GREAT DESIGNS IN STEEL

TWENTY YEARS

MULTI-LEVEL MATERIAL CARDS FOR SHEET METAL FORMING SIMULATIONS

Dr. Eren Billur
Billur Metal Form
& Atılım University

Adem Karşı
Coşkunöz R&D Center

OUTLINE

1) Introduction

2) Simulation Input
   a) Material Card
   b) Process Data

3) Multi-Level Material Cards

4) Experimental Validation with 3rd Gen 980

5) Conclusions and Future Work

INTRODUCTION - BMF

Founded by Dr. Eren Billur in 2015. Located in Ankara and employs 3 engineers.

Consulting, engineering, training and simulation services around sheet metal forming processes and different sheet metal grades.

Core-competence: Hot stamping of steel and aluminum, new generation AHSS.

Customers from USA, Germany, Japan and China accounting over 60%.

«Cutting Edge» column in Metalforming Magazine since 2020

Contribution to WorldAutoSteel's AHSS Guidelines.

INTRODUCTION - COŞKUNÖZ

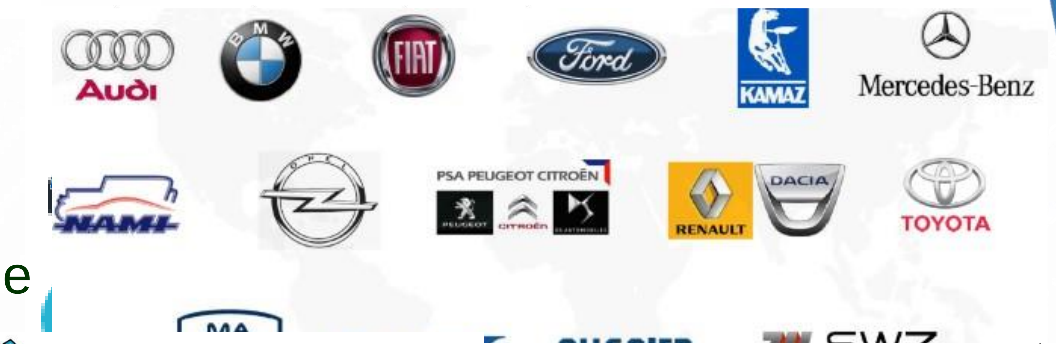
Founded in 1968 as one of the first tier 1 suppliers and die makers in Turkey.

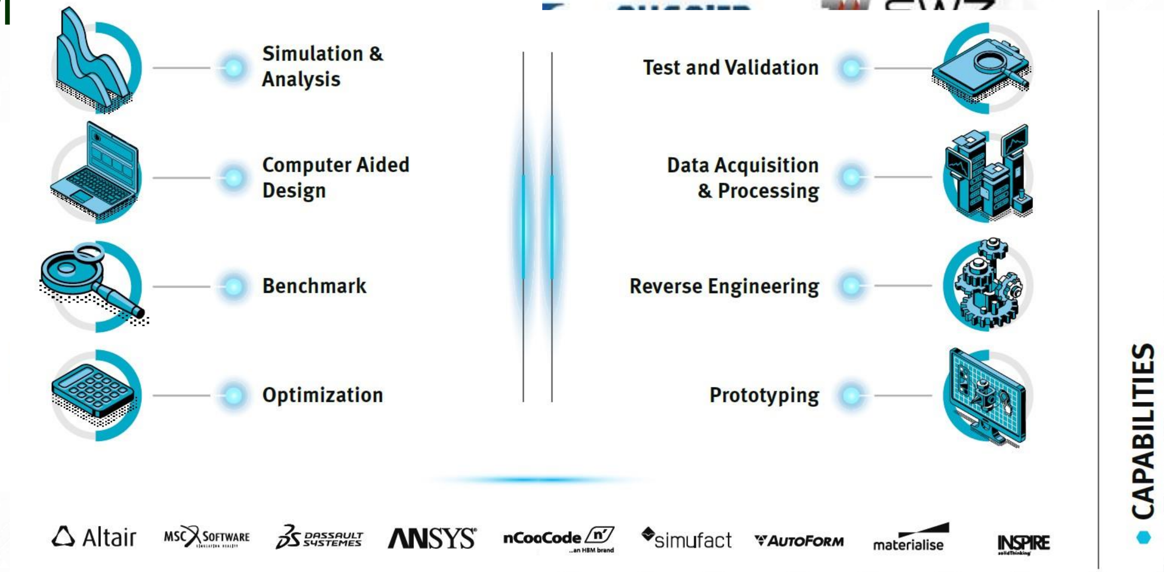
CKM was formed in 1983 as the die maker of the group.

The group owns a total of 5 companies around the globe only in automotive sector (a total of 12 wit… others).

Supplies parts and dies to numerous OEM's around the globe.

One of the most advanced R&D facilities in metal forming research in Turkey.





SHOP FLOOR VS. SIMULATION

Factor	Shop Floor	Simulation
Sheet metal properties	Complex	Simplified
	Not constant through the coil, or coil-to-coil	Assumed constant within the coil and between coils
Press speed	Not constant	Assumed constant or neglected
Friction (tool-sheet)	Dependent on: oil quantity, surface roughness, contact pressure, sliding velocity, average temperature.	Typically considered constant – recently tribology add-on's are used.
Temperature	Increases due to heat generation	Typically considered constant
Tool and press	Elastic	Considered rigid

Ref: Roll 2008

MULTI-LEVEL MATERIAL CARDS IDEA

In the automotive industry, the most common method for simulation is:

		Level 0
Material Card	Hardening Curve	Supplied
	Yield Locus	Supplied
	FLC (or TFC)	Supplied
	Strain Rate / Temperature dependent data	Typically not included
	Kinematic Hardening	Typically not included
	Failure / Fracture Max Edge Strain	Typically not included
Process	Friction Model	Constant
	Press	Neglected

- Receive a material card from the material supplier or the OEM
  - Considered constant for different coils, head to tail!
- Assume constant friction, neglect press speed,…
  - In reality, press Strokes per Minute – SPM, affects part quality (whether it be wrinkles, splits or springback).
  - Link-motion and servo-drive presses offer significant advantages, which would be neglected.

LEVEL 1

		Level 0	Level 1
Material Card	Hardening Curve	Supplied	Test-data
	Yield Locus	Supplied	Only Hill 1948
	FLC (or TFC)	Supplied	Estimated
	Strain Rate / Temperature dependent data	Typically not included	Not included
	Kinematic Hardening	Typically not included	Not included
	Failure / Fracture Max Edge Strain	Typically not included	Not included
Process	Friction Model	Constant	Constant
	Press	Neglected	Neglected

Lowest Cost and fastest:

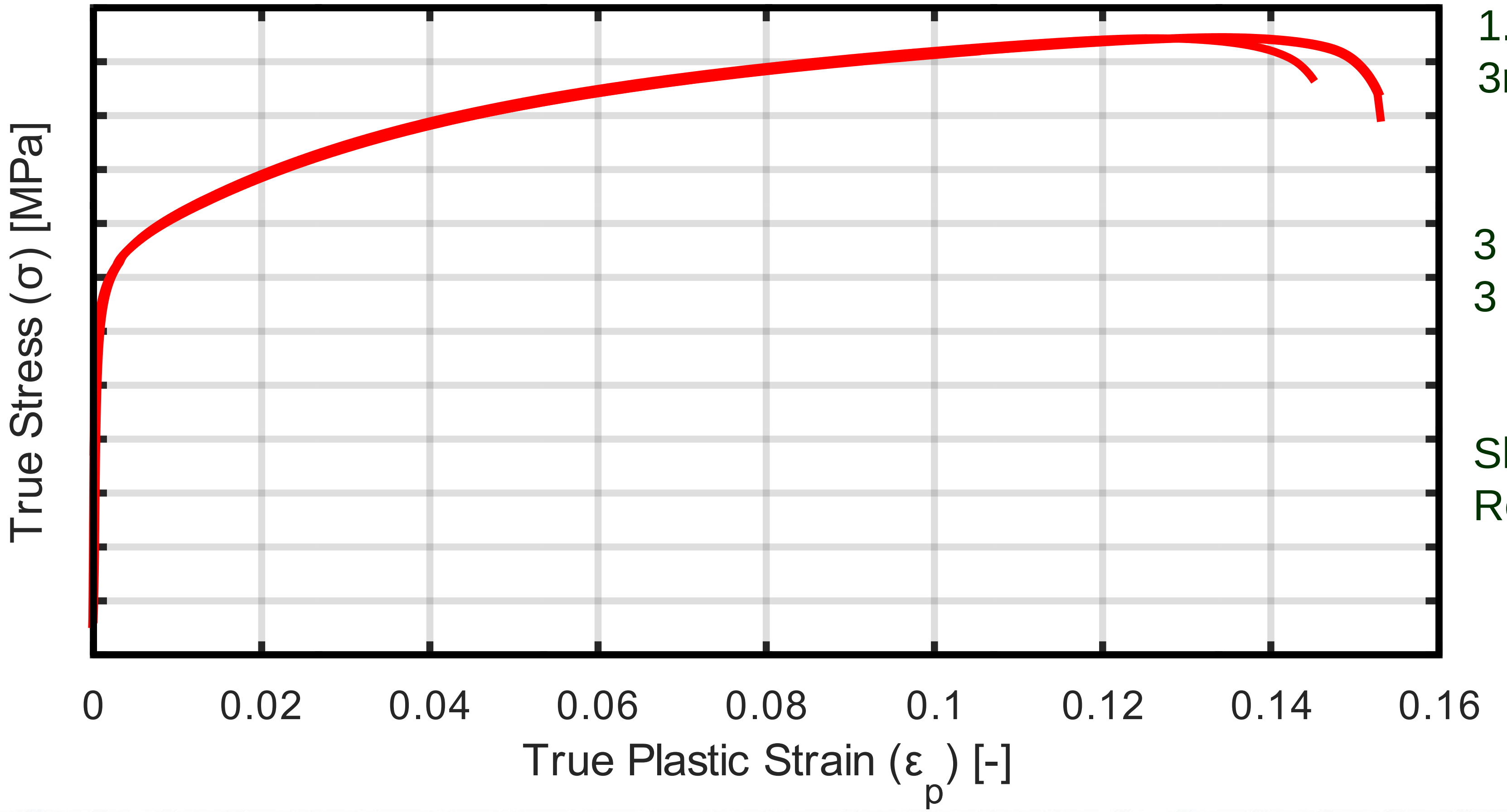
1) Requires 3-direction tensile tests (a minimum of 3 repetitions is advised)

2) DIC is advised (at least in RD)

3) Mixed model extrapolation is advised. (Swift/Hockett-Sherby, Hollomon/Voce or similar)

4) Plastic strain ratio (r-values) must be recorded, (Both for yield locus and FLC estimation)

HARDENING CURVE

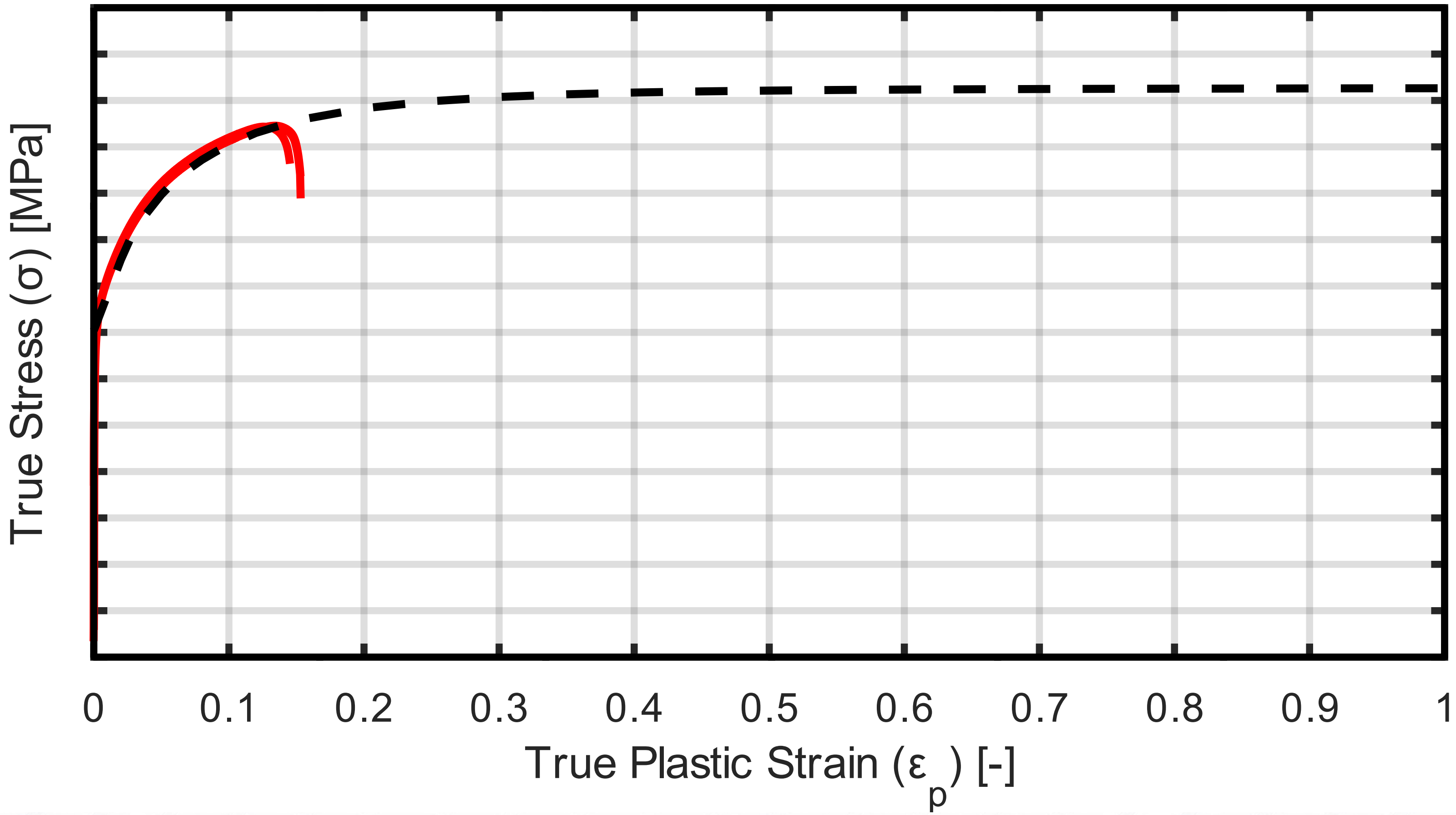


1.5 mm Uncoated
3rd Gen 980

3 repetitions in
3 directions

Shown here:
Rolling direction

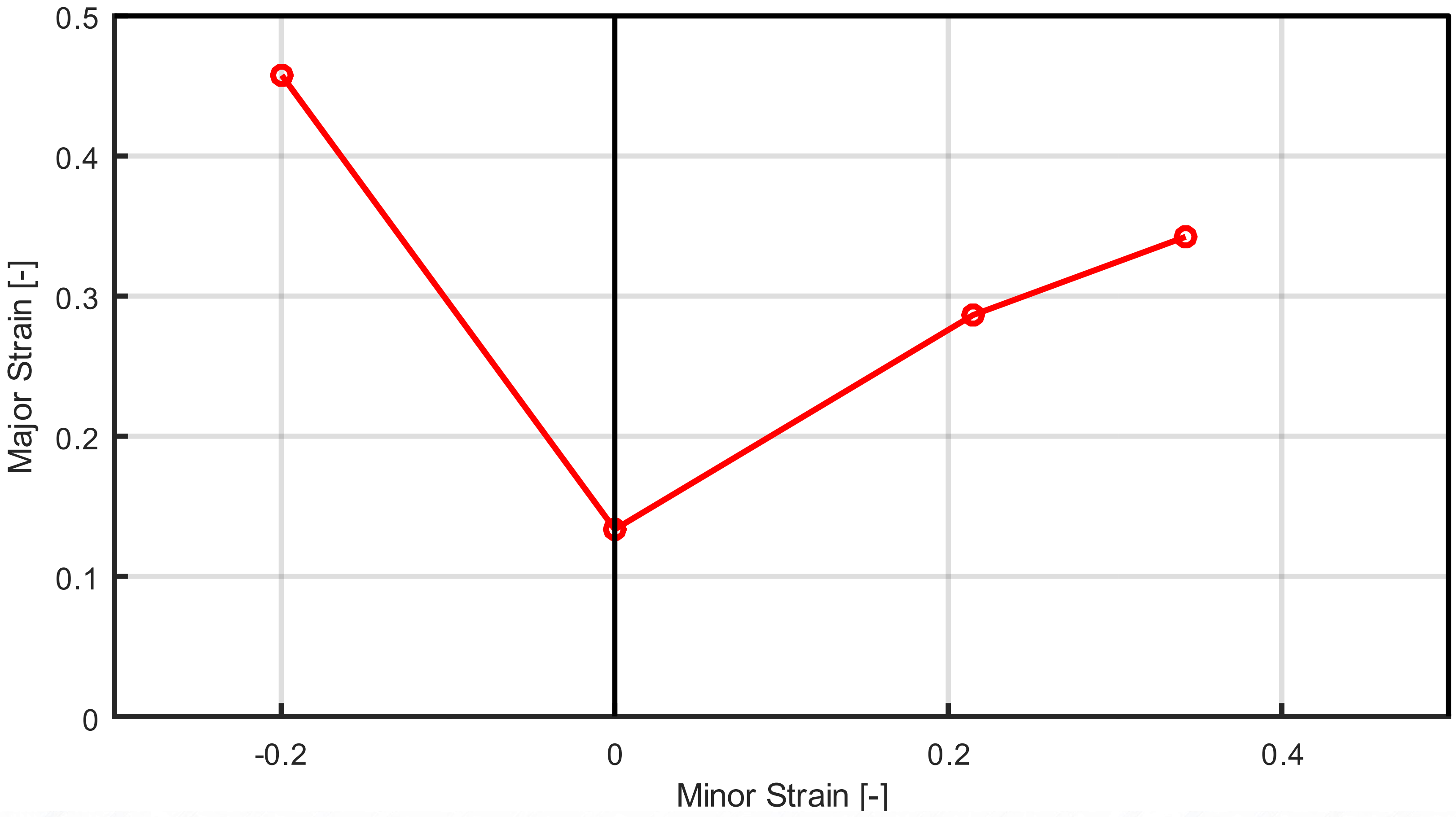
HARDENING CURVE



1.5 mm Uncoated
3rd Gen 980

Combined
Swift/Hockett-Sherby
model

FORMING LIMIT CURVE

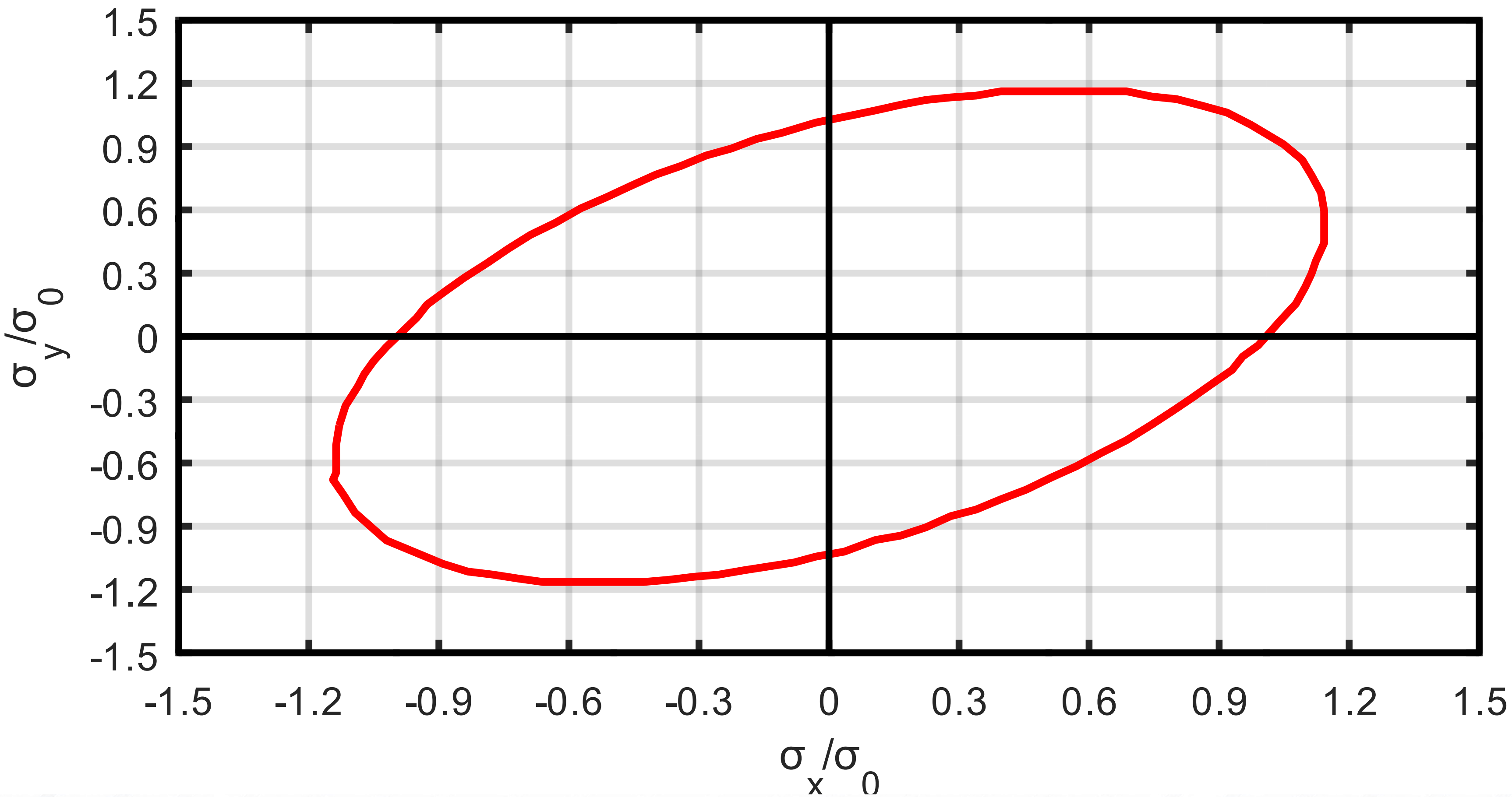


In low-level cards

FLC can be generated using built-in macro's, using:

1) A_{80} total elongation values,
2) r – plastic anisotropy coefficients.

YIELD LOCUS



In low-level cards Hill 48 is the easiest to use.

This model is not advised for materials with r<1.

3rd Gen 980 tested had all r values less than 1!

LEVEL 2

		Level 0	Level 1	Level 2
Material Card	Hardening Curve	Supplied	Test-data	Test-data
	Yield Locus	Supplied	Only Hill 1948	Only Hill 1948
	FLC (or TFC)	Supplied	Estimated	Estimated
	Strain Rate / Temperature dependent data	Typically not included	Not included	Strain rate tested
	Kinematic Hardening	Typically not included	Not included	Not included
	Failure / Fracture Max Edge Strain	Typically not included	Not included	Not included
Process	Friction Model	Constant	Constant	Constant
	Press	Neglected	Neglected	Modeled

In addition to Level 1:

1) Strain rate sensitivity (m-value) is determined with at least 3 tensile tests at different strain rates.

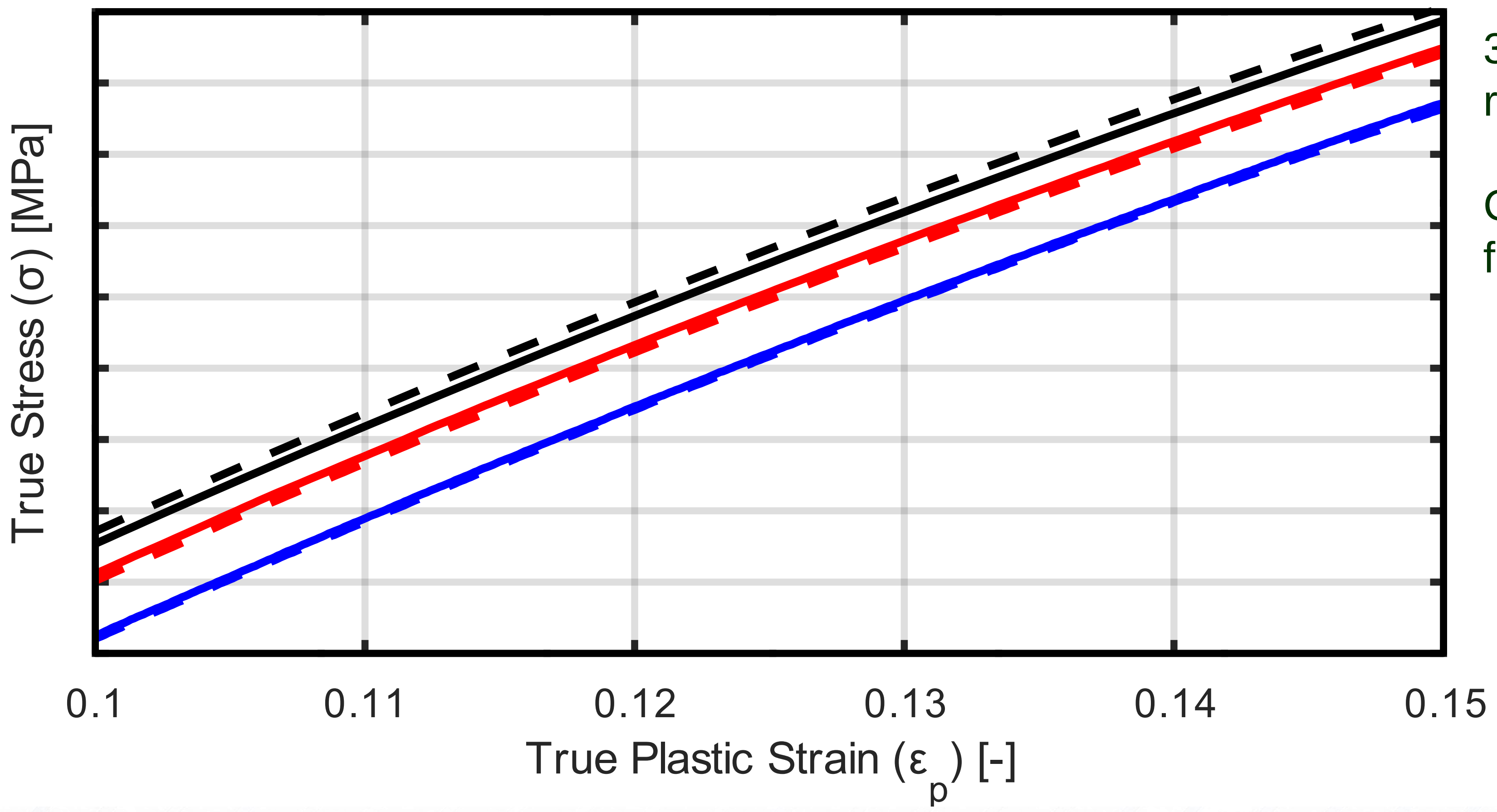
2) The press stroke-time curve is modeled.

Possible improvement:

If material itself may have SPM-related problems.

Real SPM optimization may require friction and thermal data!

STRAIN RATE SENSITIVITY

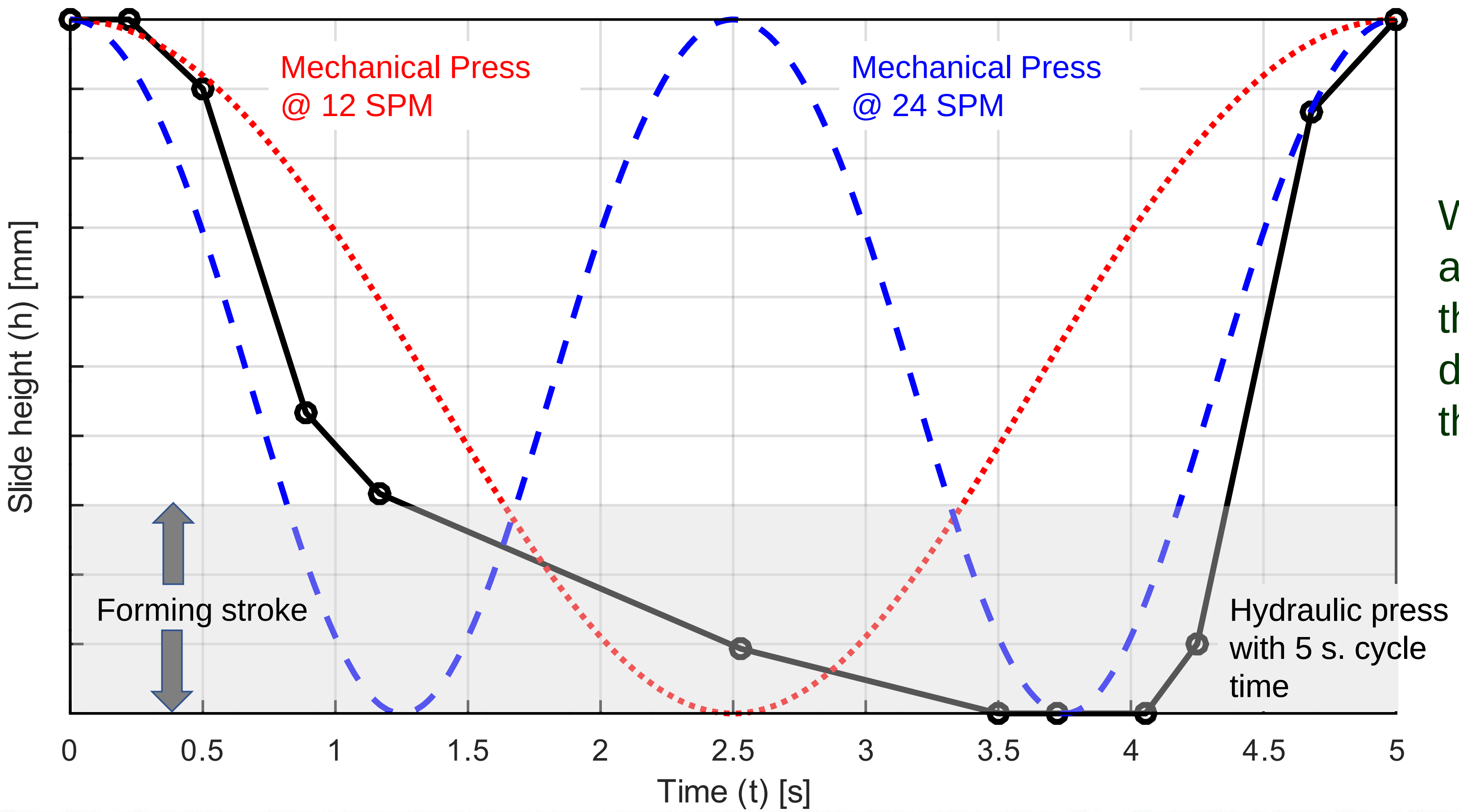


3 different strain rates were tested.

Constant m-value fit was done.

$$\sigma = \sigma_{\dot{\epsilon}_0}\left(\frac{\dot{\epsilon}}{\dot{\epsilon}_0}\right)^m$$

PRESS MODEL



Without strain rate, and friction model, there would be no difference between these!

LEVEL 3

		Level 0	Level 1	Level 2	Level 3
Material Card	Hardening Curve	Supplied	Test-data	Test-data	Test-data
	Yield Locus	Supplied	Only Hill 1948	Only Hill 1948	Bulge Test
	FLC (or TFC)	Supplied	Estimated	Estimated	Experimental
	Strain Rate / Temperature dependent data	Typically not included	Not included	Strain rate tested	Strain rate tested
	Kinematic Hardening	Typically not included	Not included	Not included	Not included
	Failure / Fracture Max Edge Strain	Typically not included	Not included	Not included	Not included
Process	Friction Model	Constant	Constant	Constant	f (V, P)
	Press	Neglected	Neglected	Modeled	Modeled

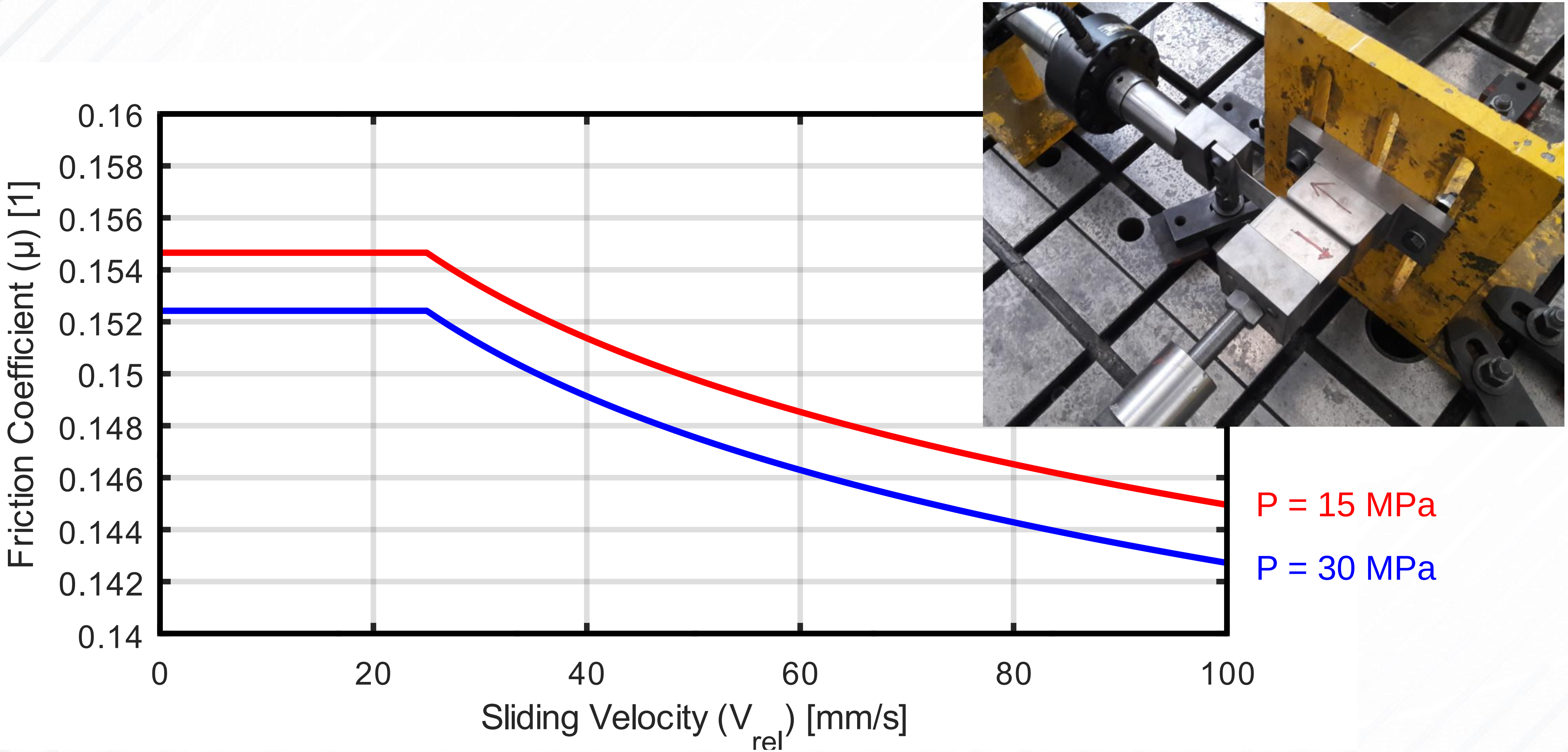
In addition to Level 2:

1) Yield locus is improved with bulge test: BBC2005 or Vegter Lite.

2) Experimental FLC (based on ISO 12004).

3) Friction tests are conducted to have friction coefficient as a function of contact pressure (p) and sliding velocity (v).

FRICTION TESTS @ COŞKUNÖZ



LEVEL 4

		Level 0	Level 1	Level 2	Level 3	Level 4
Material Card	Hardening Curve	Supplied	Test-data	Test-data	Test-data	Yoshida-fit
	Yield Locus	Supplied	Only Hill 1948	Only Hill 1948	Bulge Test	Bulge Test
	FLC (or TFC)	Supplied	Estimated	Estimated	Experimental	Experimental
	Strain Rate / Temperature dependent data	Typically not included	Not included	Strain rate tested	Strain rate tested	Strain rate tested
	Kinematic Hardening	Typically not included	Not included	Not included	Not included	Yoshida-Uemori
	Failure / Fracture Max Edge Strain	Typically not included	Not included	Not included	Not included	Not included
Process	Friction Model	Constant	Constant	Constant	f (V, P)	f (V, P)
	Press	Neglected	Neglected	Modeled	Modeled	Modeled

In addition to Level 3:

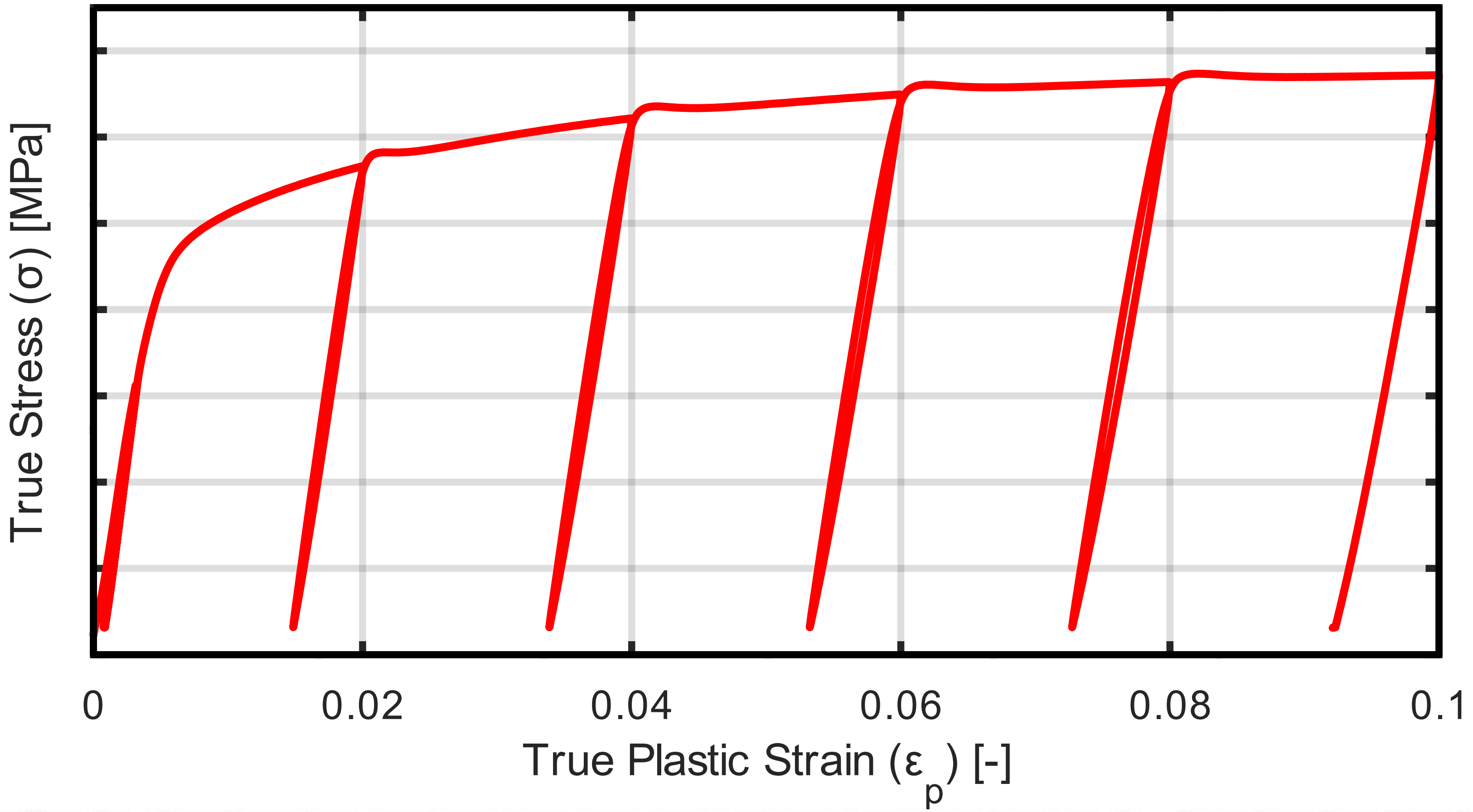
1) Unloading modulus changes with plastic strain.

2) Bauschinger effect and transient behavior is modelled using Yoshida-Uemori model.

Possible Improvement:

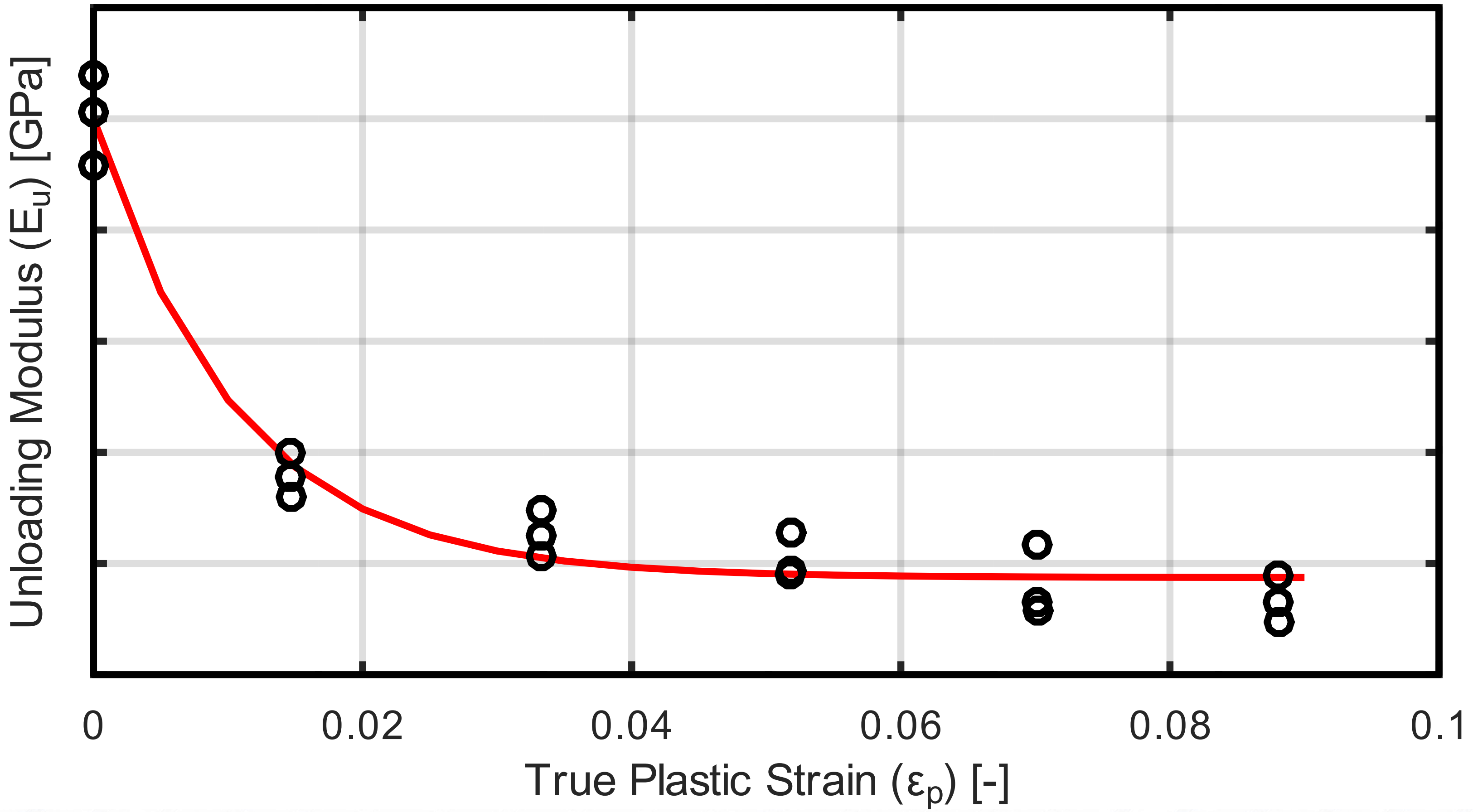
1) Significantly improved springback predictions.

LOAD-UNLOAD TEST



Load-unload tests are done to experimentally determine `unloading modulus` as a function of plastic strain.

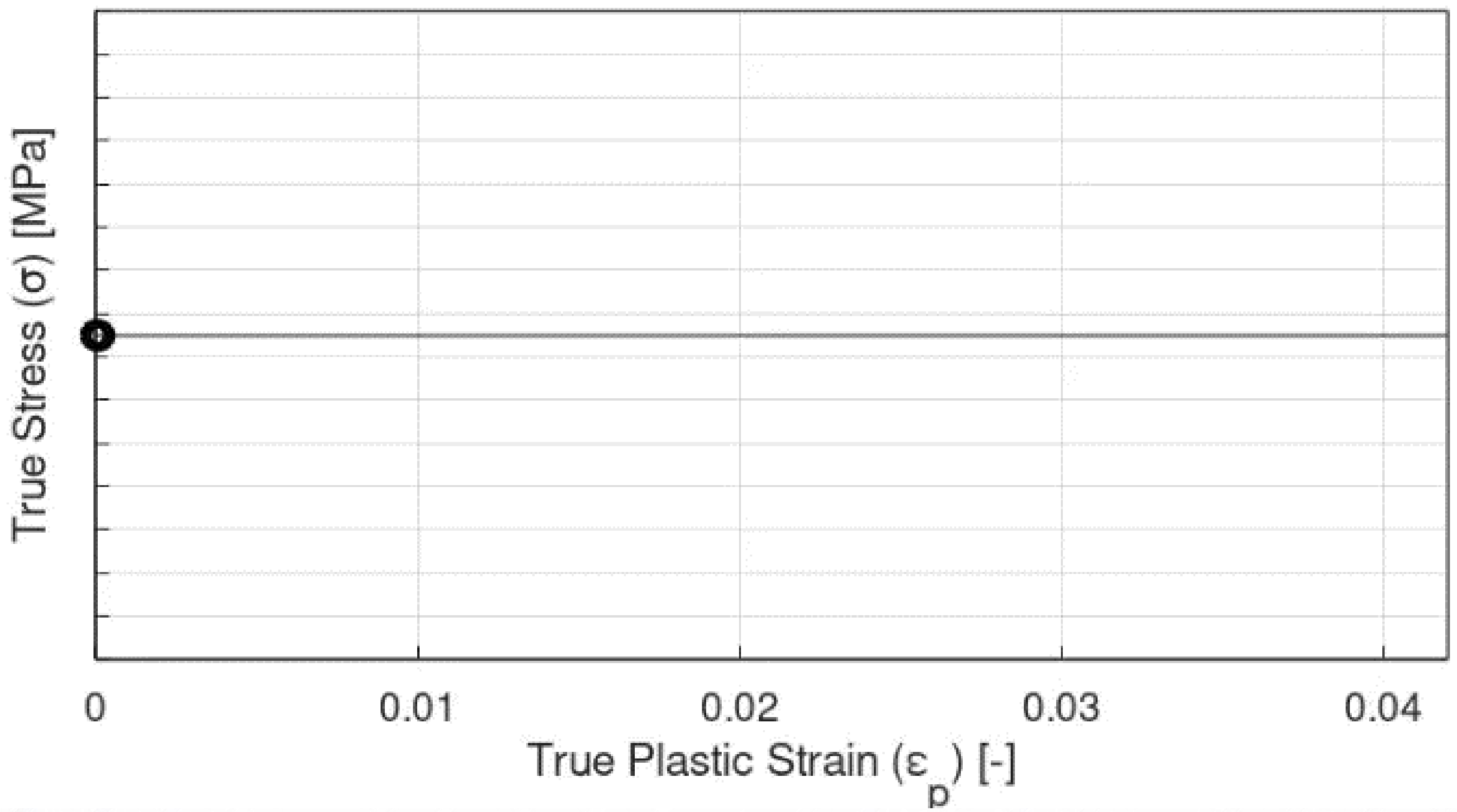
UNLOADING MODULUS DEGRADATION



Load-unload tests are done to experimentally determine ‘unloading modulus’ as a function of plastic strain.

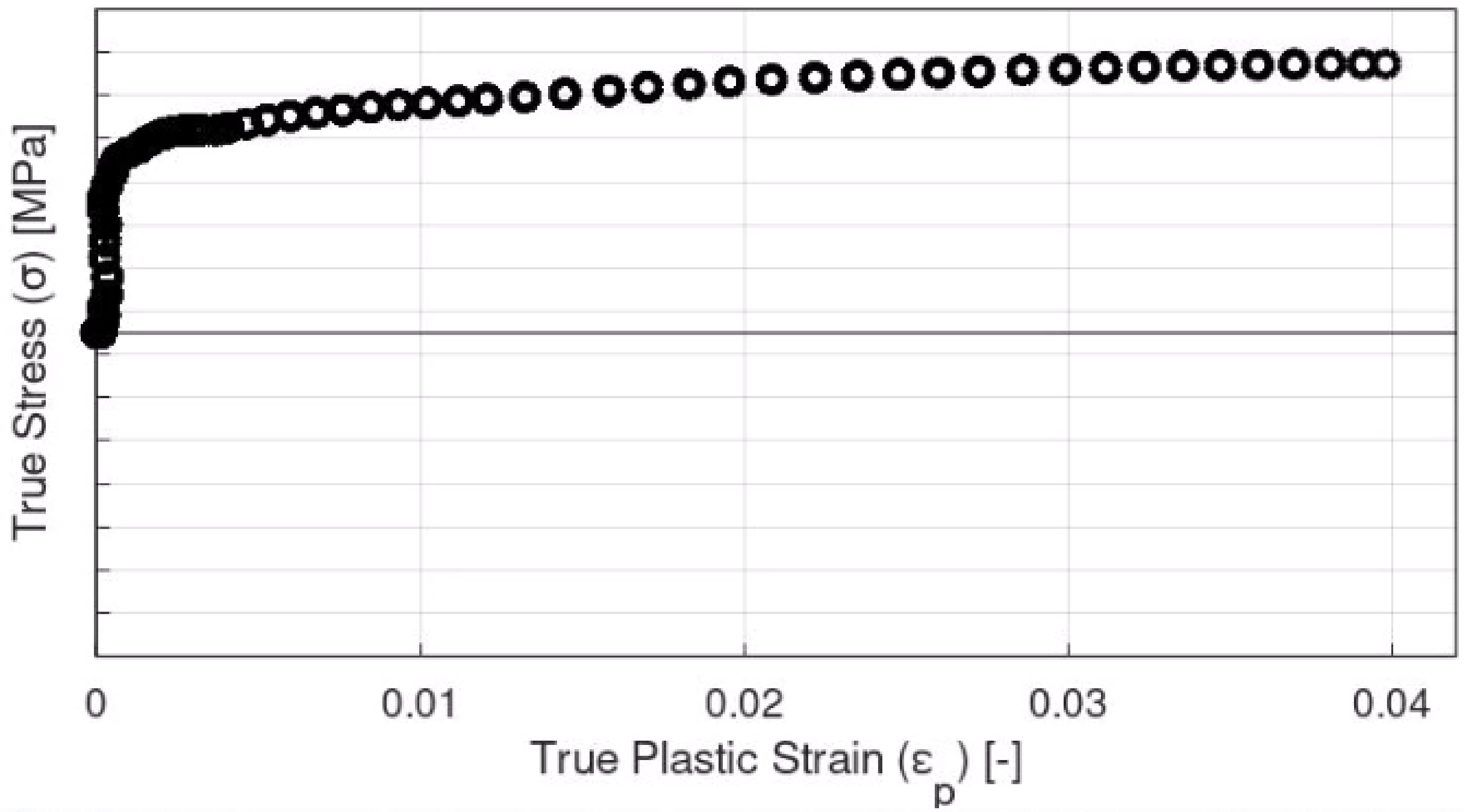
This data is then fit to a “Modulus Decrease Model” proposed by Yoshida, et. al.

TENSION-COMPRESSION TESTS



Starts just like a tensile test.

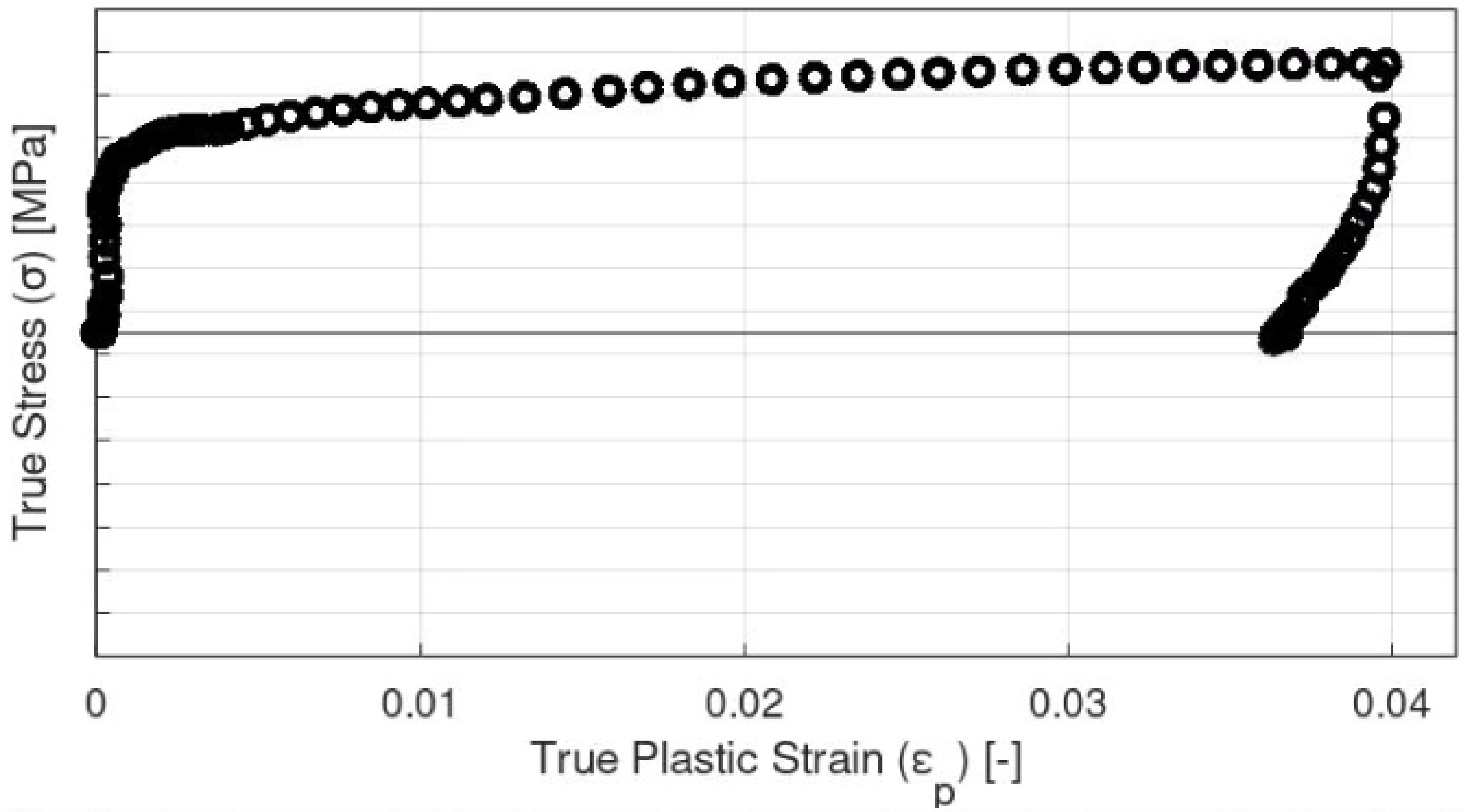
TENSION-COMPRESSION TESTS



Continues like a load-unload test.

Until this point can be done in any universal tensile test machine, as there will be no compressive force and risk of buckling

TENSION-COMPRESSION TESTS

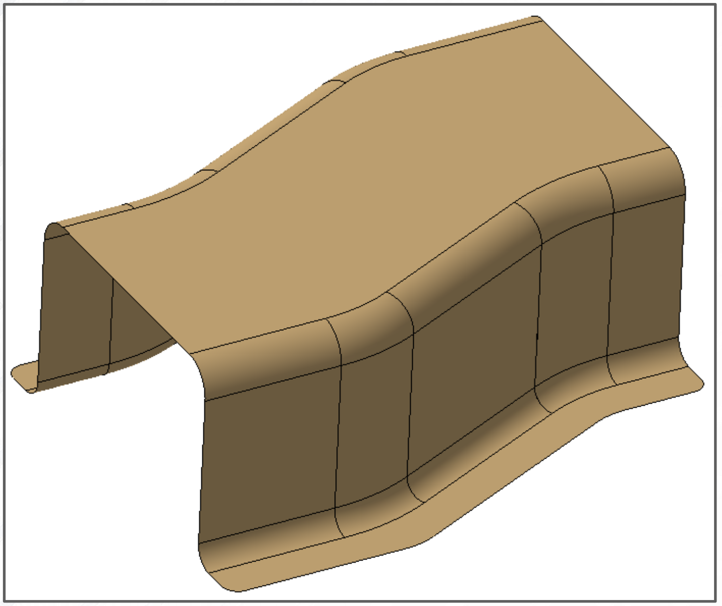


This part requires:

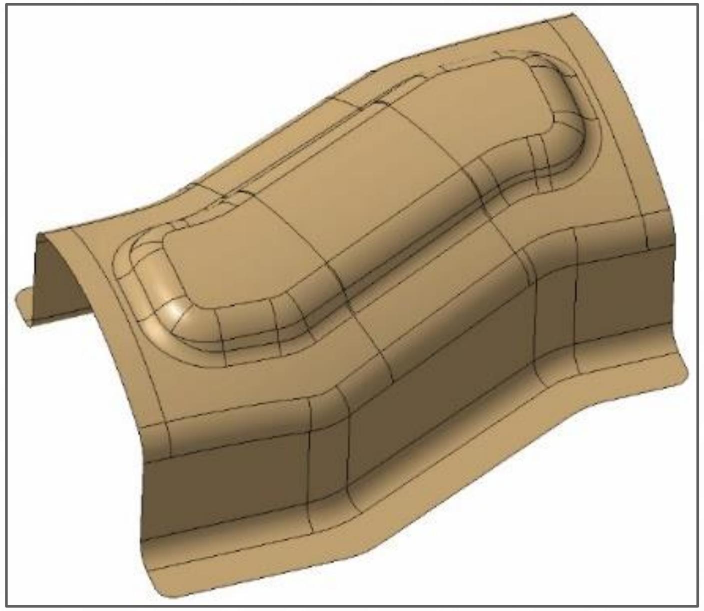
Special grips to handle compressive forces

Anti-buckling device.

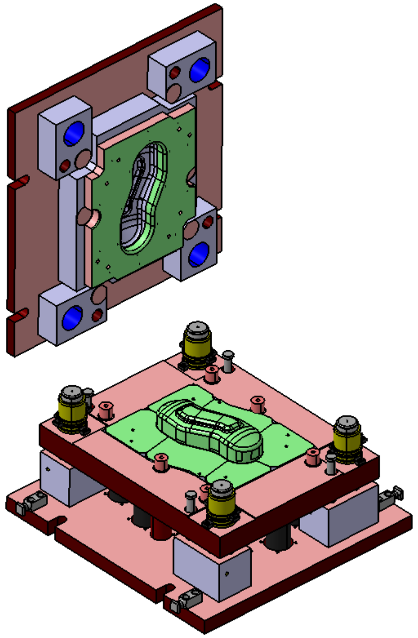
EXPERIMENTAL VALIDATION



S-shape to model stretch and shrink flanging

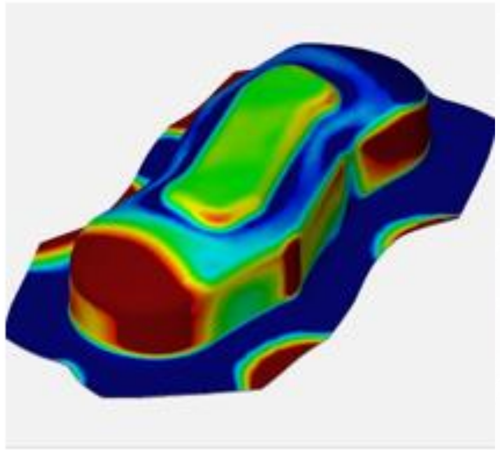


Modified S-shape for further thinning the material



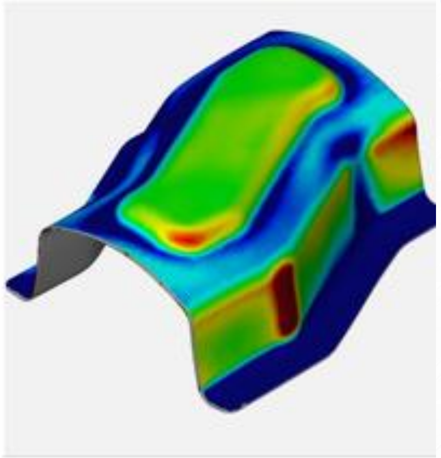
SIMULATION VS. EXPERIMENT

OP10 – Forming → OP15 - Springback → OP20 - Laser Cut → OP25 - Springback

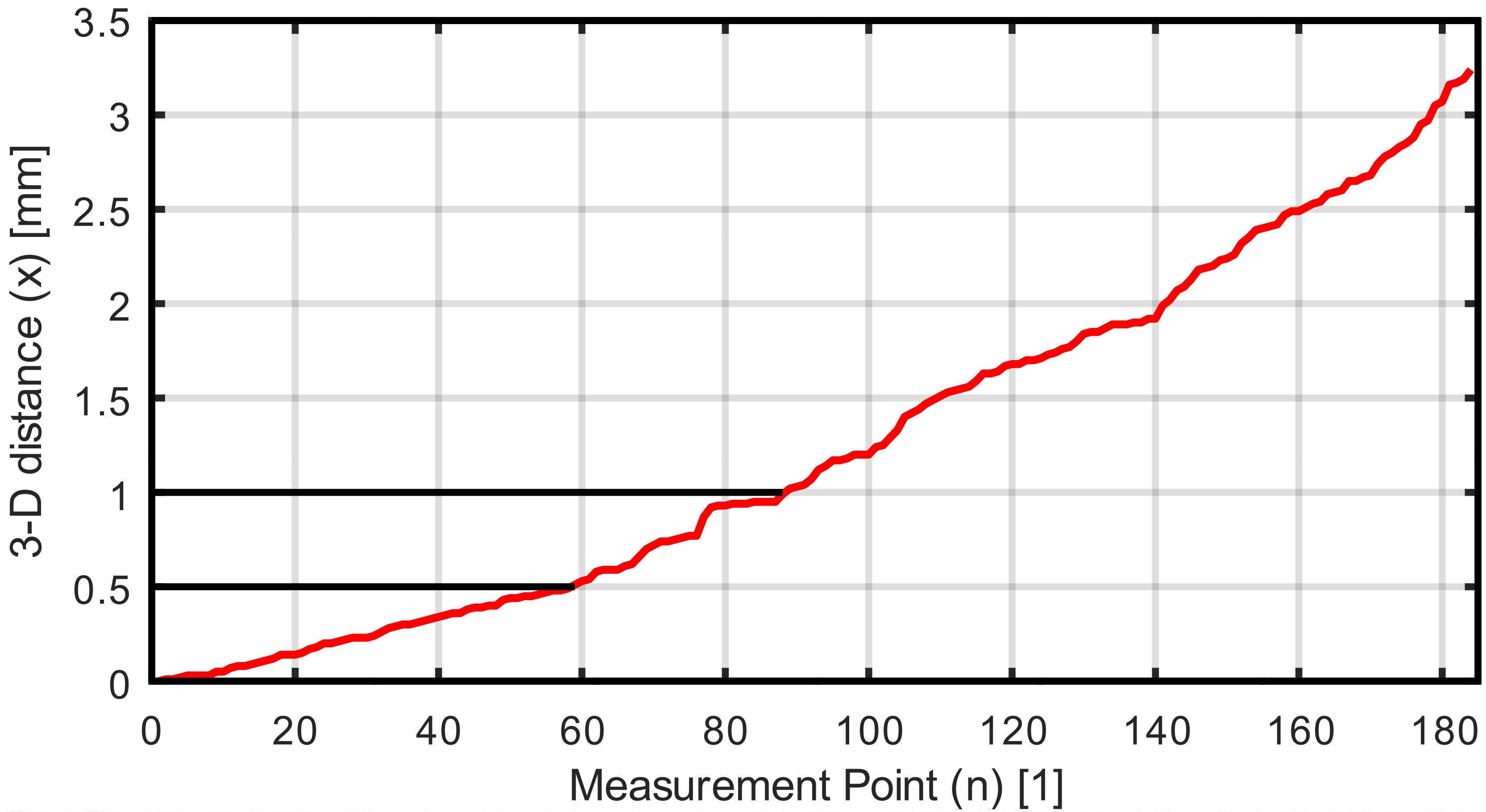


3-D Visual scans are done after OP15 and OP25 to compare with the simulation.

Circle grid analyses were also done.



SIMULATION VS. EXPERIMENT

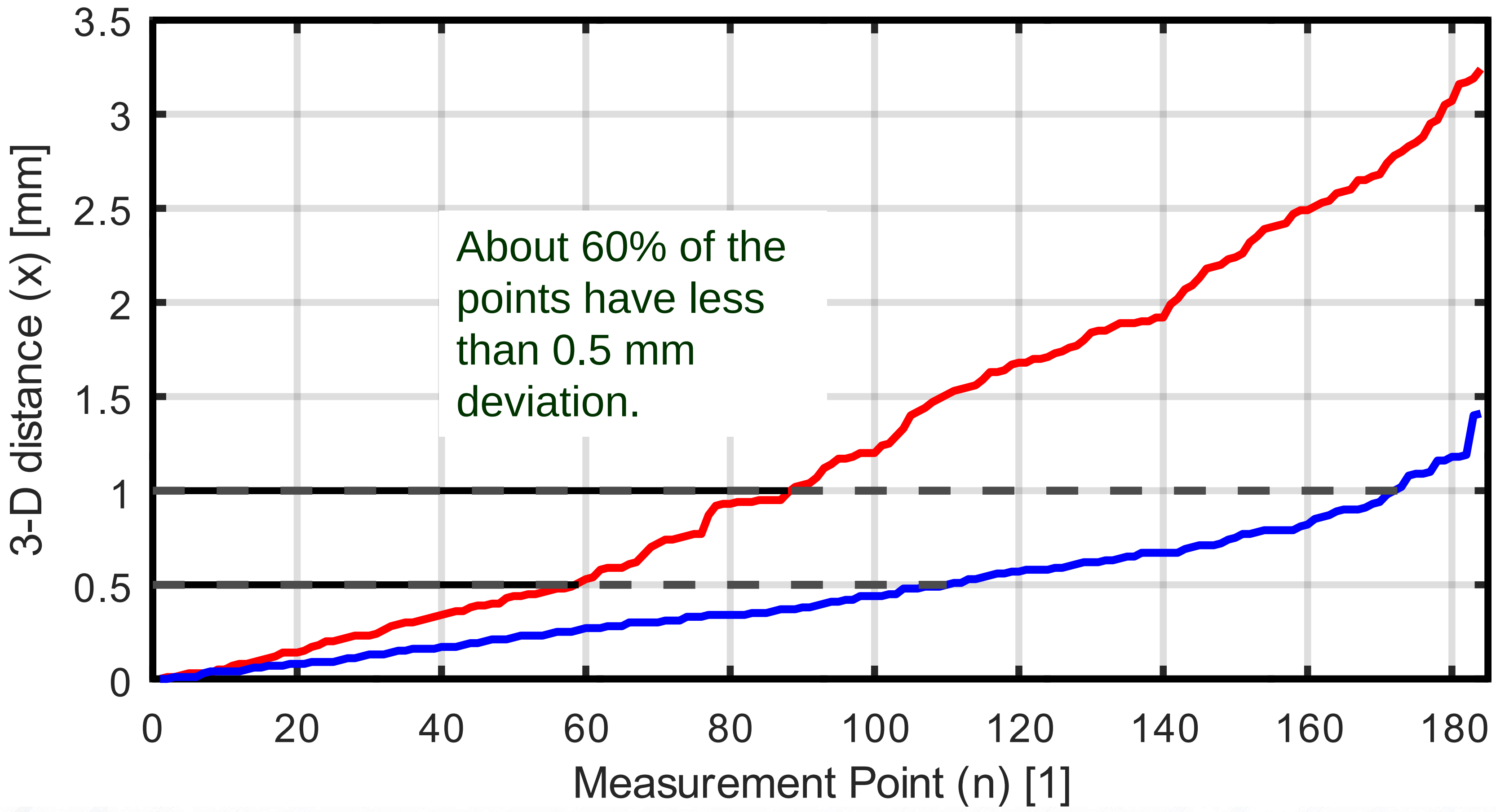


Level 0 – Material card from the steel mill

Only 32% of the pre-selected points have less than 0.5 mm deviation between simulation and experiment.

About 48% of the points have less than 1 mm deviation.

LEVEL 4



Level 0 – Material card from the steel mill

Level 4 – Material card with Yoshida-Uemori model.

Almost 94% of the points have less than 1 mm deviation.

FUTURE WORK

1) Comparison of minor and major strain distribution,

2) Splitting the part with increased Blank Holding Force (BHF) – trying to estimate the splitting BHF tonnage in simulation.

3) SPM-effects will be further investigated.

FUTURE WORK – LEVEL 5

		Level 0	Level 1	Level 2	Level 3	Level 4	Level 5
Material Card	Hardening Curve	Supplied	Test-data	Test-data	Test-data	Yoshida-fit	Yoshida-fit
	Yield Locus	Supplied	Only Hill 1948	Only Hill 1948	Bulge Test	Bulge Test	Bulge Test
	FLC (or TFC)	Supplied	Estimated	Estimated	Experimental	Experimental	Experimental
	Strain Rate / Temperature dependent data	Typically not included	Not included	Strain rate tested	Strain rate tested	Strain rate tested	Strain rate tested
	Kinematic Hardening	Typically not included	Not included	Not included	Not included	Yoshida-Uemori	Yoshida-Uemori
	Failure / Fracture Max Edge Strain	Typically not included	Not included	Not included	Not included	Not included	Diabolo Test or similar
Process	Friction Model	Constant	Constant	Constant	f (V, P)	f (V, P)	TriboForm Plug-in
	Press	Neglected	Neglected	Modeled	Modeled	Modeled	Modeled

FUTURE WORK

1) Temperature effects
2) Coil-to-coil, head-to-tail variation

CONCLUSIONS

- Full Material and process characterization may be time consuming and costly. Depending on the phase of the project, different levels of simulations may be developed.

- Springback modeling can be improved significantly with tension-compression tests and decaying unloading modulus.

- SPM optimizations may require thermal considerations.

- Digital twin of the coil / or an on-line measurement is required to handle coil-to-coil and intra-coil variations.

FOR MORE INFORMATION

Dr. Eren Billur

Billur Metal Form

eren@bilur.com.tr

Mr. Adem Karşı

Coşkunöz Kalıp Makina Ar-Ge

akarsi@coskunoz.com.tr