○	Decision Making
●	Information Sharing
○	Directions

Improvements to material 58 (woven composite) (Addition of strain rate effects)

LS-DYNA Anwender Forum, Stuttgart, 2013

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Contents

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Motivation - Background

- In the global quest to reduce CO_2 emissions, via reduced vehicle mass, there is an increasing use of high strength glass composites in the EU.

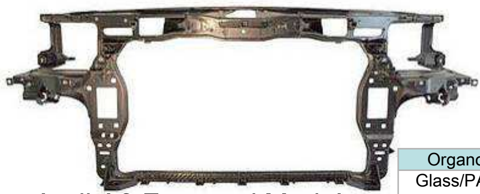
- The new generation of new woven fiber composites with thermoplastic matrices (organo-sheet) can be thermoformed and then back over-molded.

- Of these, glass based woven composites have been identified for high strength with low specific weight and cost.
  - Serial Examples :
    - ⇒ BMW M3 Bumpers
    - ⇒ Audi A8 Frontend Module
    - ⇒ Opel Astra OPC Front Seat Pan
    - ⇒ VW Brake Pedal (SoP 2013)

BMW M3 Front Bumper

Organo	Matrix	Reinf	Process
Glass/PA6	PA6 GF30	Steel	Welding

http://techcenter.lanxess.com/



Audi A8 Frontend Module

Organo	Matrix	Reinf	Process
Glass/PA6	PA6 GF30	Steel	Overmold

http://techcenter.lanxess.com

Organo	Matrix	Reinf	Process
Glass/PA6	PA6 GF30	Steel	Overmold

http://www.reinert-kunststofftechnik.de/

Organo	Matrix	Reinf	Process
Glass/PA6	PA6 GF50		Overmold

http://www.zf.com/

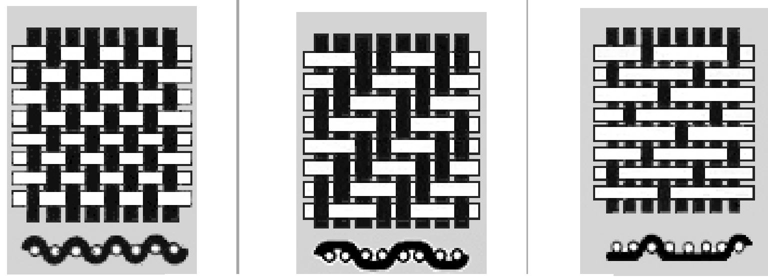
Examples of Organo-sheet Serial Products

Motivation - Material Details

- Organo-sheet is a woven material:
  - Fiber:
    - ⇒ Glass
    - ⇒ Carbon fibers
  - Matrix
    - ⇒ Polyamide
    - ⇒ Polypropylene

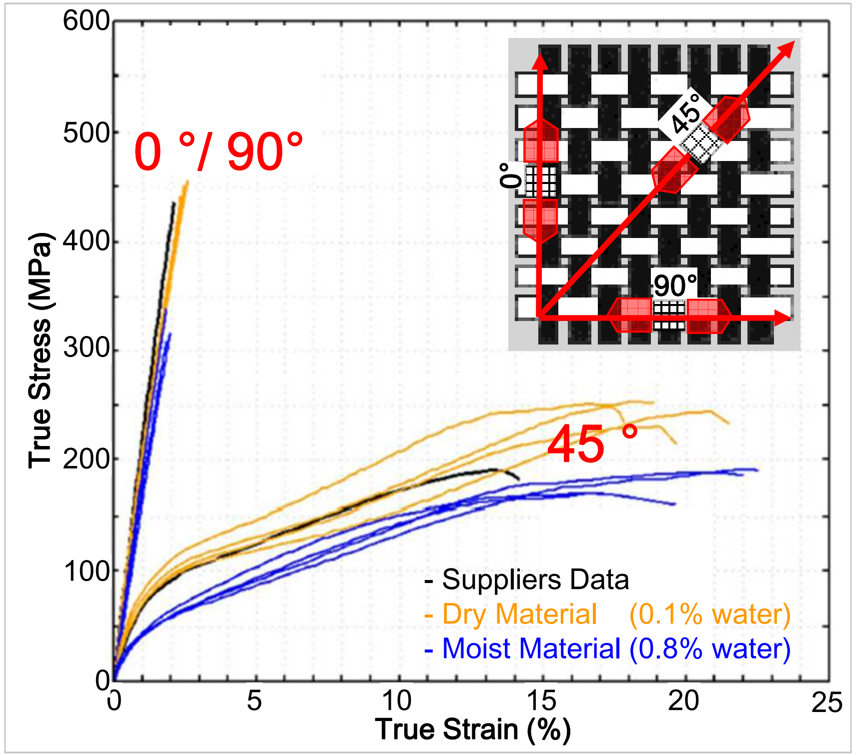
- Unlike steel, the material stiffness is anisotropic i.e. the stiffness and strength are unequal in different directions. This makes CAE much more difficult.

Plain weave	Twill weave	Satin weave



Source http://www.bond-laminates.com/

Organo-sheet weaves



Tensile Tests – Effect of Fiber Angle

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Motivation – Effects of strain rate on material

- Similar to steel, the effect of strain rate on material strength is significant
- Using the 1983 Johnson and Cook expression for strain rate sensitivity the effect of strain rate can be quantified:

$$\sigma = \sigma_0 \left(1 + c \ln \frac{\varepsilon'}{\varepsilon_0} \right)$$

- Red highlighted strain rate factors (c) for organo-sheet material are greater than those for steel

Material	Fiber Angle	Loading direction	Rate effect (c)	
			Modulus	Strength
① Organo-sheet (Supplier 1 – Glass fiber + PP matrix)	0°	+	0.008	0.027
		-	0.131	0.086
	45°	+	-0.074	-0.017
		-	No Data	No Data
② Organo-sheet (Supplier 2 - Glass fiber + PA matrix	0°	+	-0.012	0.038
		-	0.014	0.080
	45°	+	0.015	0.058
		-	0.022	0.008
Material	**Grade**	**Yield Stress**	**Modulus**	**Strength**
③ Steel (Data from '83 Johnson/Cook paper)	1006	350	No Data	0.022
	4340	792		0.014
	S-7 Tool	1537		0.012

Generalized effects of applied strain rate on material properties

Problem to be solved / Material model choices

- **Key** to high CAE accuracy is the inclusion of strain rate dependency for strength.
  - This is not available for the majority of composite material models and has only recently been included in material 54 in version 971 release R7.
- Material model 58 is a good model as it includes non-linearity.
  - Material model 158 is limited to 15% strain rate effect. This is not enough.
  - No strain-rate effect means the user needs two, or more models for quasi-static and "dynamic" load cases.

LS-DYNA model	Stiffness				Strength			Extra cost
	In-Plane				In-Plane		Out of Plane	
	0/90°		45°		0/90°	45°		
	Non-lin.	$\dot{\varepsilon}$ rate	Non-lin.	$\dot{\varepsilon}$ rate	$\dot{\varepsilon}$ rate		Damage	
22	X	X	X	X	X	X	X	X
54	X	X	X	X	✓	✓	✓	X
58	X	X	✓	X	X	X	X	X
158	X	✓	✓	✓	✓	✓	X	X
162	✓	✓	✓	✓	✓	✓	✓	✓
261	X	X	✓	X	X	X	X	X
262	X	X	✓	X	X	X	X	X

Overview of composite material model features

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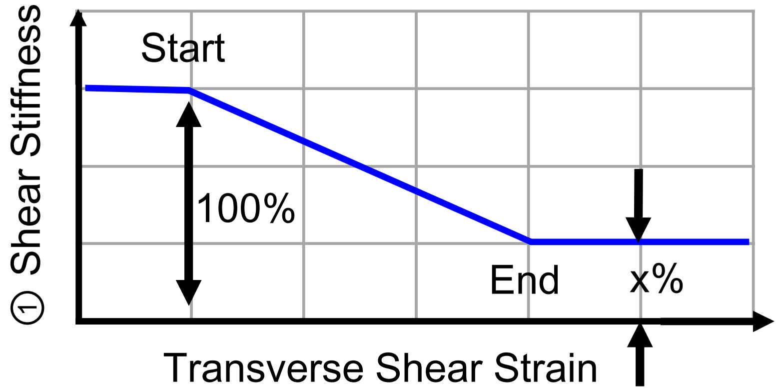
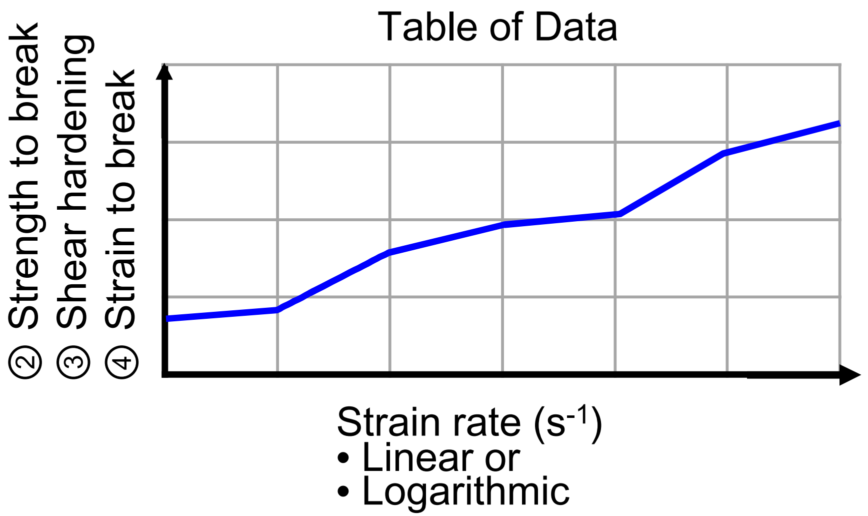
Proposed Changes to Material Model 58

- Similar to the changes to mat 54, the following new features were added to the standard mat 58 material model:
  - ① Out of plane transverse shear damage
  - ② Generalized strain rate dependency of breaking strength
- In addition the following additional effects were also added
  - ③ Generalized strain rate dependency of shear hardening stiffness
  - ④ Generalized strain rate dependency of strain to break (damage)



Out of Plane Shear Damage



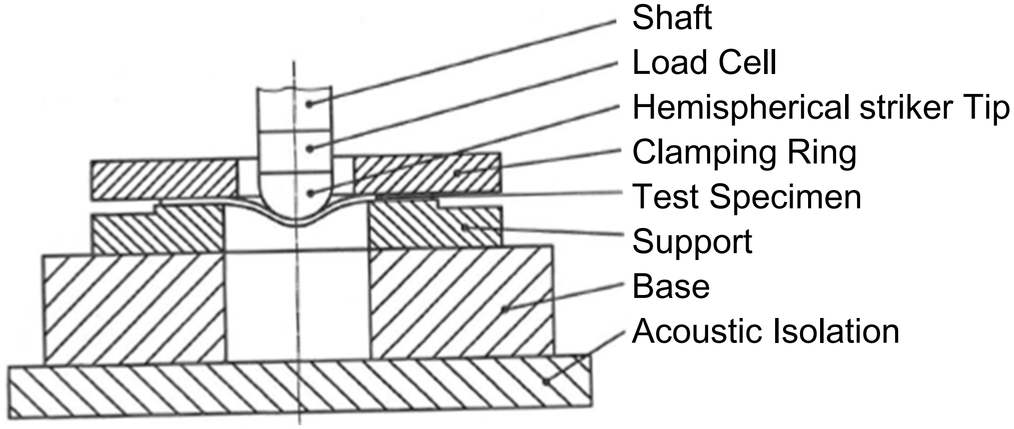
Generalized Strain rate Dependency

Validation Load Case

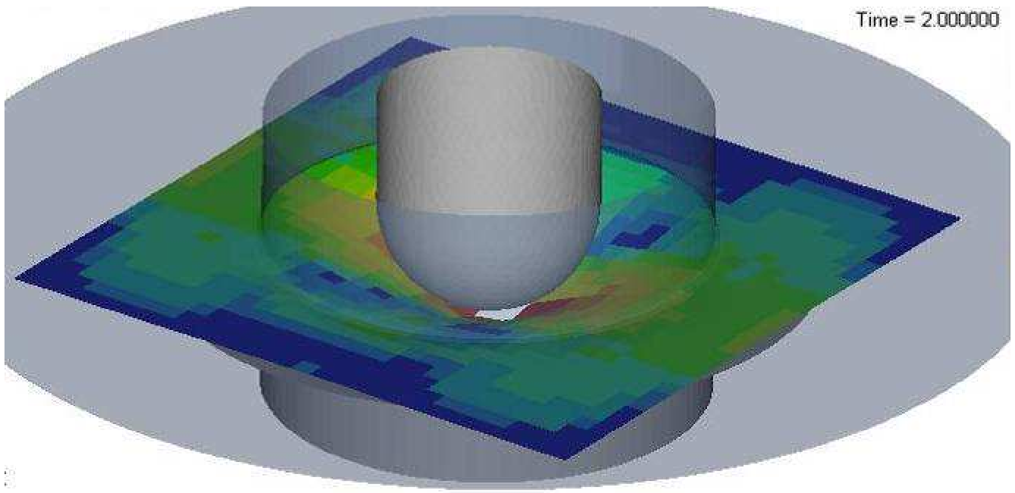
Punch Test

- DIN EN ISO 6603-2
  - ⇒ PA6 GF46 Organo-sheet

- Loading speeds
  - ⇒ Quasi-static (ε'~ 0.001 s-1)
  - ⇒ Dynamic (ε'~ 200 s-1)



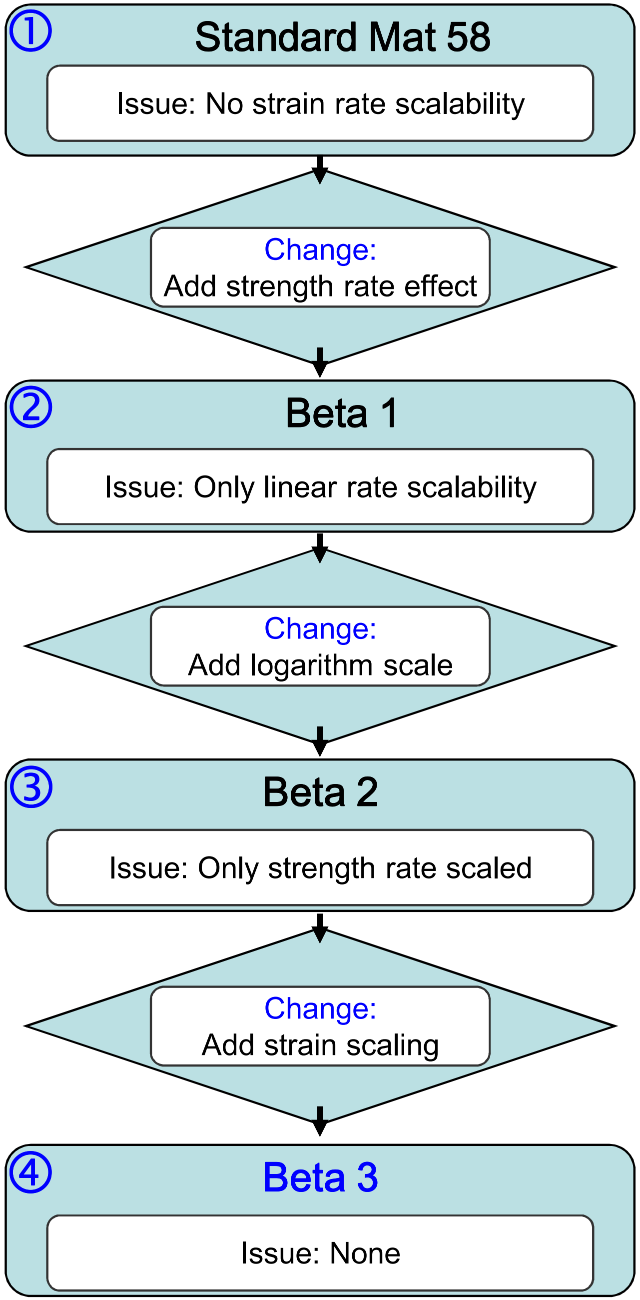
Disc Punch Test Configuration



Simulation Model

Project Phases

1. Status models
   - Issue: No strain rate effects
     - ⇒ 2 separate data sets
2. Beta 1 Review:
   - Issue: Strain rate scaling
     - ⇒ Linear resample with 100 points
3. Beta 2 Review:
   - Issue: Strength scaling only
     - ⇒ Parameter identification not possible
4. Beta 3 Review: OK
   - Strength & Ductility Scaling
     - ⇒ Parameter identification OK



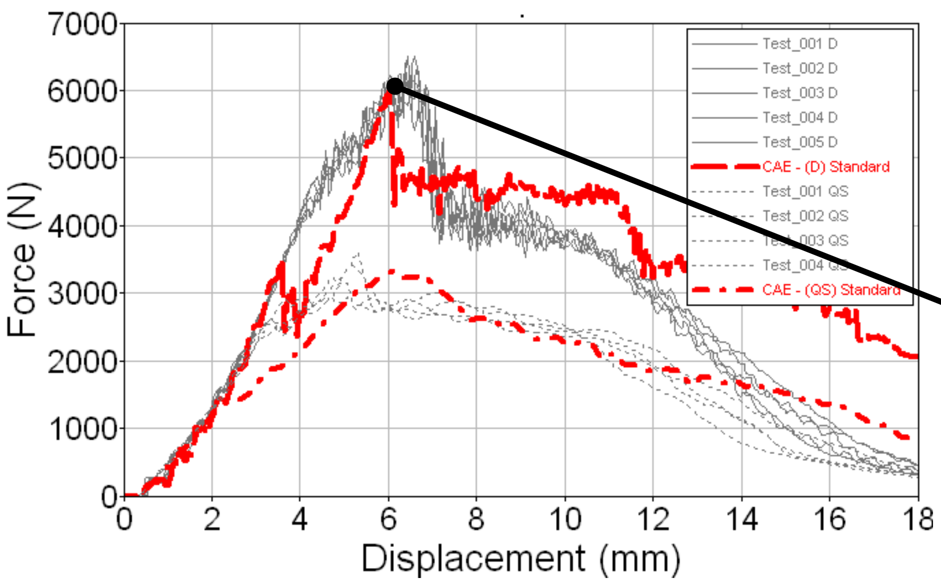
Project Steps

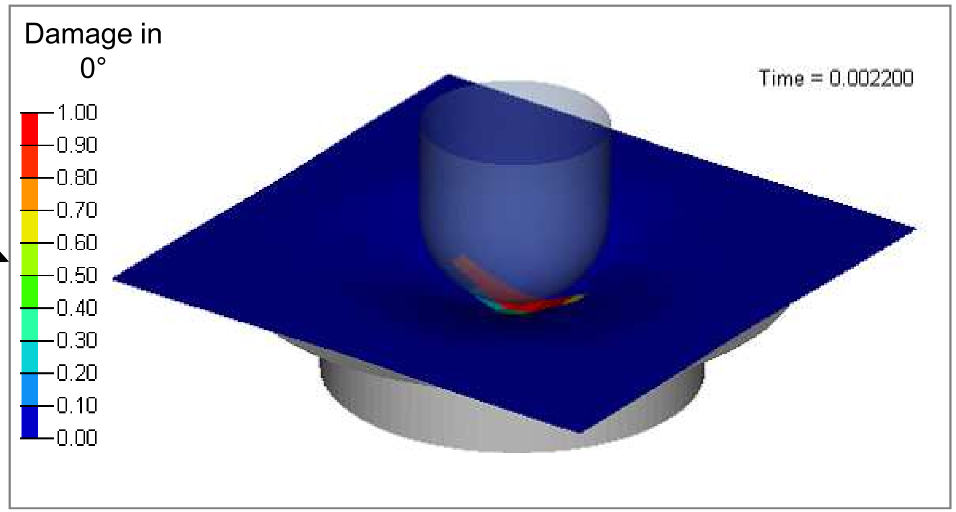
Project Phase 1: Status Model

- Status: Fixed Strain rates
  - Quasi-static (ε'~ 0.001 s-1)
  - Dynamic (ε'~ 200 s-1)

- Accuracy

WIFac Cross-correlation (%)	Test Static	Test Dynamic
CAE (Q-S) standard	85	65
CAE (Dynamic) standard	60	83

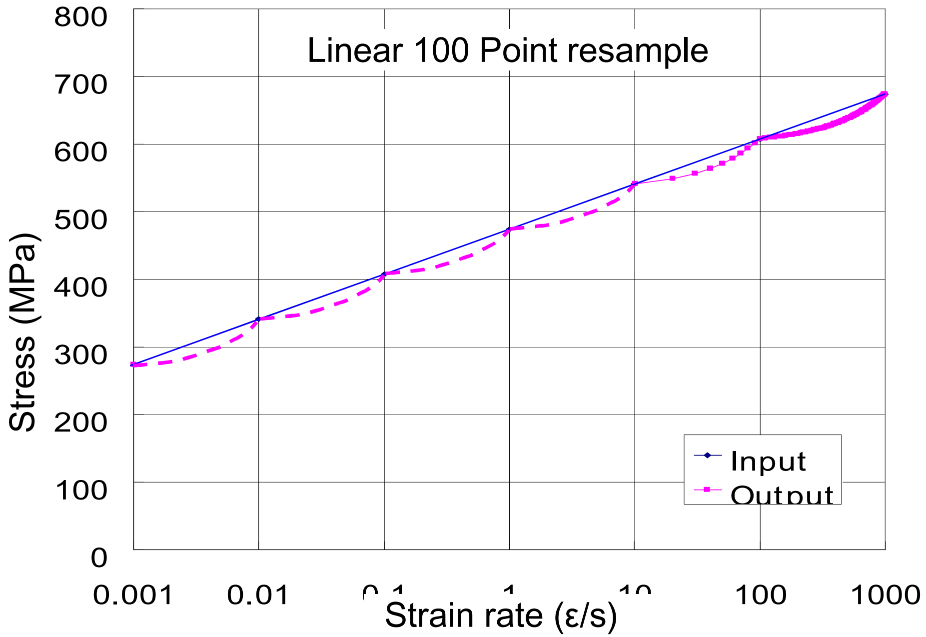




Disc Punch Test Simulation

Project Phase 2: Beta 1

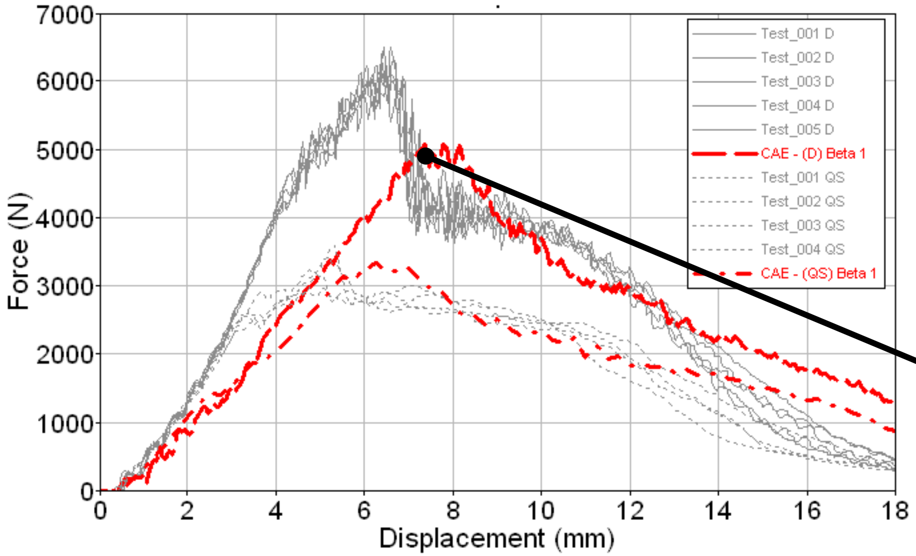
- Issue: Internal curve resampling
  - Only linear rate resampling
    - ⇒ Underestimates strength

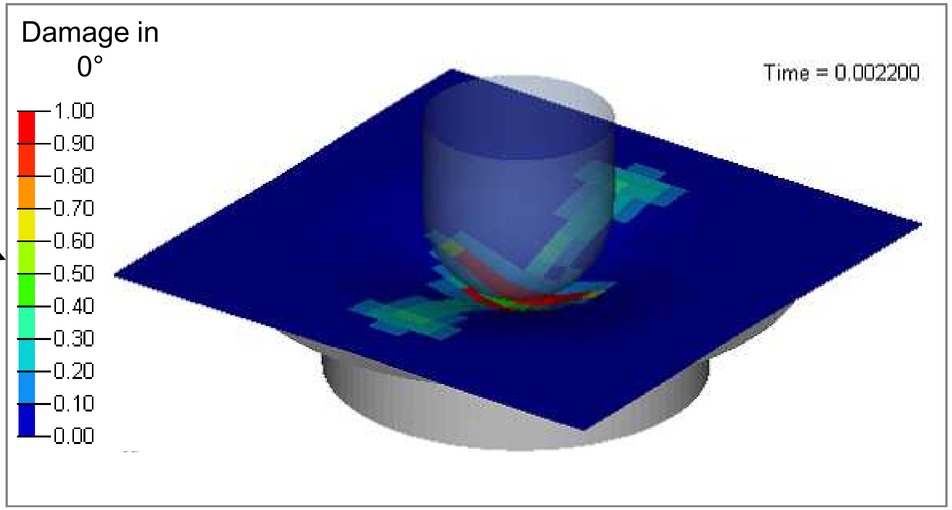


Effect of internal curve resampling

- Accuracy

WIFac Cross-correlation (%)	Test Static	Test Dynamic
CAE Beta 1	86	80





Disc Punch Test Simulation

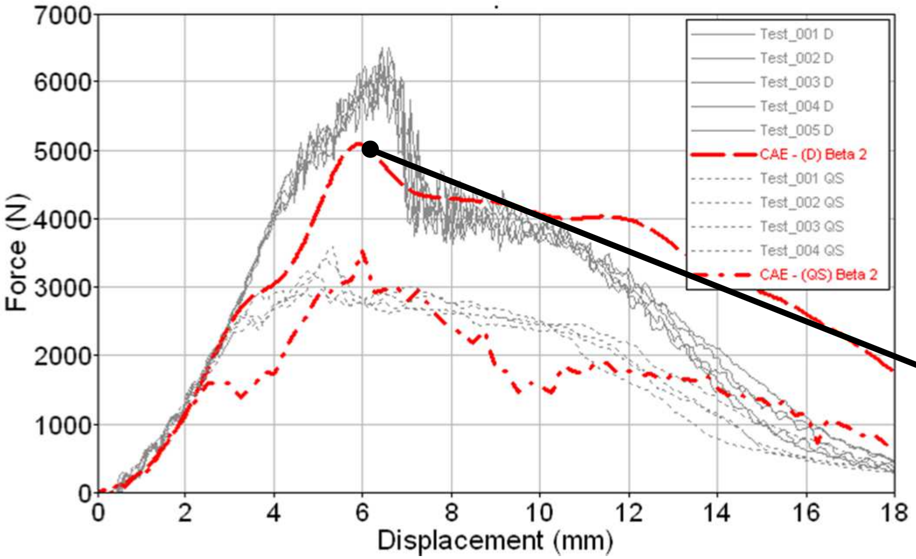
- Identification of issue:
  - Resampling of curves

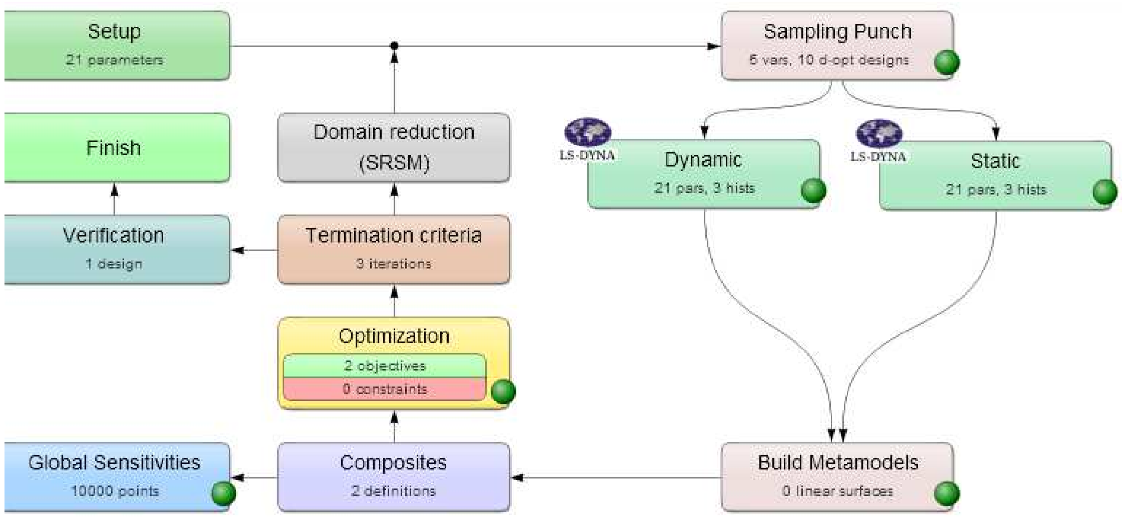
Project Phase 3: Beta 2

- Issue: Only Break Stress Scaling
  - Underestimates strength

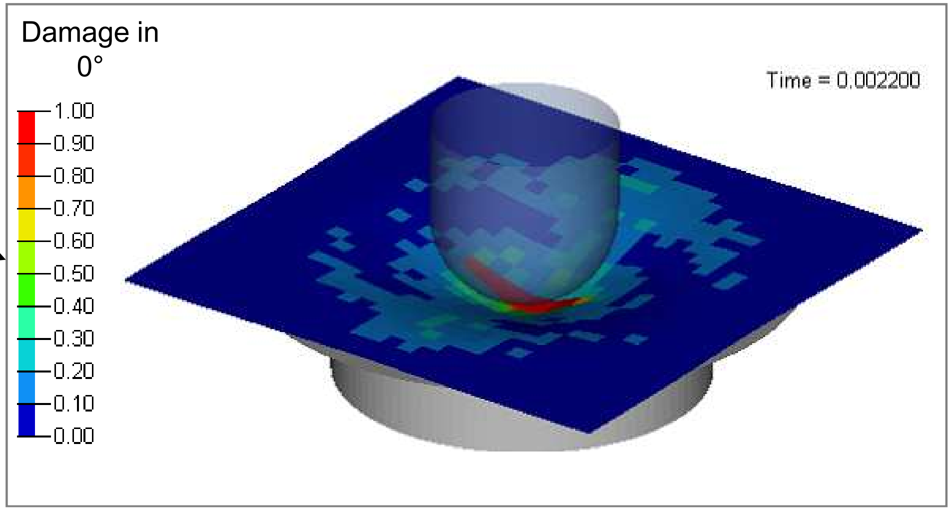
- Accuracy

WIFac Cross-correlation (%)	Test Static	Test Dynamic
CAE Beta 2	76	82





LSOPT Process – 2 load cases

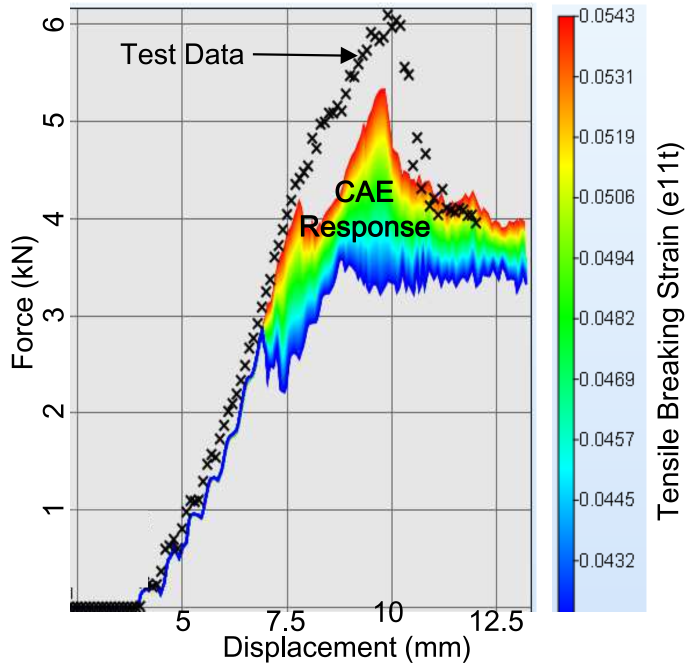


Disc Punch Test Simulation

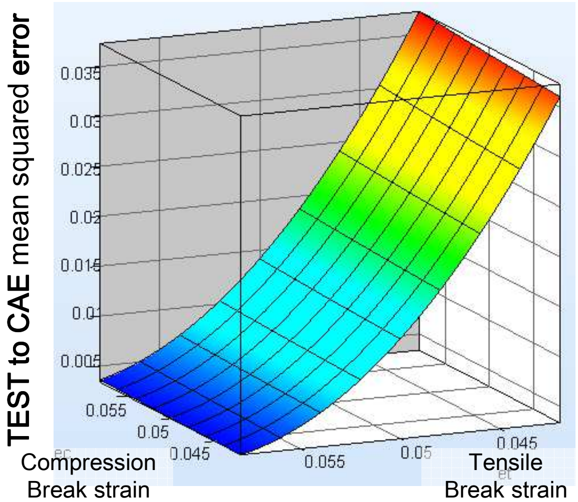
- Identification of issue:
  - LSOPT parameter identification

Project Phase 3: Beta 2

- Identification of Issue:
  - LSOPT parameter identification
    - ⇒ Tensile Strain to break critical
    - ⇒ Conflicting requirements
    - ❖ Quasi-static = low strain
    - ❖ Dynamic = high strain
  - No solution possible with stress scaling only (e.g. mat 54)

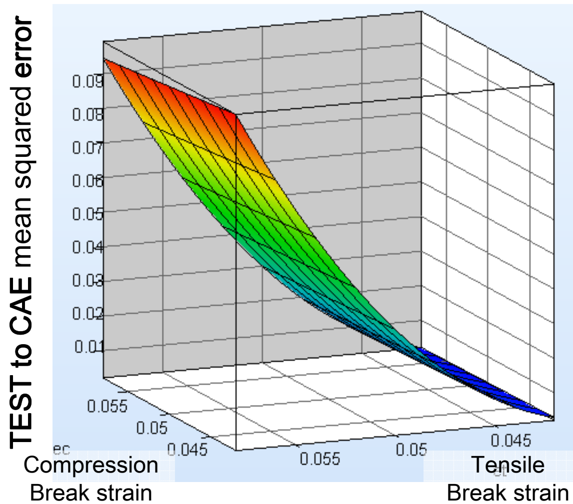


Effect of Breaking Strain Parameter



Quasi-static Meta Surface Response

Opposing Requirements



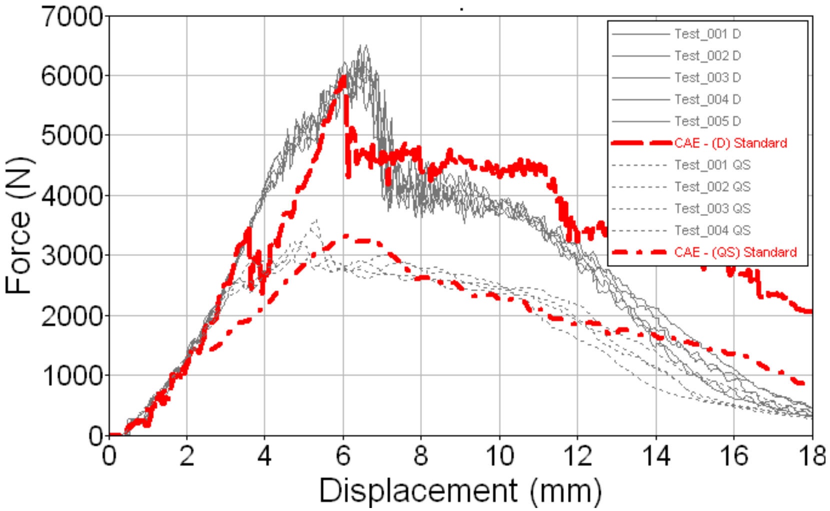
Dynamic Meta Surface Response

▣ Project Phase 4: Beta 3 - Final

- ❑ Issue:
  - ➢ None

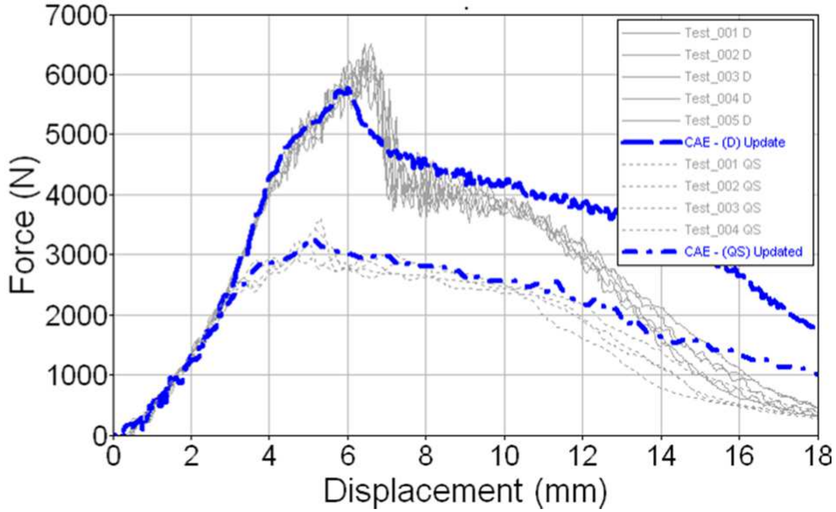
- ❑ Accuracy

Initial Status



WIFac Cross-correlation (%)	Test Static	Test Dynamic
CAE (Q-S) standard	85	65
CAE (Dynamic) standard	60	83

Final Status



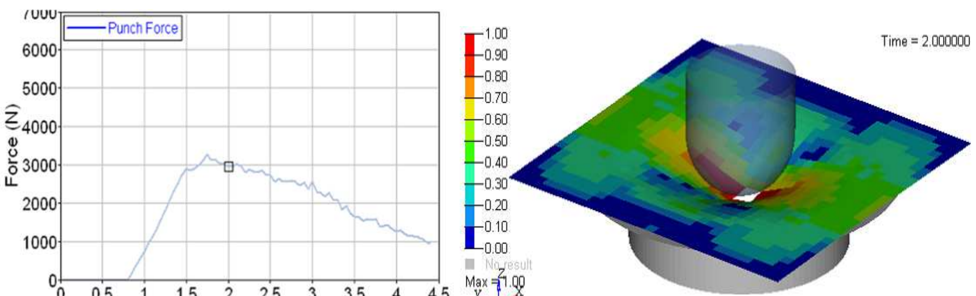
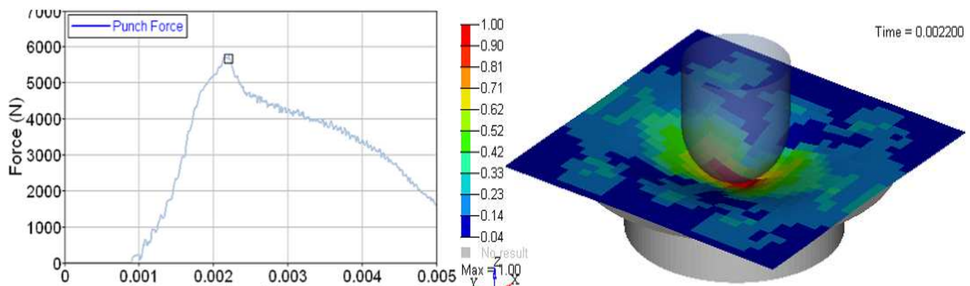
WIFac Cross-correlation (%)	Test Static	Test Dynamic
CAE (variable rate) updated mat 58	97	85

Achievements and Conclusions

- Single model for both static and dynamic CAE
  - Variable strain rate effect

- Flexible implementation of strain rate effects
  - Arbitrary (not limited by Johnson/Cook or Power laws)
  - Independent in 5 directions
    - ⇒ 0° Tension ≠ Compression
    - ⇒ 45° Tension = Compression
    - ⇒ 90° Tension ≠ Compression

- Real Effect Modeling Possible
  - Different strength and damage modes dependent on strain rate

Quasi-Static Response	Dynamic Response
 Damage in 0°	 Damage in 0°

Acknowledgements

- The work presented is the result of a consortium between :
  - Hyundai Motor Europe Technical Center GmbH
    http://www.hmetc.com/
  - DYNAmore GmbH
    http://www.dynamore.de/
- The author would like to especially express his thanks to:
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Hyundai Motor Europe Technical Center GmbH, Rüsselsheim / Germany

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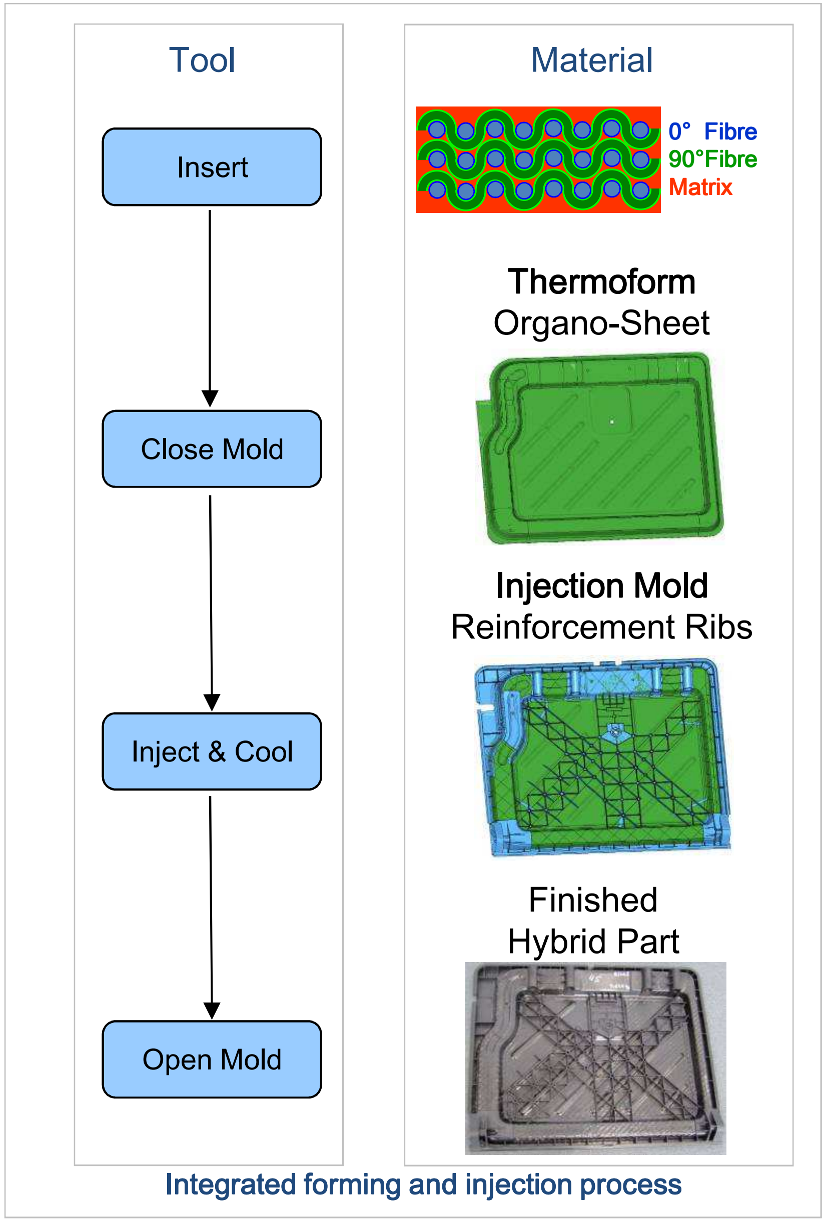
Appendix 1: Manufacturing Process

- SpriForm (in-mold forming:
  - Woven glass composites with a thermoplastic matrix is generically called "organo-sheet" and consists of:
    - ⇒ Plain woven (filament glass) fiber mat.
    - ⇒ Polyamide-6 or Polypropylene matrices.
  - A particular advantage of these organo-sheets is that they can be thermoformed and then over-molded in one tool resulting in fast cycle times i.e. low production costs.
  - In order to take advantage of the high strength of long fiber thermoplastic material systems and design new products, CAE optimization of proposed designs are necessary.



The SpriForm Process (in-mold forming)

Appendix 2: Material Card

Card 1	1	2	3	4	5	6	7	8
Variable	MID	RO	EA	EB	(EC)	PRBA	TAU1	GAMMA1
Type	A8	F	F	F	F	F	F	F
Card 2	1	2	3	4	5	6	7	8
Variable	GAB	GBC	GCA	SLIMT1	SLIMC1	SLIMT2	SLIMC2	SLIMS
Type	F	F	F	F	F	F	F	F
Card 3	1	2	3	4	5	6	7	8
Variable	AOPT	TSIZE	ERODS	SOFT	FS	EPSF	EPSR	TSMD
Type	F	F	F	F	F	F	F	F
Card 4	1	2	3	4	5	6	7	8
Variable	XP	YP	ZP	A1	A2	A3		
Type	F	F	F	F	F	F		
Card 5	1	2	3	4	5	6	7	8
Variable	V1	V2	V3	D1	D2	D3	BETA	
Type	F	F	F	F	F	F	F	
Card 6	1	2	3	4	5	6	7	8
Variable	E11C	E11T	E22C	E22T	GMS			
Type	F	F	F	F	F			
Card 7	1	2	3	4	5	6	7	8
Variable	XC	XT	YC	YT	SC			
Type	F	F	F	F	F			
Card 8	1	2	3	4	5	6	7	8
Variable	LCXC	LCXT	LCYC	LCYT	LCSC	LCTAU1	LCGAM1	DT
Type	I	I	I	I	I	I	I	F
Card 9	1	2	3	4	5			
Variable	LCE11C	LCE11T	LCE22C	LCE22T	LCGMS			
Type	I	I	I	I	I			

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Appendix 3: Parameter Definitions

- **LCXC** — Load curve ID for XC vs. strain rate (XC is ignored with that option)
- **LCXT** — Load curve ID for XT vs. strain rate (XT is ignored with that option)
- **LCYC** — Load curve ID for YC vs. strain rate (YC is ignored with that option)
- **LCYT** — Load curve ID for YT vs. strain rate (YT is ignored with that option)
- **LCSC** — Load curve ID for SC vs. strain rate (SC is ignored with that option)
- **LCTAU1** — Load curve ID for TAU1 vs. strain rate (TAU1 is ignored with that option, only active for FS=-1.0)
- **LCGAM1** — Load curve ID for GAMMA1 vs. strain rate (GAMMA1 is ignored with that option, only active for FS=-1.0)
- **DT** — Strain rate averaging option.
  - EQ.0.0: Strain rate is evaluated using a running average.
  - LT.0.0: Strain rate is evaluated using average of last 11 time steps.
  - GT.0.0: Strain rate is averaged over the last DT time units.
- **LCE11C** — Load curve ID for E11C vs. strain rate (E11C is ignored with that option)
- **LCE11T** — Load curve ID for E11T vs. strain rate (E11T is ignored with that option)
- **LCE22C** — Load curve ID for E22C vs. strain rate (E22C is ignored with that option)
- **LCE22T** — Load curve ID for E22T vs. strain rate (E22T is ignored with that option)
- **LCGMS** — Load curve ID for GMS vs. strain rate (GMS is ignored with that option)

Appendix 4: New Output Time Histories

#	19	dmg56	Damage parameter for transverse shear behavior
#	20	e1dot	Strain rate in the longitudinal direction: $\acute{\varepsilon}_{aa}$
#	21	e2dot	Strain rate in the transverse direction: $\acute{\varepsilon}_{bb}$
#	22	e3dot	Strain rate in the in-plane direction: $\acute{\varepsilon}_{ab}$