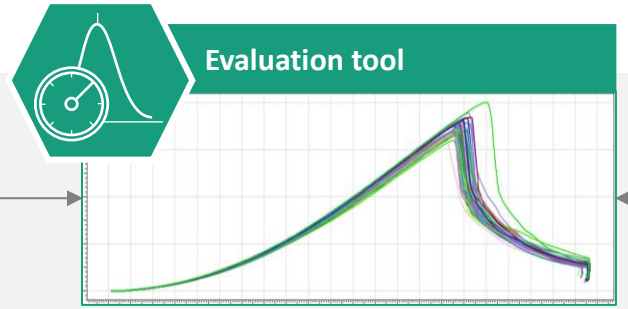
- Application of the Mini-Deepening
- Curve recording and visualization
- Training of ML model

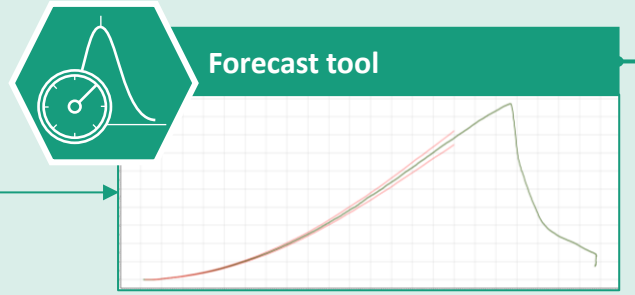
Production phase

- Accompanying mini deepening
- Curve recording and visualization in test software
- Evaluation of the curve with ML model
- Derivation of a forecast









Feedback quality feature :

- Good part / rejects
- Mechanical parameters from parallel tensile tests
- …

Feedback to production :

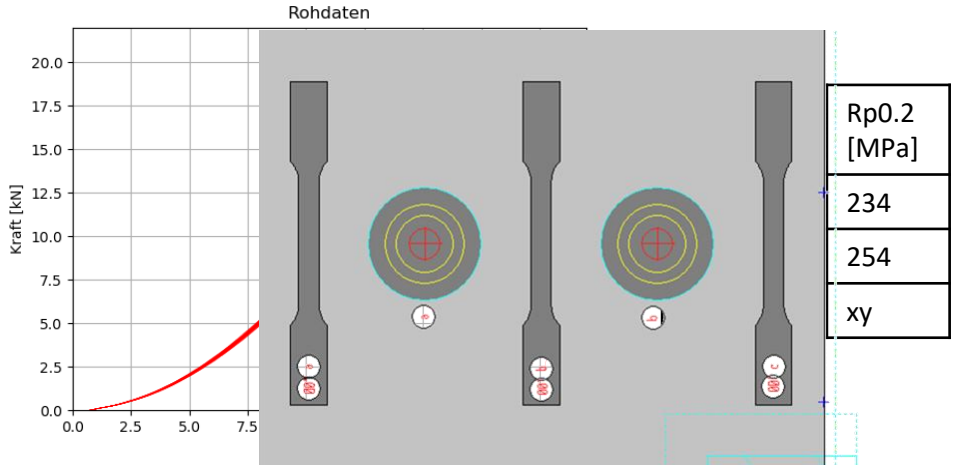
- Forecast of process capability
- Good part / rejects
- Initiation of control processes
- …

IWU-Materialtester

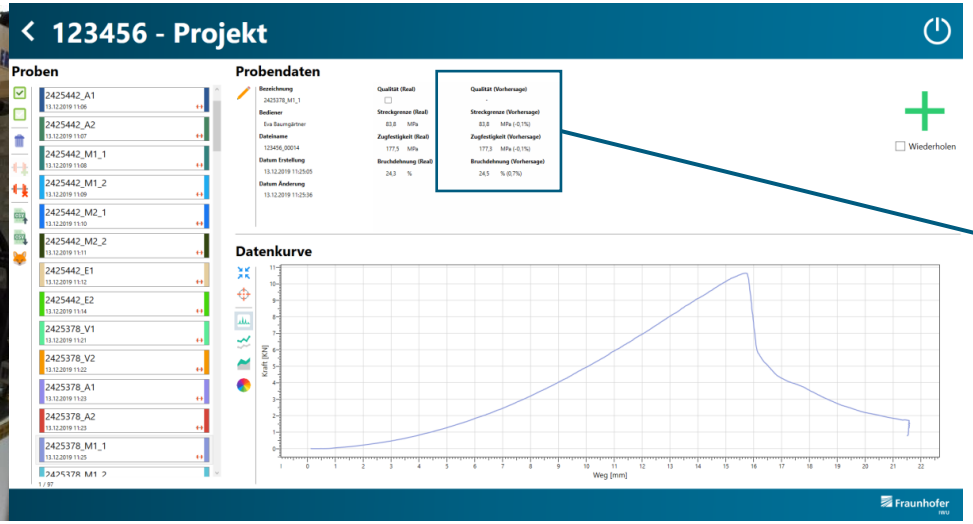
Example

Training

- Collection of training data
  (tensile test and modified deep drawing test at different material batches)
- Training of prediction model
- Validation and implementation of the model



Application of the model



Qualität (Vorhersage)

-

Streckgrenze (Vorhersage)

83,8 MPa (-0,1%)

Zugfestigkeit (Vorhersage)

177,3 MPa (-0,1%)

Bruchdehnung (Vorhersage)

24,5 % (0,7%)

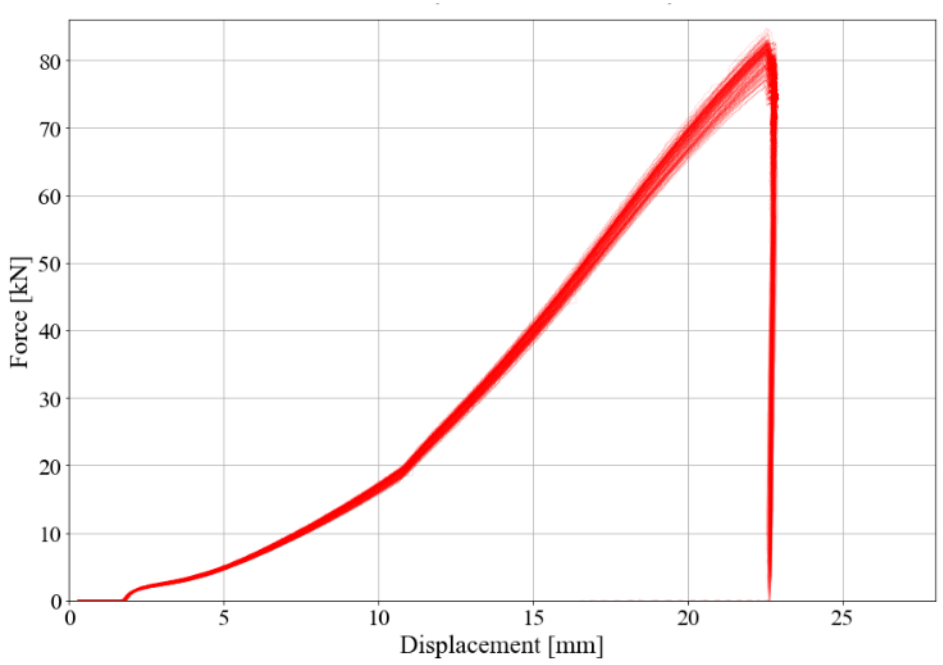
IWU-Materialtester

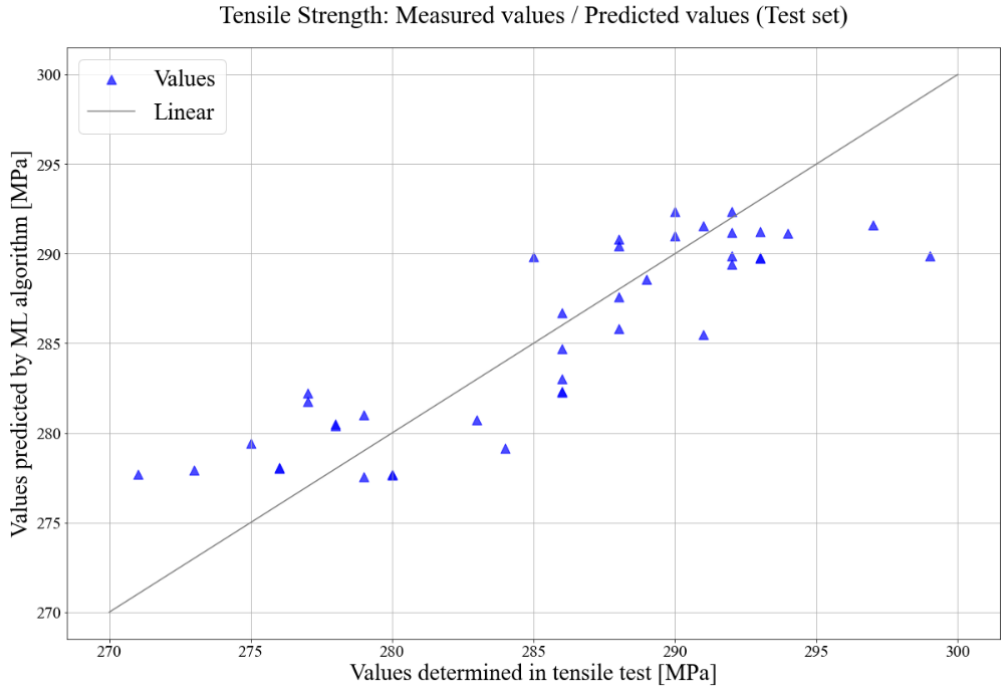
Industrial application

Regression of the mech. values in the "Automotive" sector

Objective: prediction good/bad and mechanical material properties
Material: Cold-Rolled Steel (CR3), Sheet Thickness s = 2 mm
Samples: 156 samples for training and 40 samples for validation

- Prediction deviation Rp0.2 = ±3%
- System runs in series as a stand-alone unit
- Problem: Tracking good / bad





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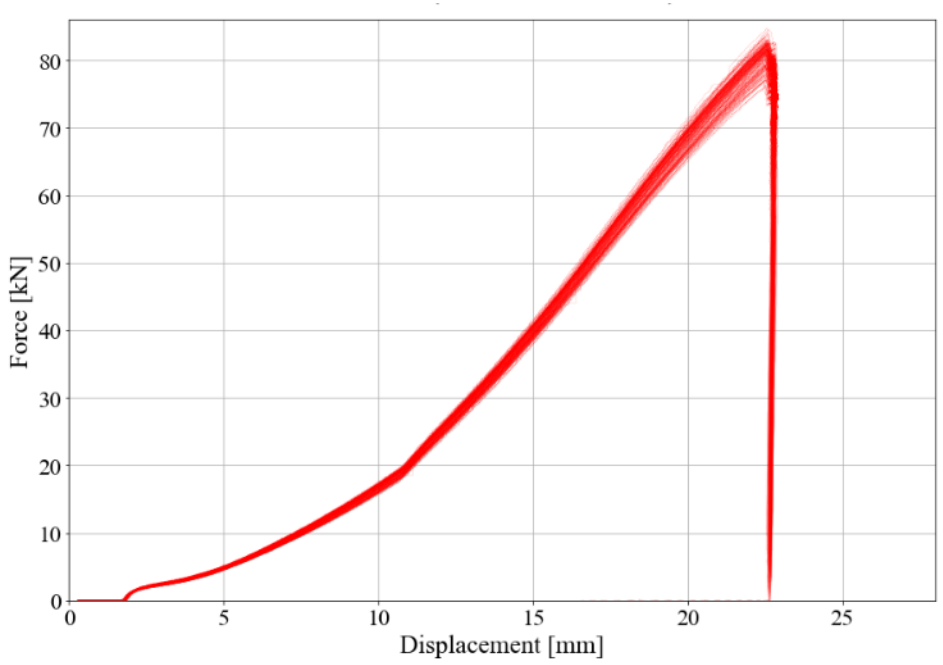
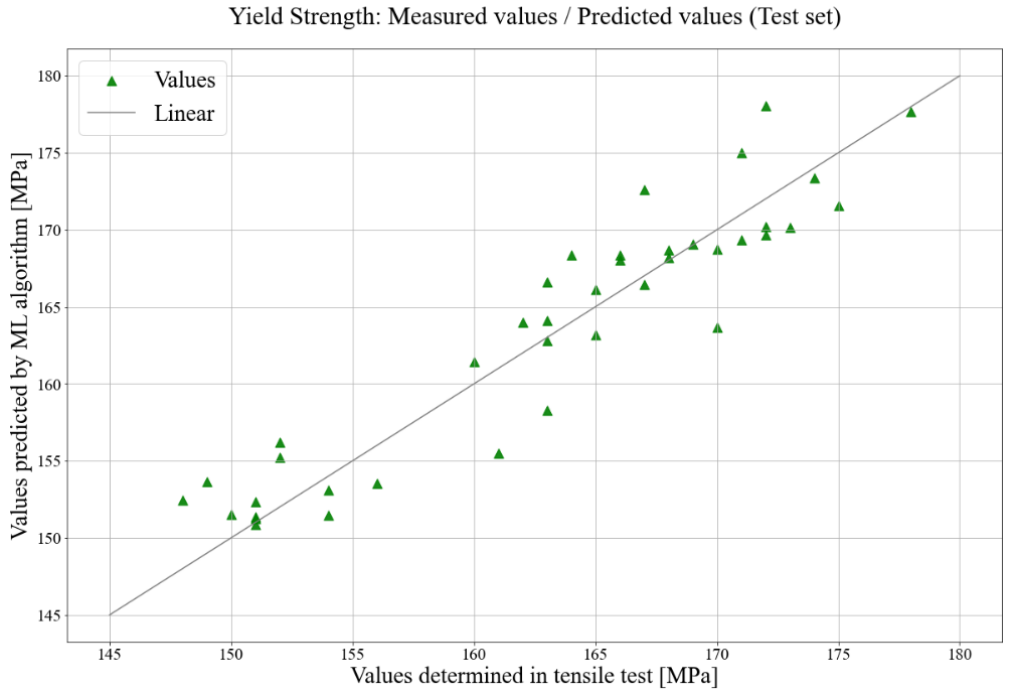
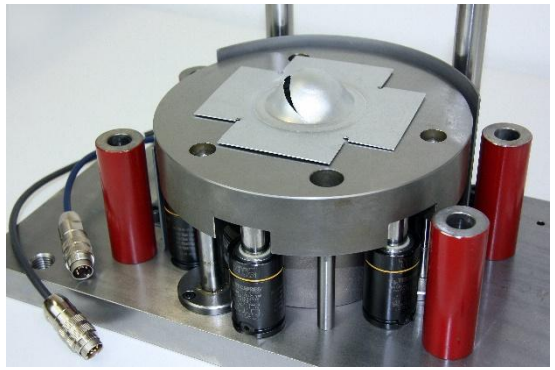
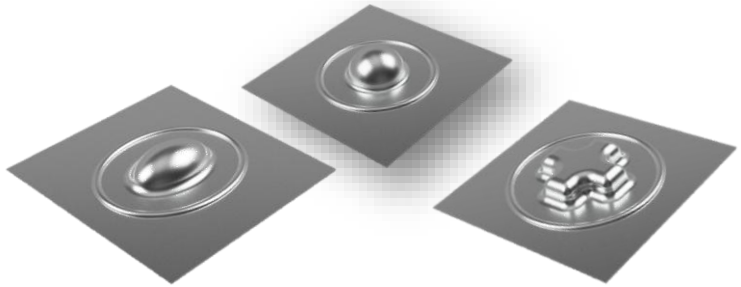




Conclusion





Advantages:

- Uncomplicated quick test (direct integration in forming tools possible)
- High significance for process suitability of material batches
- Prediction of material characteristics possible

Currently available as a stand-alone system:

- Cost-effective (mobile) system with measuring tool and hydraulic drive
- System available at Fraunhofer IWU, e.g. for feasibility studies
- Various test geometries possible, design according to load condition and material thickness

Current industrial application scenarios:

- as an incoming goods inspection for quick testing and, if necessary, reclamation of the material
- Process-advancing for setting the technical parameters
- Predictions are already good with a small amount of data <3% deviation

What's next?

- Training of models based on virtual data, transferability of models
- Integration of additional sensors, process-integrated measurements
- Automated determination of the material behavior for the material parametrization for FE simulation

Contact

Jakub Korenek, M.Sc.

Department Sheet Metal Forming
Tel. +49 371 5397-1944
Jakub.korenek@iwu.fraunhofer.de

Fraunhofer IWU
Reichenhainer Straße 88
09126 Chemnitz
www.iwu.fraunhofer.de

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