Afera Virtual Technical Seminar

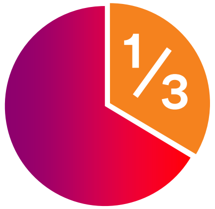
3M Adhesive Tapes

Characterization, Modeling and Simulation

Dr.-Ing. Tobias Waffenschmidt | 3M Corporate Research | Neuss, Germany | 29 April 2021

3M at a Glance

More than 55,000 products



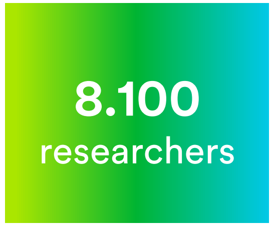
One third of our sales come from products developed within the past five years

91,000 employees worldwide

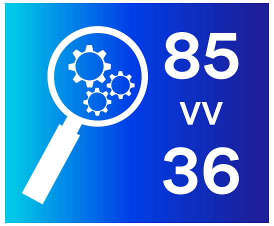
Operations in 70 countries and sales into 200

You are likely to come across 3M Science more than 100 times every day

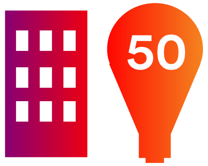
Approximately six per cent of our revenue is reinvested into research and development around the world



8,100 researchers worldwide

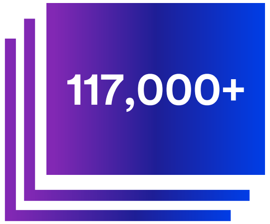


85 research and development facilities spanning 36 countries

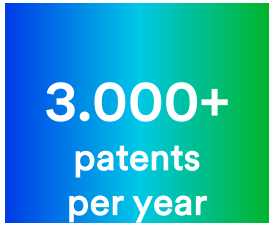


More than 50 Customer Innovation Centres around the world

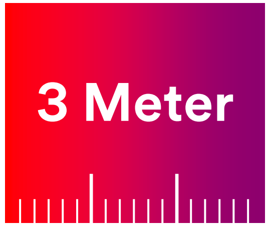
200 manufacturing facilities across 37 countries



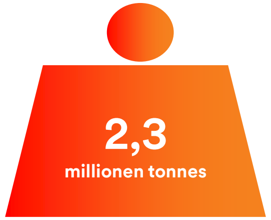
We have 117,000+ registered patents



Our scientists amass patents at an average of more than 3,000 per year



You are rarely more than three metres away from 3M Science



More than 2.3 million tonnes of pollutants eliminated since 1975

Adhesives and Modeling – Two of 3M's Core Technologies

Ab Abrasives												
Ad Adhesives	Em Electronic Materials										Di Display Components	Hd Healthcare Data Management
Bi Biomaterials	Fi Films	Nw Nonwovens							Ms Modeling & Simulation	Ac Acoustic Management	Ec Energy Components	Lm Light Management
Ce Ceramics	Fl Fluoro-materials	Pm Performance Materials	Am Additive Manufacturing	Pc Precision Coating & Web Processing	Rp Radiation Processing	An Analytical Science	Pr Process Design & Control	Cv Computer Vision	Ro Advanced Robotics	Bd Biodetection & Microbial Management	Eg Engineered Graphics	Mf Mechanical Fasteners
Co Advanced Composites	Mm Metamaterials	Po Porous Materials & Membranes	Mo Molding	Pd Particle & Dispersion Processing	Su Surface Modification	Cp Converting & Packaging	Sd Sustainable Design	Ds Data Science & Analytics	Se Sensors	Cs Connected Systems	Fe Flexible Electronics	Sw Skin & Wound Management
Do Dental & Orthodontic Materials	Nt Nano-technology	Rm Release Materials	Mr Micro-replication	Pp Polymer Processing	Tf Thin Film & Plasma Processing	In Inspection & Measurement	We Accelerated Weathering	Es Electronic Systems	Ss Software Solutions	Dd Drug Delivery	Fp Filtration & Purification	Tm Thermal Management

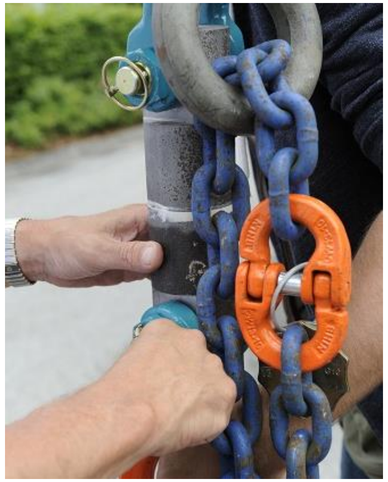
Materials — **Processing** — **Capabilities** — **Digital** — **Applications**

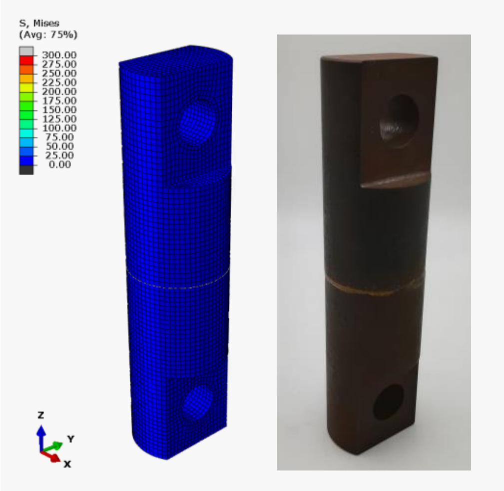
3M

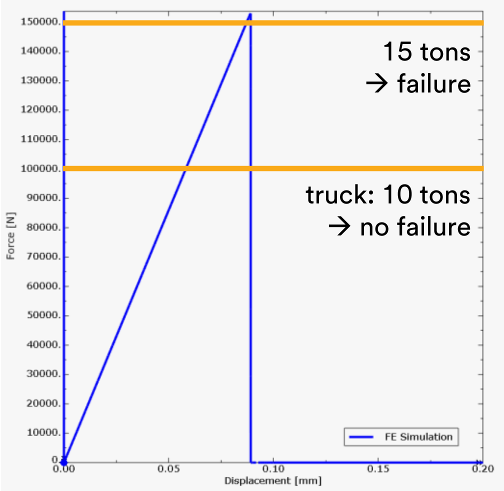
Agenda

- Intro on the Simulation of Adhesive Bonds
- Numerical Analysis of Structural Adhesives
- Numerical Analysis of 3M™ VHB™ Tapes
- Summary and Conclusion

Guinness World Record in Adhesive Bonding, 2013







Introduction on the Simulation of Adhesive Bonds

Overview of Adhesive Technologies

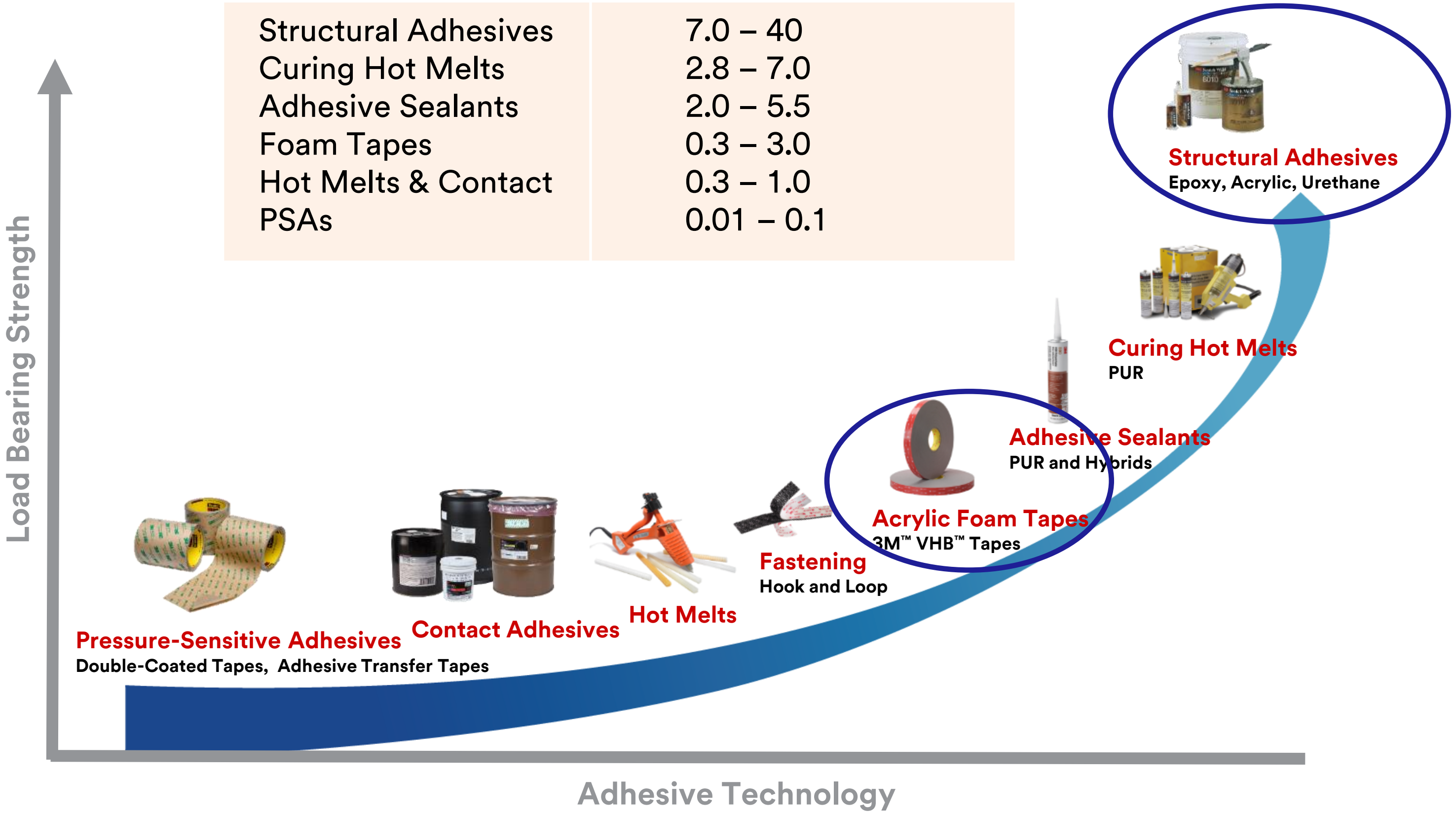
Why Adhesives?

- Adhesive bonding is the key bonding technology for multi-material construction and an essential aspect for lightweight design

Advantages

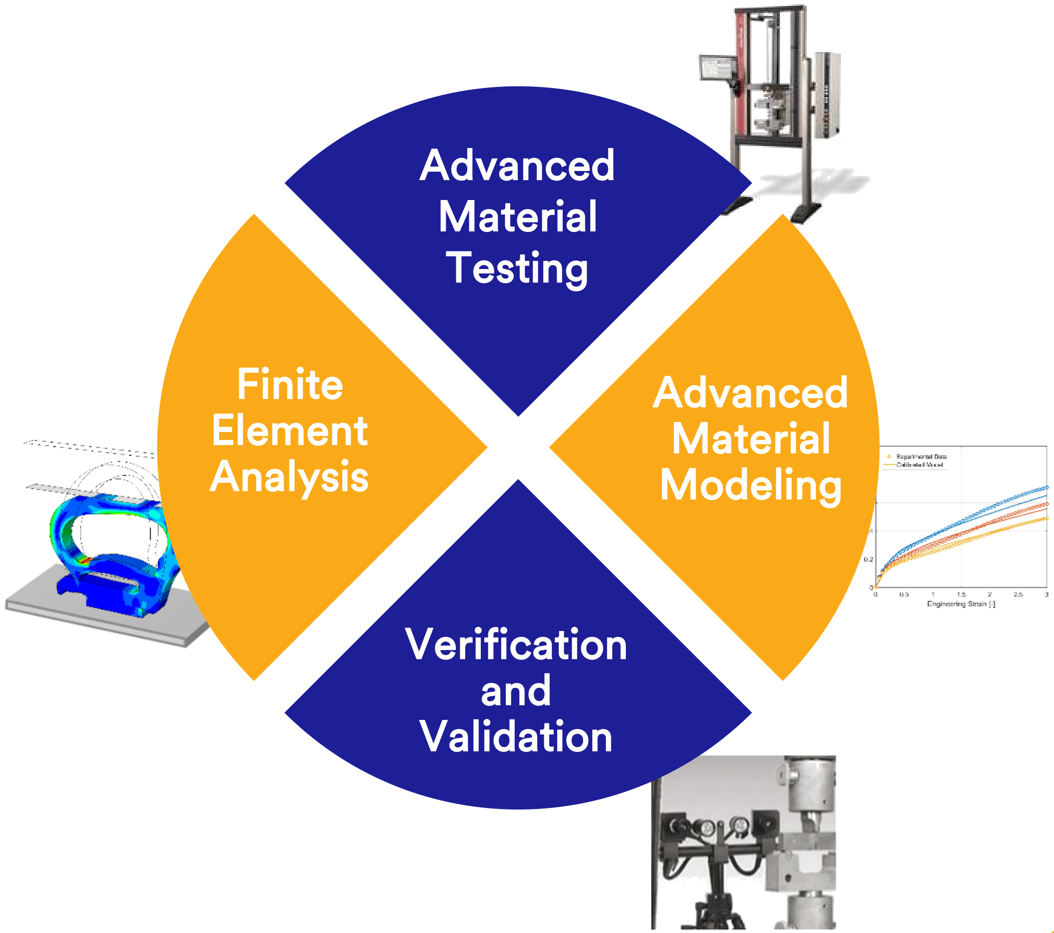
- Structural adhesives enable lightweight applications and simultaneously improve crash performance

Adhesive Load Bearing Capability	
Type	Shear Strength (MPa)
Structural Adhesives	7.0 – 40
Curing Hot Melts	2.8 – 7.0
Adhesive Sealants	2.0 – 5.5
Foam Tapes	0.3 – 3.0
Hot Melts & Contact	0.3 – 1.0
PSAs	0.01 – 0.1



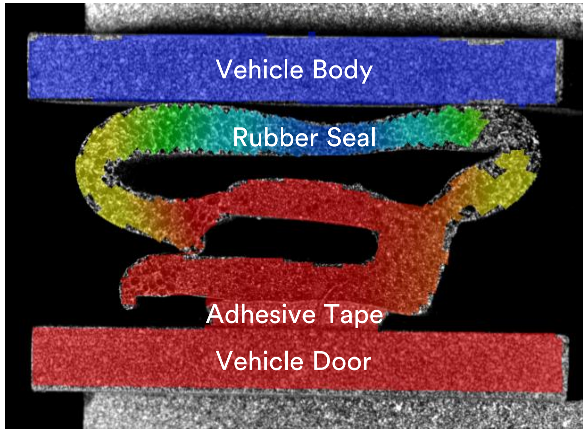
3M Technology Framework for Modeling and Simulation

Technology Framework



Example – Bonded Door Seal for Vehicles

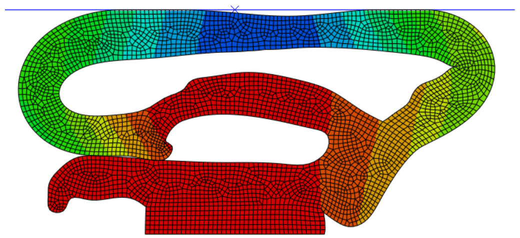
Experimental Test



Design evaluations can be performed **ONLY IF** prototype has been manufactured already!

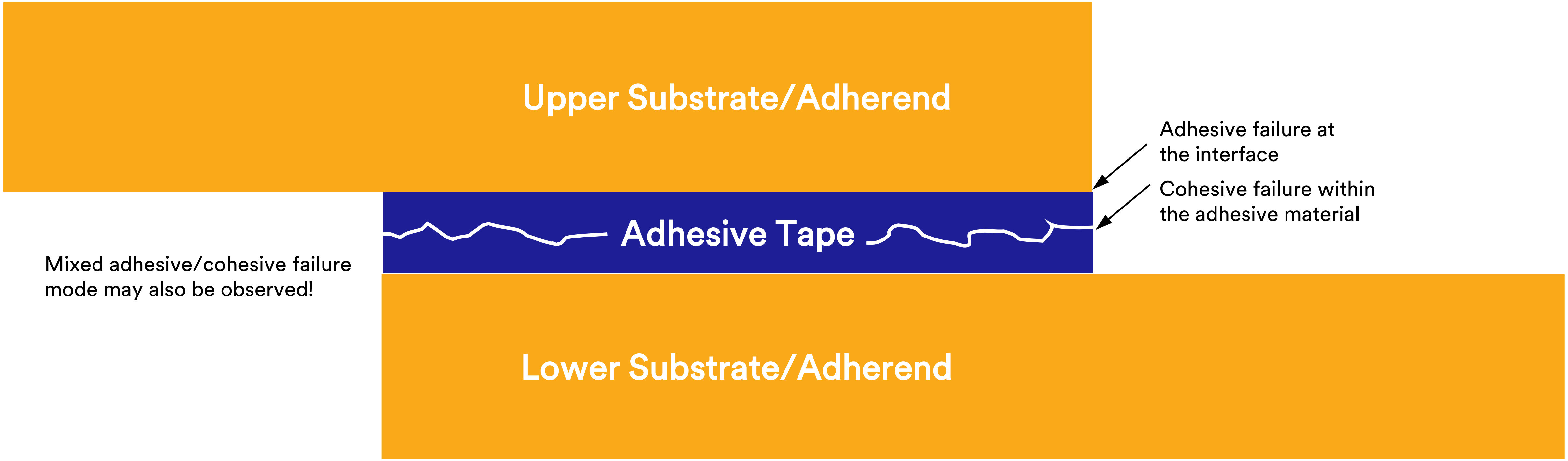
vs.

FE Simulation



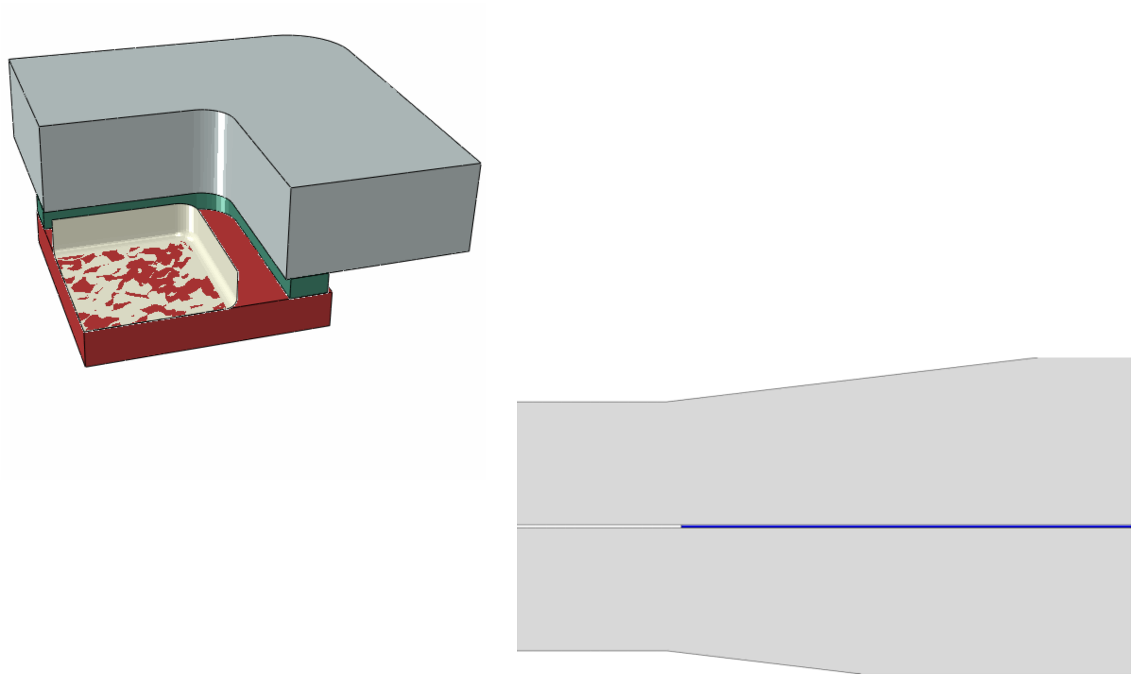
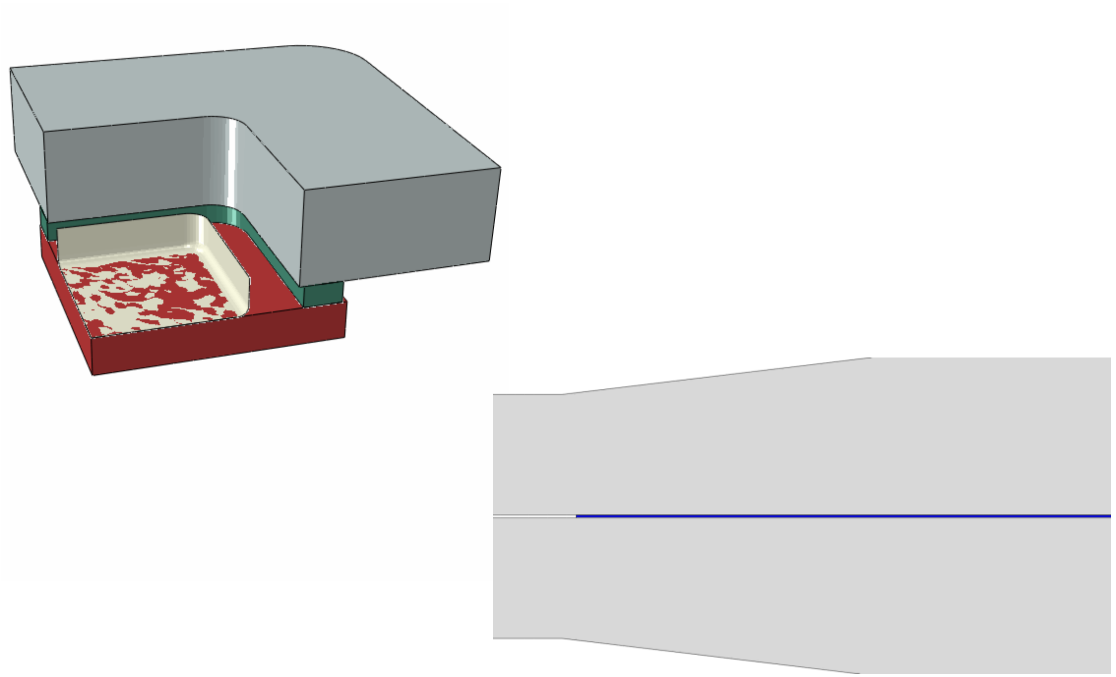
Design evaluations can be performed **BEFORE** prototype is developed!

Important Prerequisite for Adhesive Failure Modeling



- Current simulation methods only consider the **COHESIVE** failure mode, i.e., failure of the adhesive material itself
- Interfacial **ADHESIVE** failure modes are out of scope – Construction such that adhesive is the weakest link in the bond

Continuum Modeling vs. Cohesive Zone Modeling

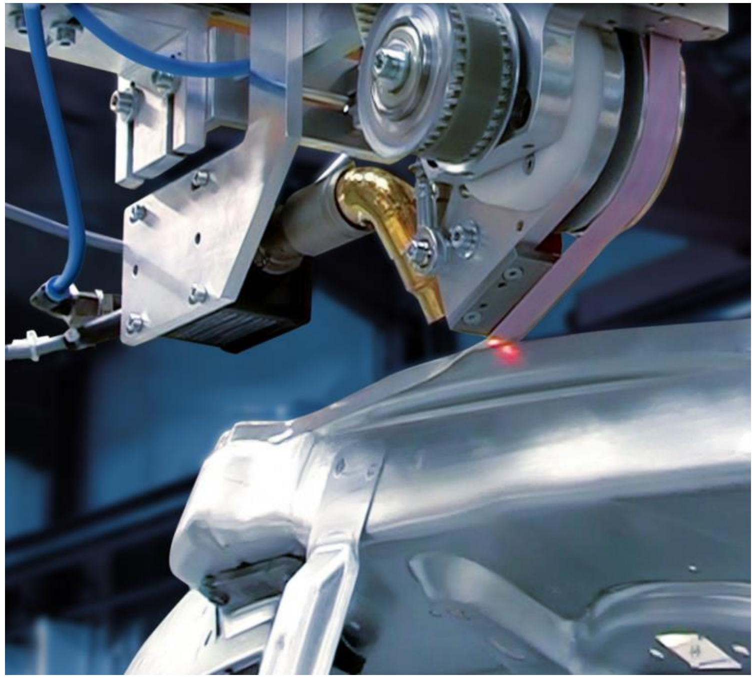
Continuum Modeling	Cohesive Zone Modeling
	
▶ Continuum modeling captures the real physics better	▶ Straightforward to include damage and failure
× Difficult to include failure and damage	× Cohesive zone modeling simplifies the real physics

Numerical Analysis of Structural Adhesive Tapes

3M™ Structural Adhesive Tapes

3M™ Structural Adhesive Tapes

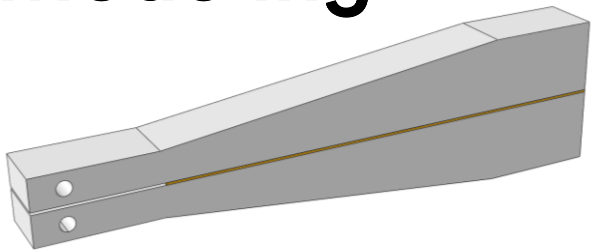
- Single layer-epoxy based adhesive tape
- Structural bonding strength
- Bonding and isolation of dissimilar materials without additional e-coat
- Gap filling properties due to expansion function
- Can be applied without pumping, dosing or squeeze-out
- Compatible with most draw and lube oils

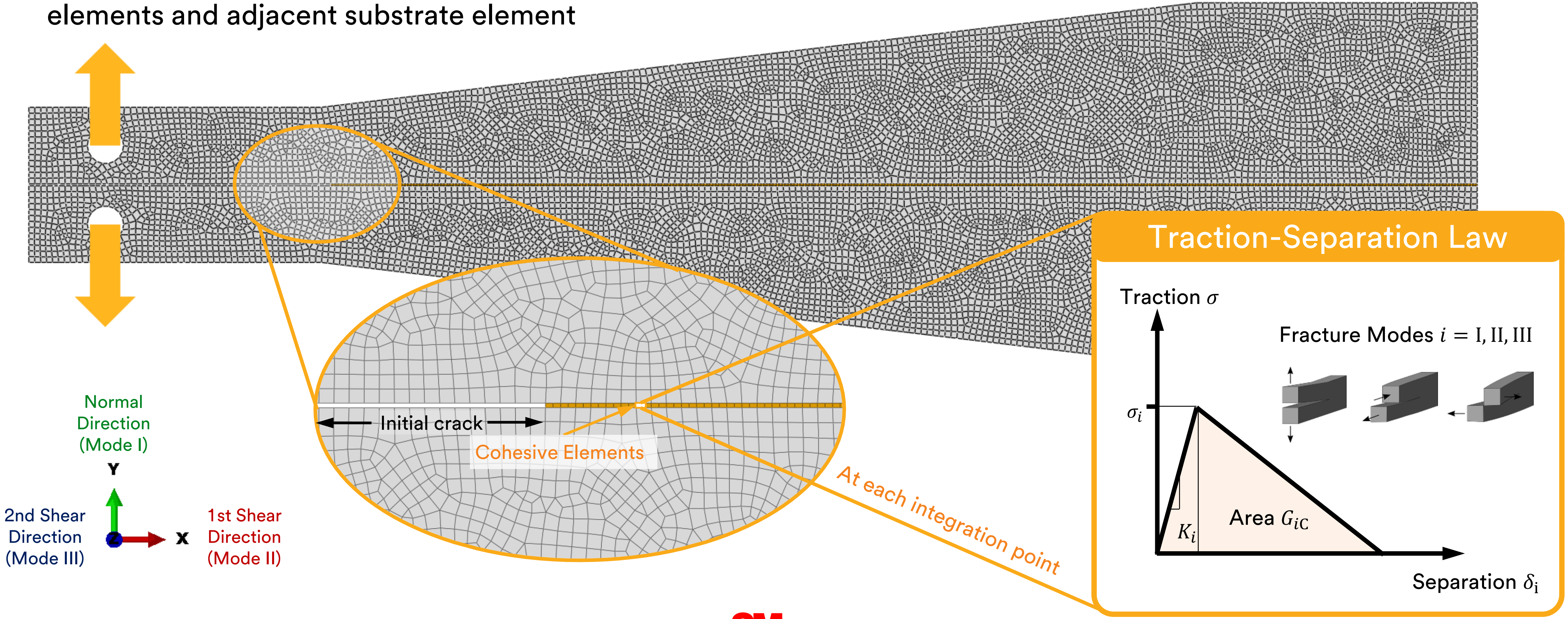


Automized application of a 3M™ Structural Adhesive Tape

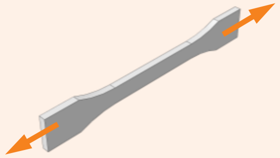
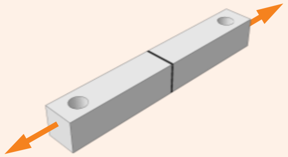
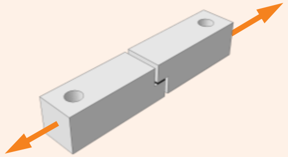
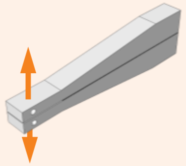
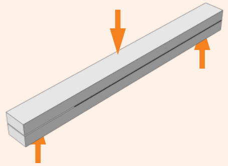
A Practical Introduction on Cohesive Zone Modeling

- Rule-of-Thumb: 2-5 cohesive elements per adjacent substrate element (Solids, Shells, etc.)
- Tie-constraints (without failure) between cohesive elements and adjacent substrate element



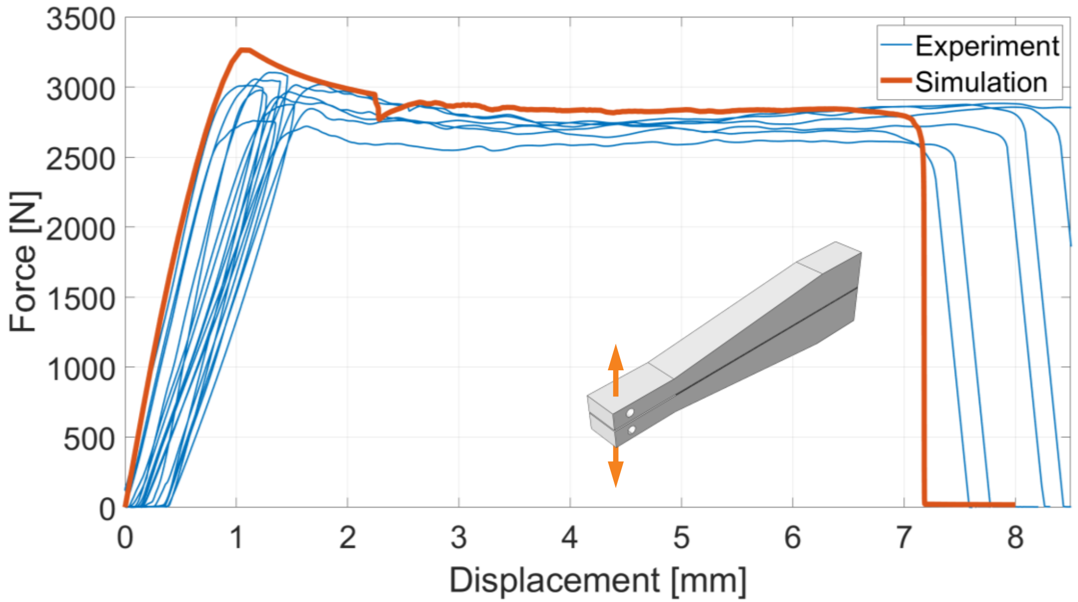


Required Tests for Cohesive Zone Modeling

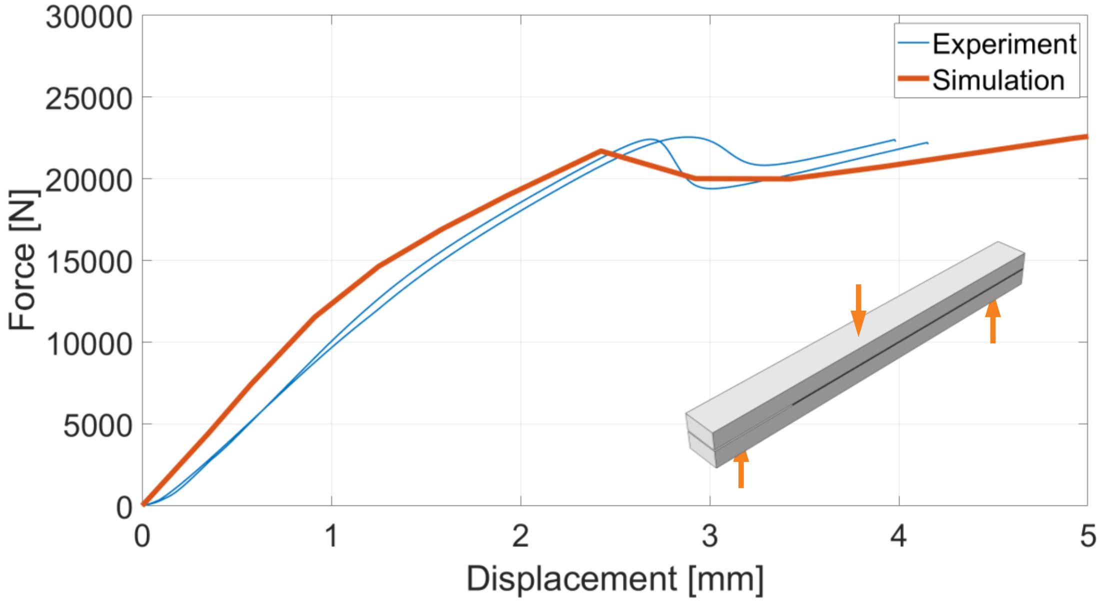
Physical Effect	Test Name	Test Sketch	Material Parameter	Description	Symbol	Unit
Elasticity	Uniaxial Tension Test		Young‘s Modulus and Poisson‘s Ratio (Stiffness of the bulk material)	Resistance to elastic deformation and transverse contraction in tension	K_{I}, K_{II}, K_{III}	MPa
Damage Initiation	Thick Adherend Butt Joint Tension Test		Tensile Strength	Maximum stress in laterally constrained tension	σ_{I}	MPa
	Thick Adherend Shear Test		Shear Strength	Maximum stress in shear	$\sigma_{II} = \sigma_{III}$	MPa
Damage Evolution	Tapered Double Cantilever Beam (TDCB) Test		Mode I Fracture Energy (Critical Energy Release Rate)	Resistance to crack propagation in Mode I (opening mode)	G_{IC}	$\frac{N}{mm}$
	Tapered End-Notched Flexure (TENF) Test		Mode II Fracture Energy (Critical Energy Release Rate)	Resistance to crack propagation in Mode II (shear mode)	$G_{IIC} = G_{IIIC}$	$\frac{N}{mm}$

Verification of the Material Data Card

TDCB Test



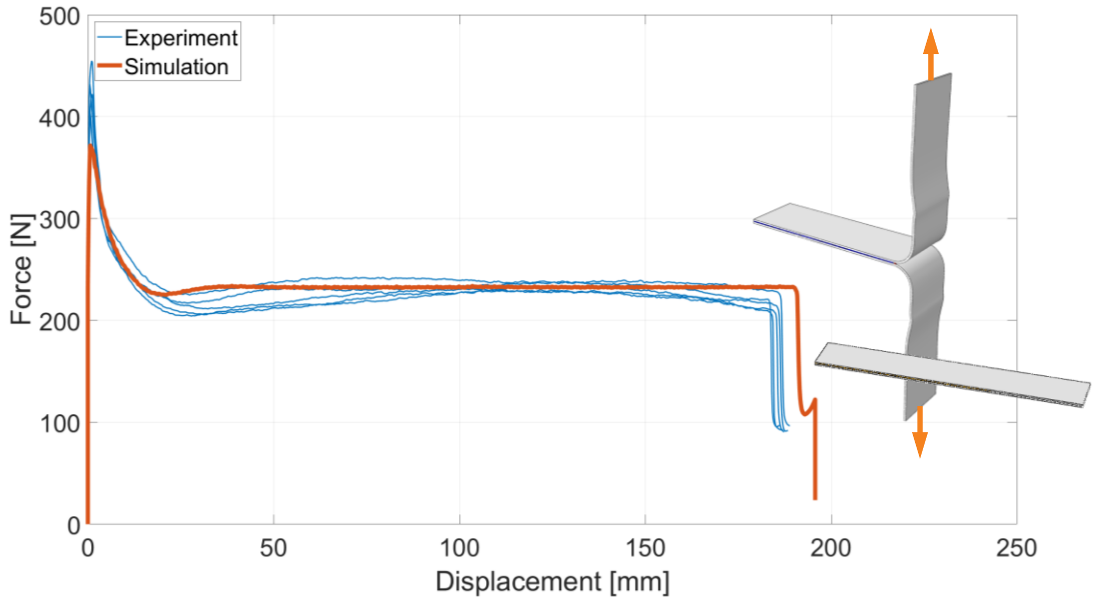
ENF Test



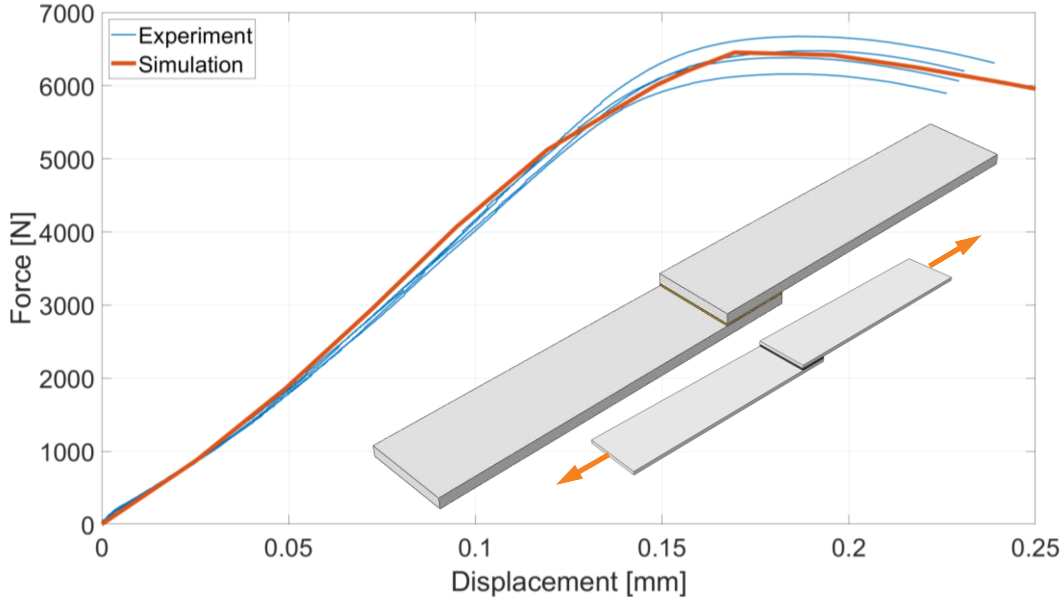
- Excellent agreement between experimental test data and simulation for TDCB test, good agreement for the ENF test

Validation of the Material Data Card

T-Peel Test



Single Lap Shear Test



- Excellent agreement between experimental test data and simulation for the T-Peel and the Single Lap Shear Test
- For both tests, the incorporation of an elastic-plastic material model for the adherends is crucial to get good agreement

Numerical Analysis of 3M™ VHB™ Tapes

Typical Properties of 3M™ VHB™ Tapes

Common Questions by Customers

- Young‘s modulus E and Poisson‘s ratio ν?
- Why are these are not given in your data sheets?

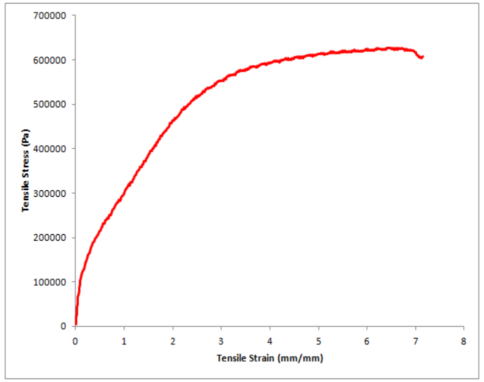
Answer by 3M – Our VHB Tapes are…

- Nonlinear elastic
- Viscoelastic (Time- and rate-dependent)
- Compressible
- Temperature-dependent

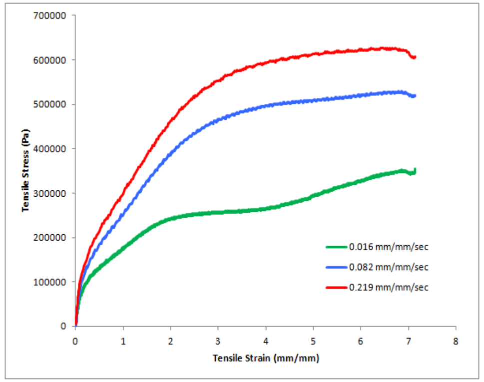
- That‘s what makes 3M VHB tapes unique
- That‘s what makes them challenging to model

Exemplary Stress-Strain Curves

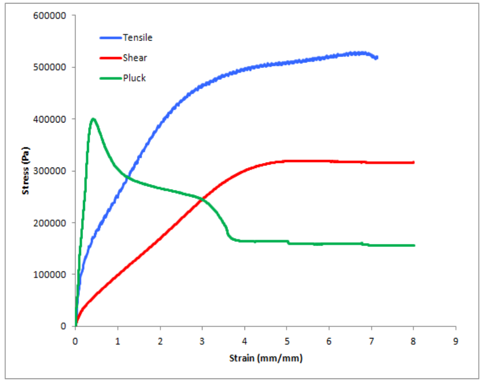
Nonlinear Slope



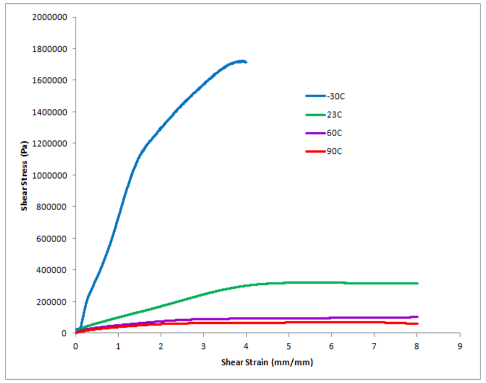
Rate-dependent



Deformation-dependent

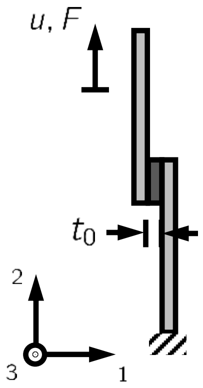


Temperature-dependent



Required Tests for Hyperelastic-Viscoelastic Modeling

Single Lap Shear Test



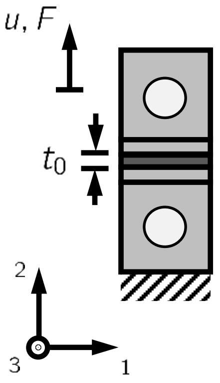
Shear strain

$\gamma = \tan(\theta) = u/t_0$

Shear stress

$\sigma_{12} = F/A_0$

Butt Joint Tension Test



Tensile strain

$\epsilon = \epsilon_2 = u/t_0$

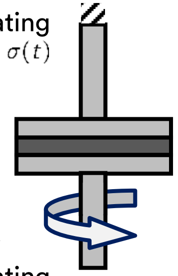
Tensile stress

$\sigma = \sigma_2 = F/A_0$

$\sigma_1 = \sigma_3 \neq 0$

Dynamic Mechanical Analysis

Measure oscillating stress $\sigma(t)$



Apply oscillating strain $\epsilon(t)$

Storage Modulus

$G' = \frac{\sigma_0}{\epsilon_0} \cos(\delta)$

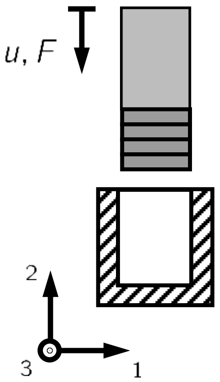
Loss Modulus

$G'' = \frac{\sigma_0}{\epsilon_0} \sin(\delta)$

Loss factor

$\tan(\delta) = G''/G'$

Volumetric Compression Test



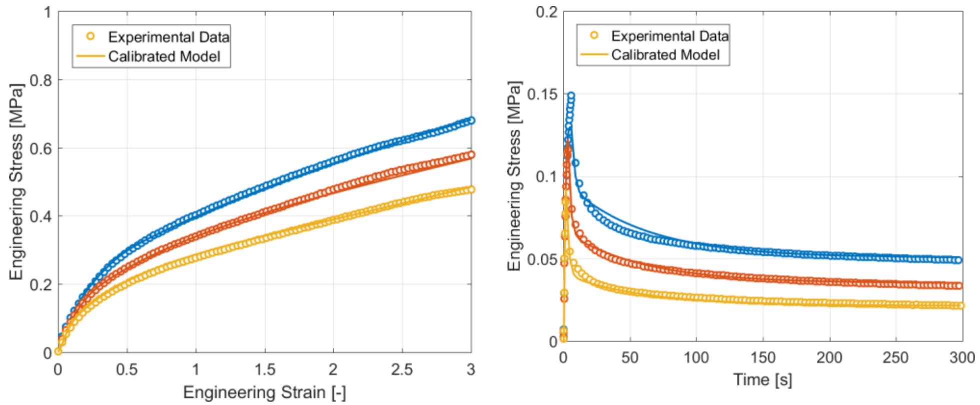
Pressure

$p = F/A_0 \approx \sigma_{1,2,3}$

Volume ratio

$J = V/V_0$

From Test Data to Material Model



- Internal capabilities for fitting elastic, hyperelastic and hyper-viscoelastic material models as well as material data cards for cohesive zone modeling
- Determination of model coefficients for different deformation modes and rates – simultaneously!

3M

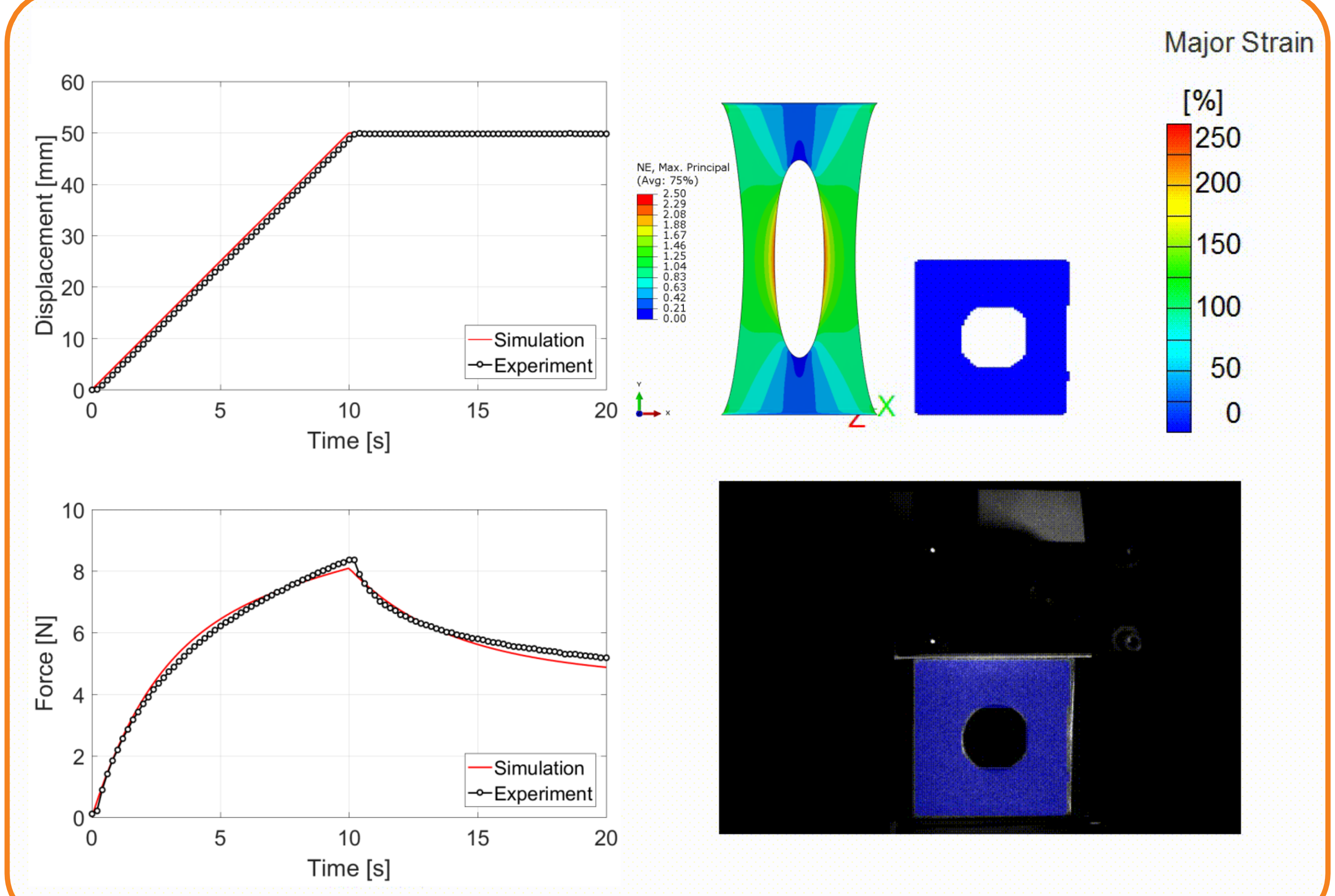
Viscoelastic Stress-Relaxation – Perforated VHB Strip

Experimental Test

- Ramp-hold test on perforated VHB strip
- Clear stress-relaxation behavior due to the viscoelastic nature of the VHB tape
- Tensile testing machine running synchronized to digital image correlation system GOM Aramis

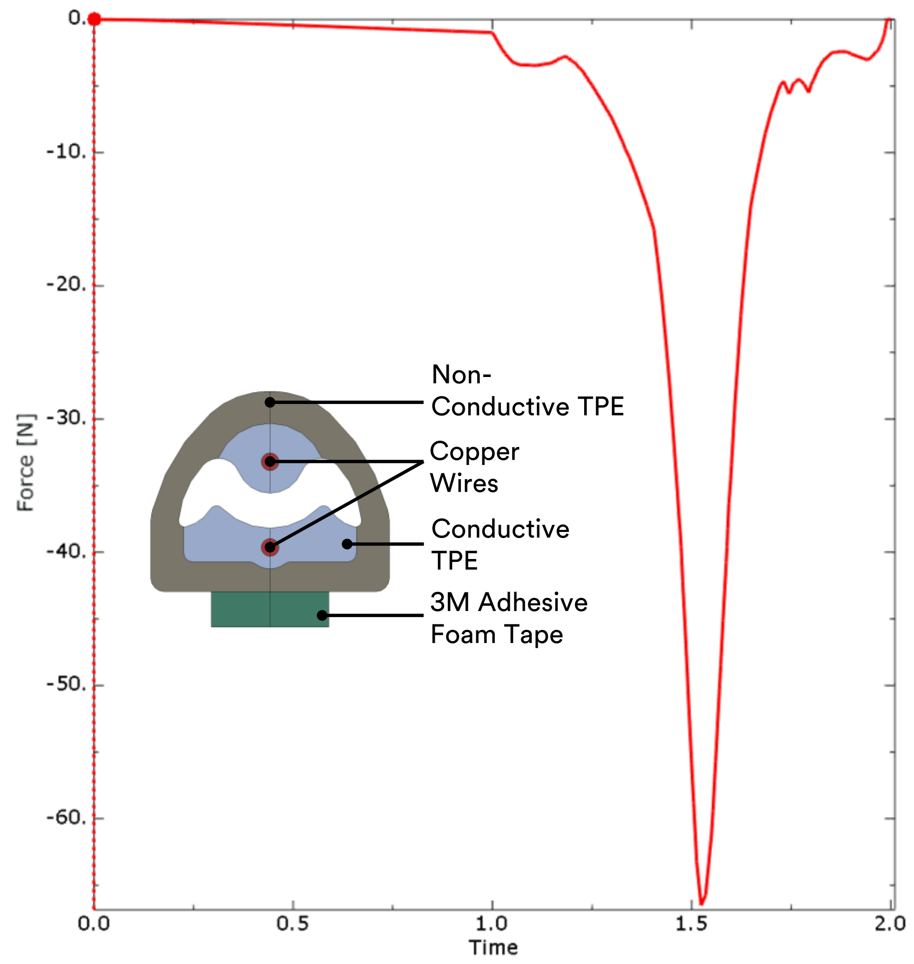
FE Simulation

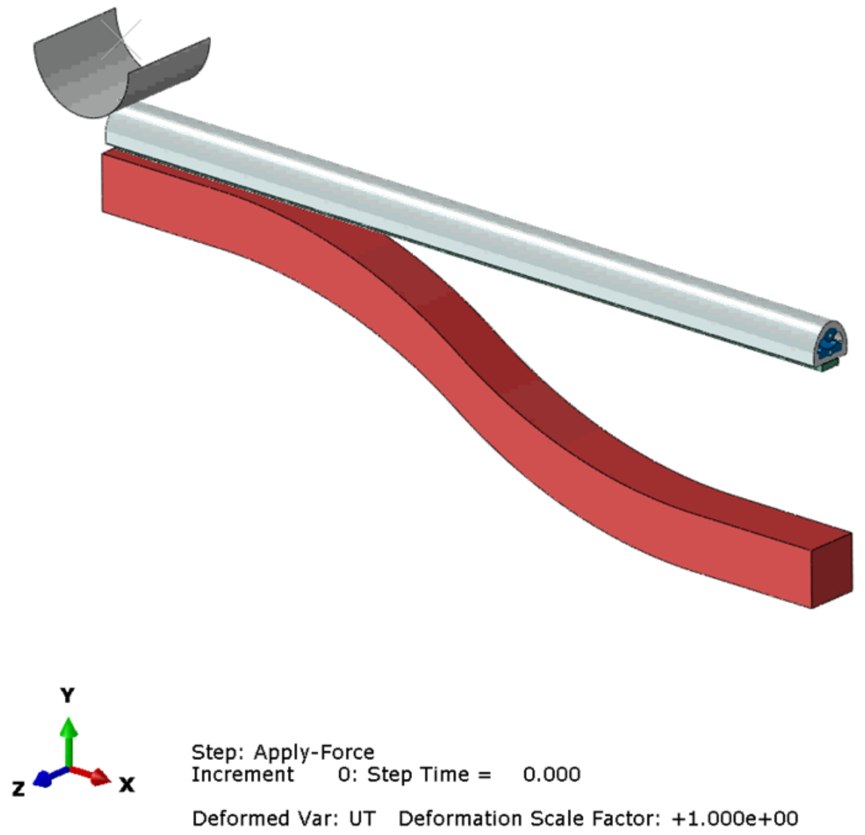
- Excellent agreement between test and simulation result
- Hyperelastic-viscoelastic material model calibrated to rate-dependent test data



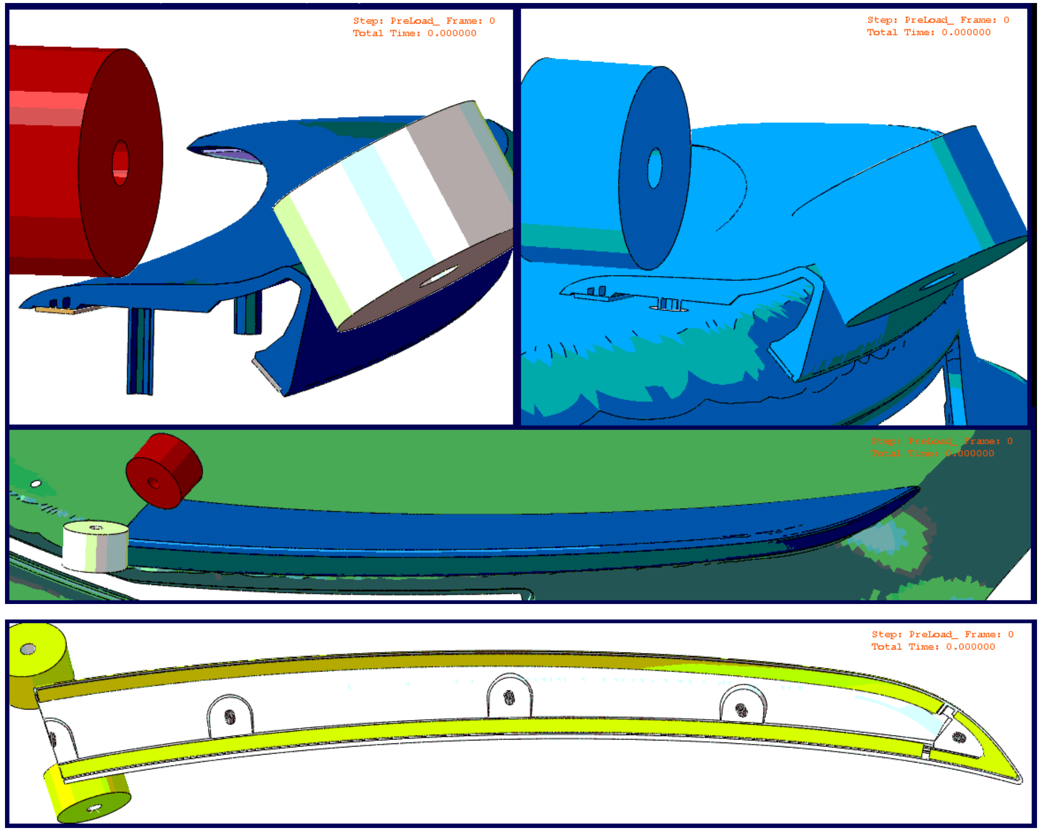
3M

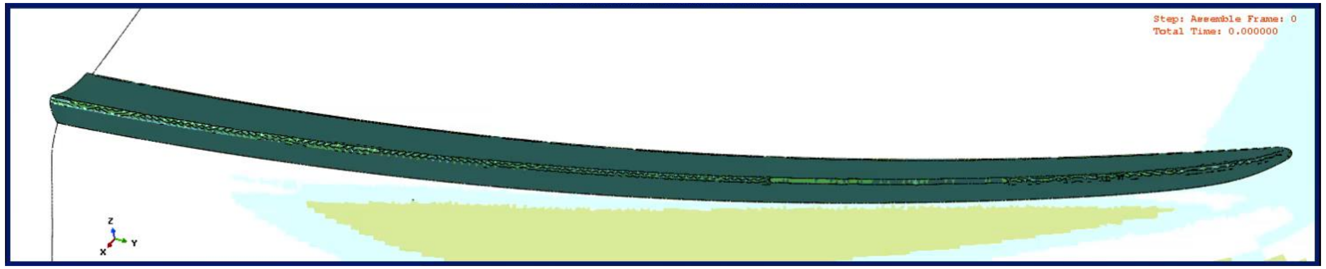
Required Application Pressure for Bonded Rubber Tubes

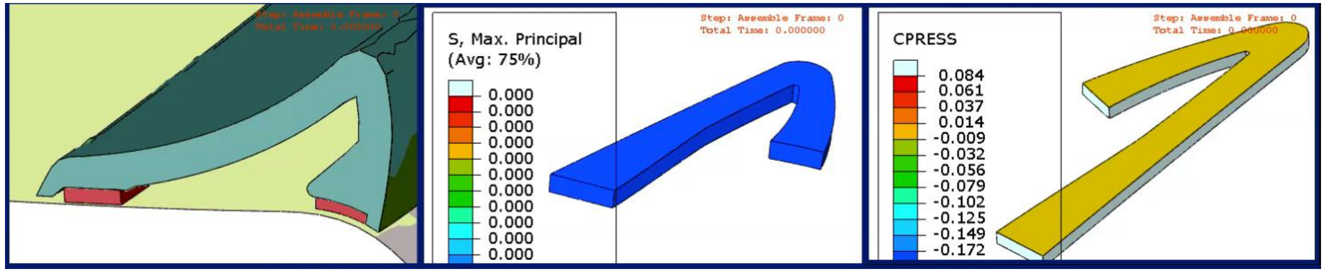


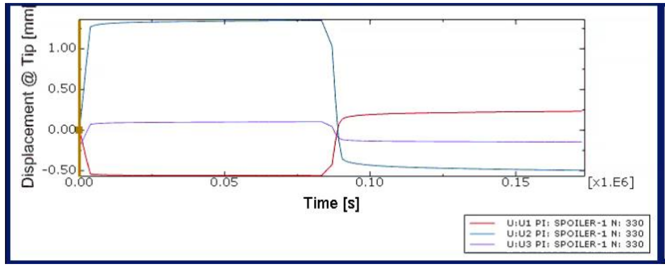


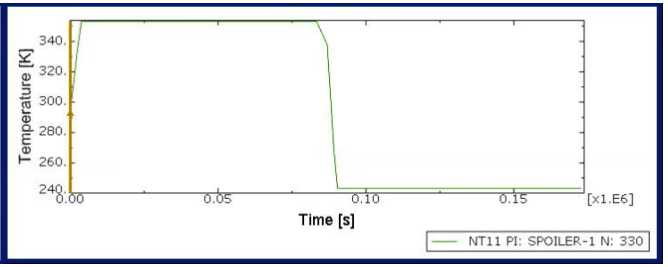
Spoiler Attachment Modeling





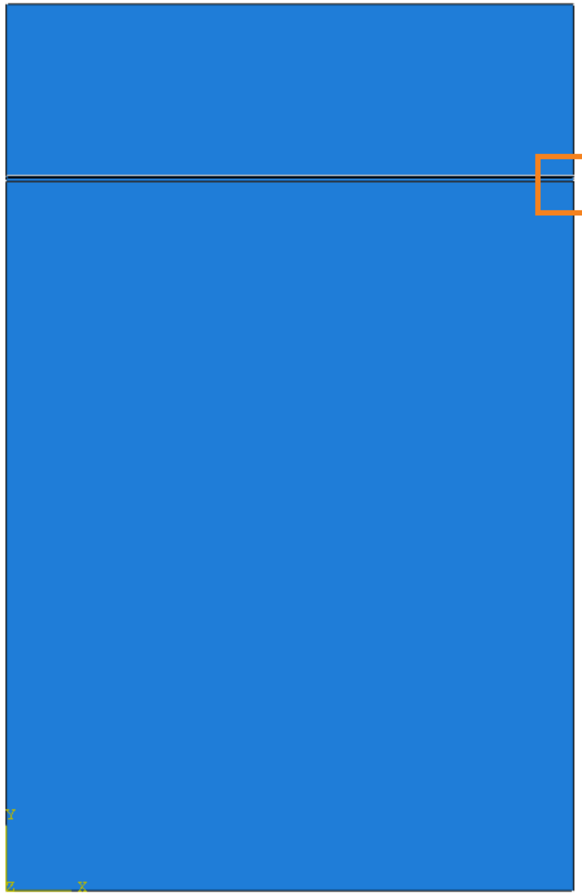




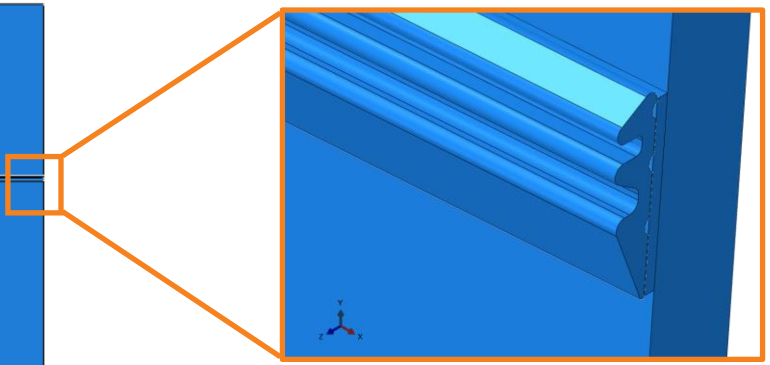


CTE Mismatch of Metal Profile bonded to Glass Panel

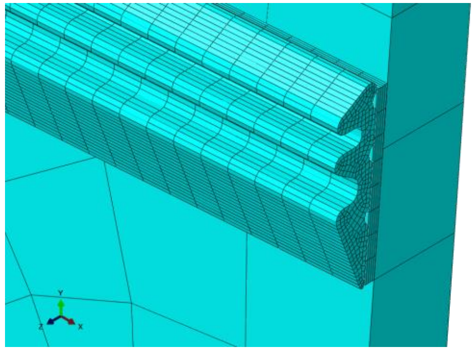
Assembly (1/4) - Front



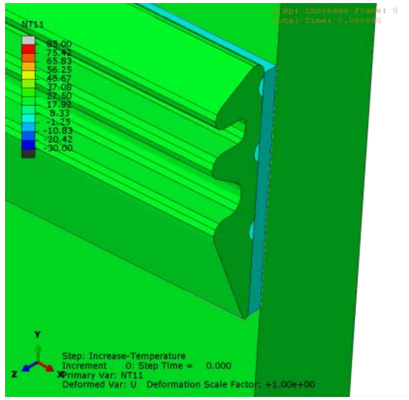
Assembly - Detail



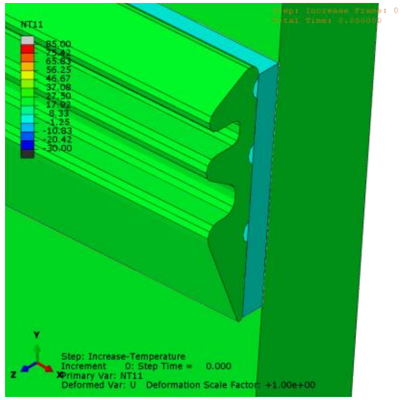
FE Mesh - Detail



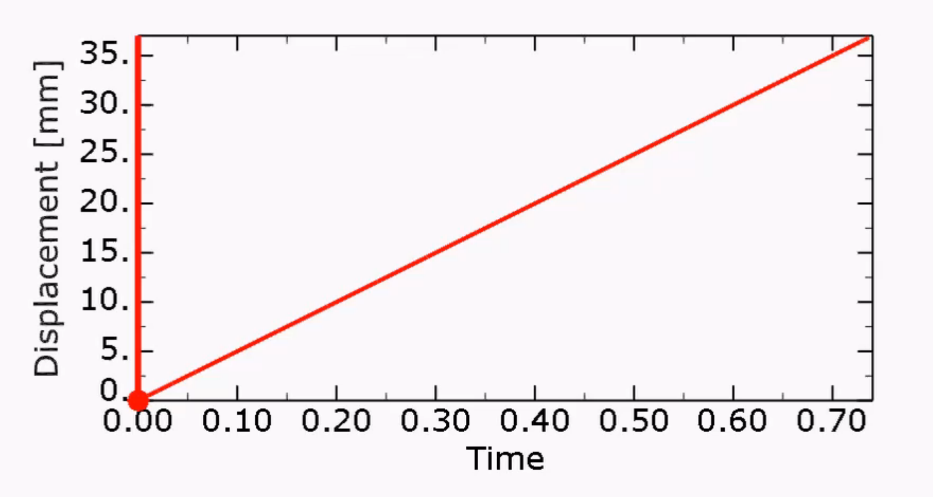
VHB Tape, $t_0 = 0.5\ \mathrm{mm}$

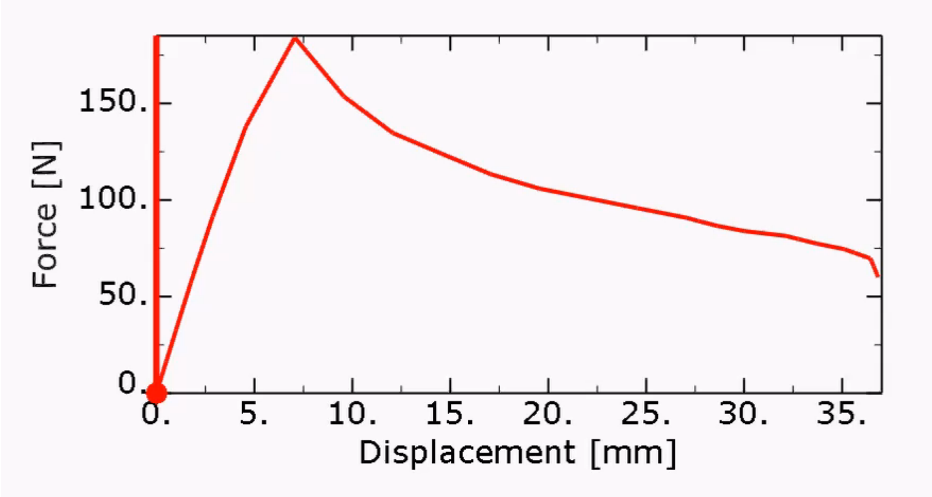


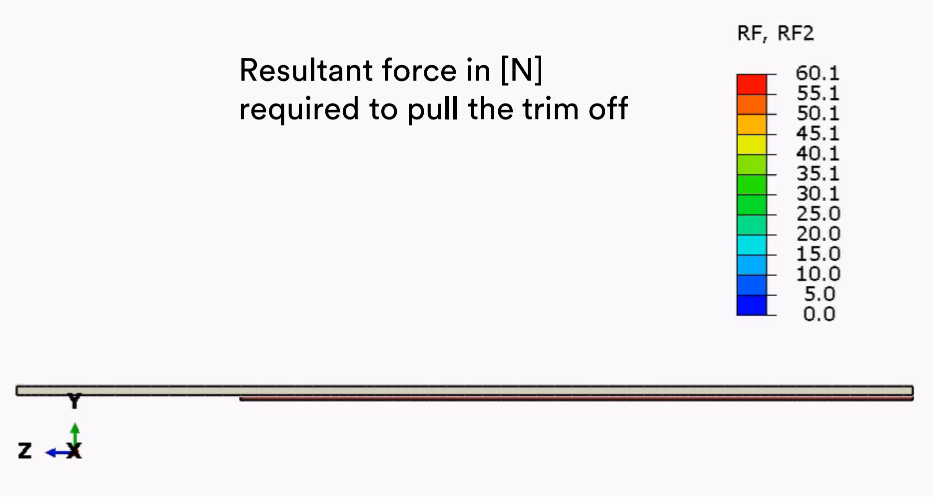
VHB Tape, $t_0 = 0.8\ \mathrm{mm}$

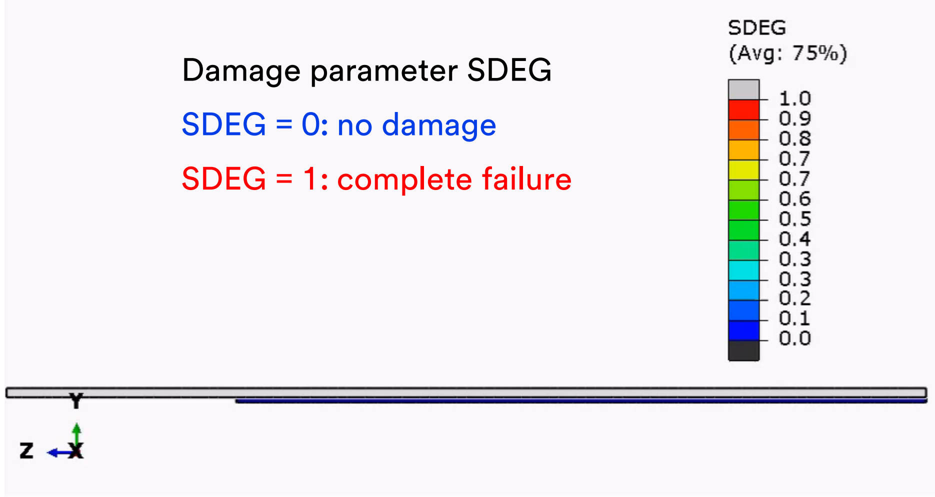


Static Failure Modeling for VHB – Interior Trim Pull-Off

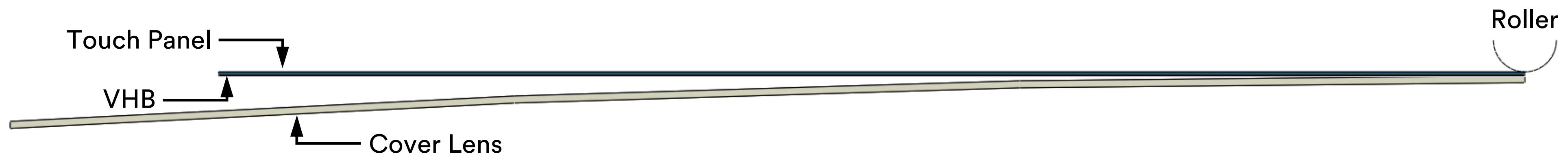




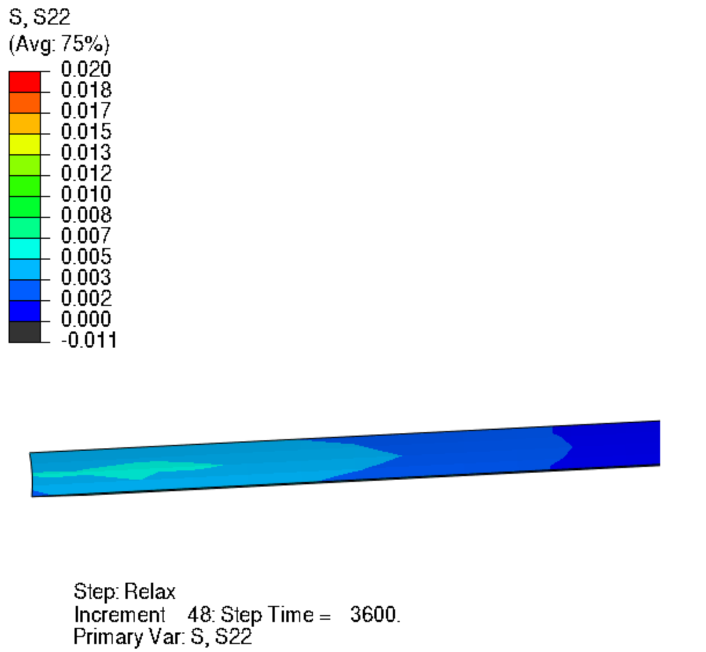


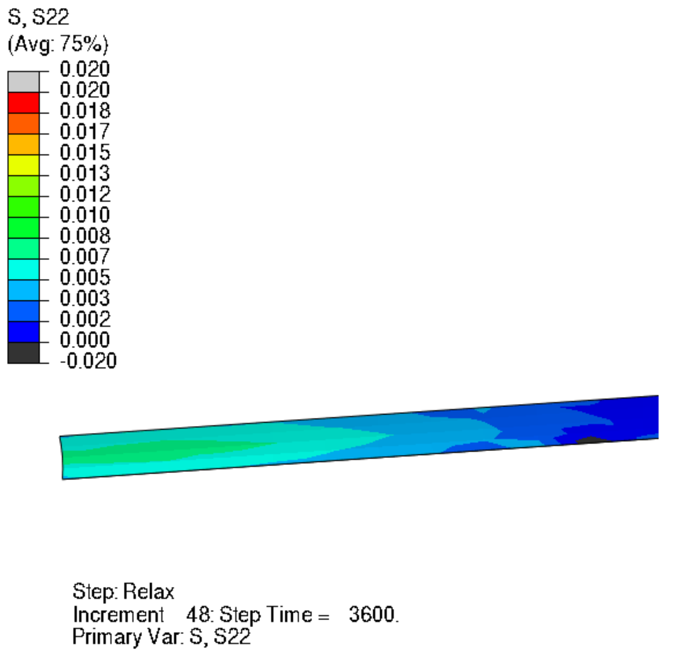


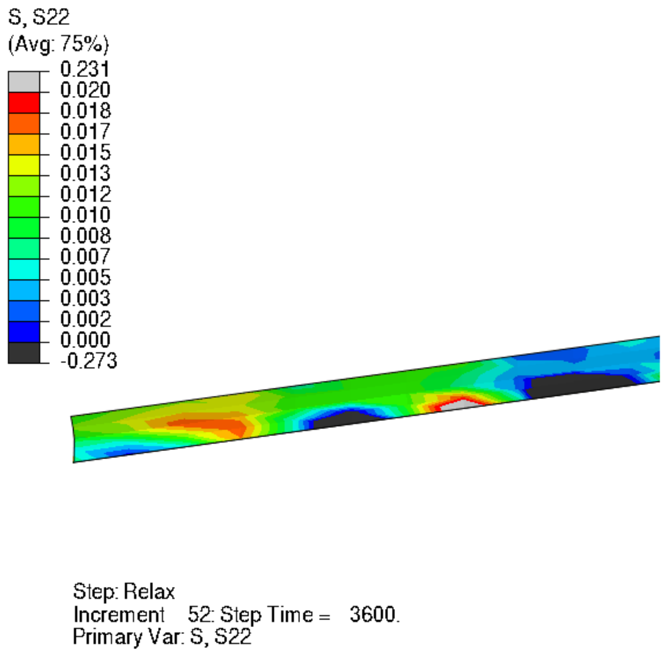
Curved Displays – Tensile Stresses in VHB Tapes



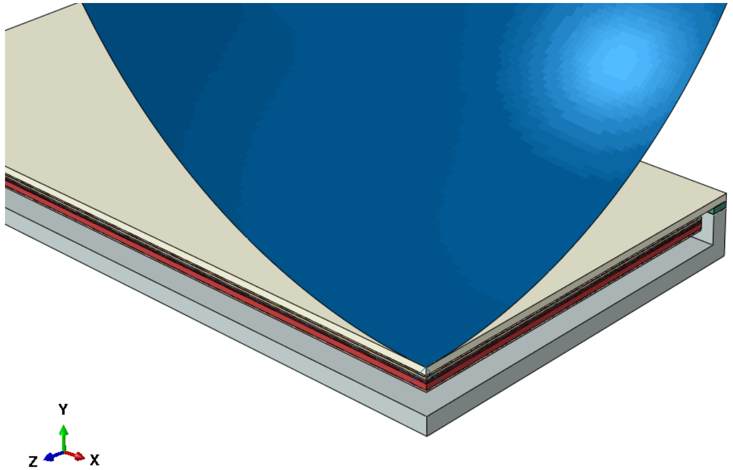
Radius 4000 mm	Radius 3000 mm	Radius 1500 mm

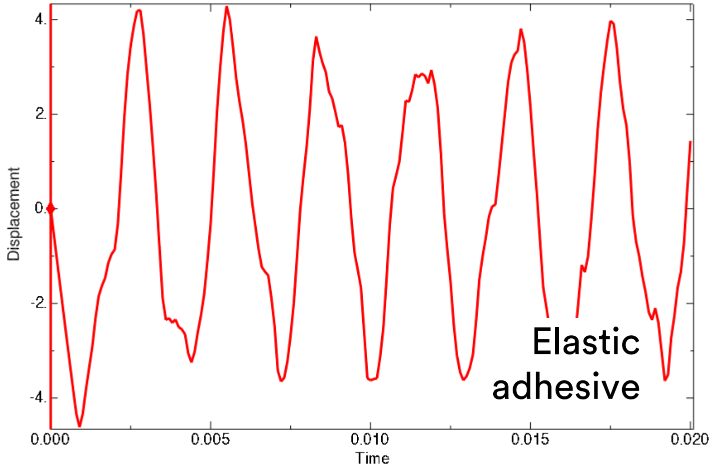


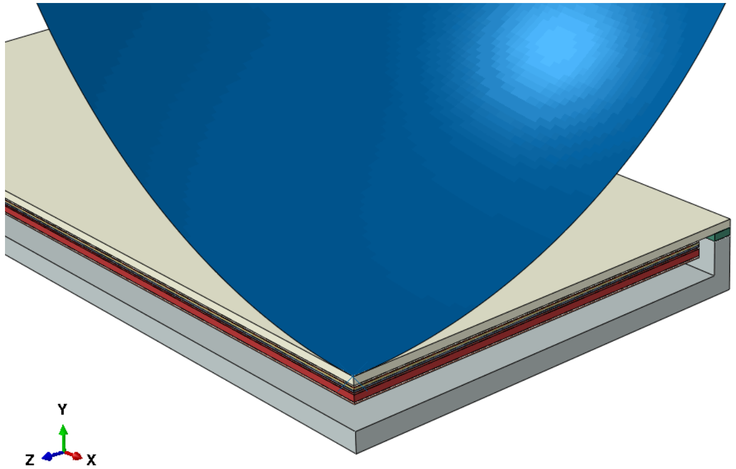


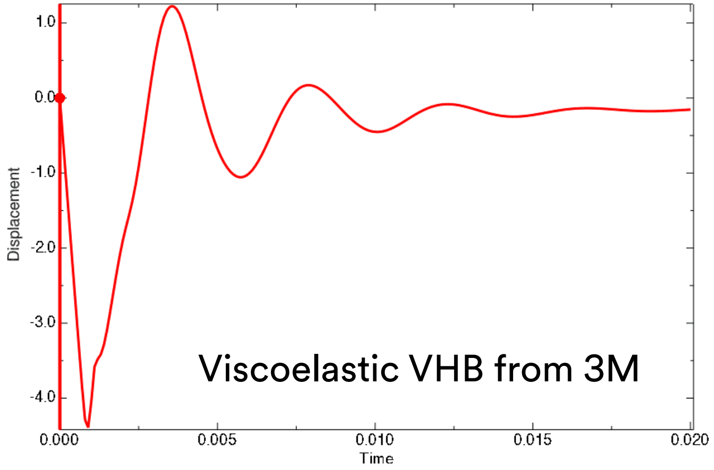


Head Impact Test Simulation – Elastic Adhesive vs. VHB





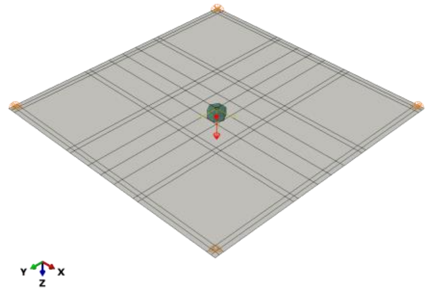


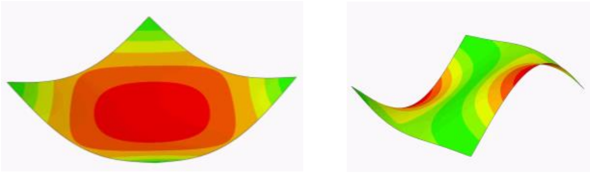


Constrained Layer Damping for Vibrating Structures

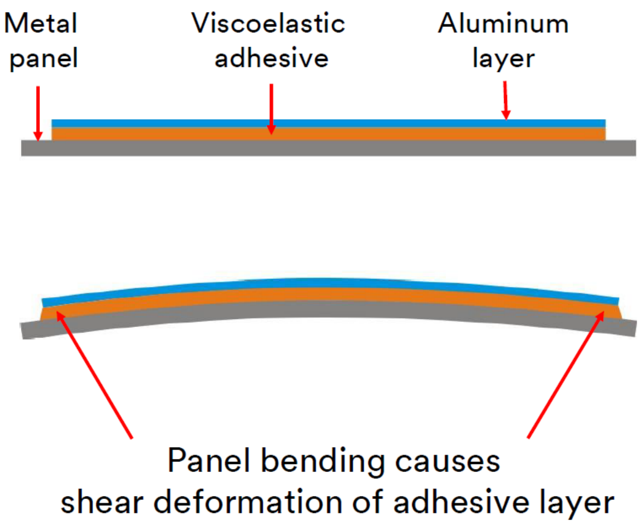
Vibrating Structure

Simple Plate

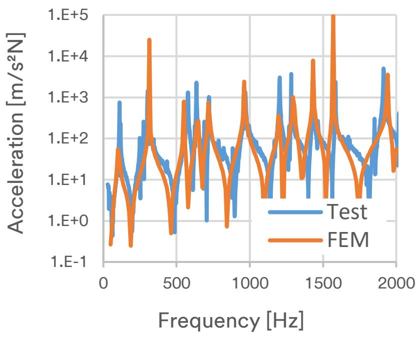


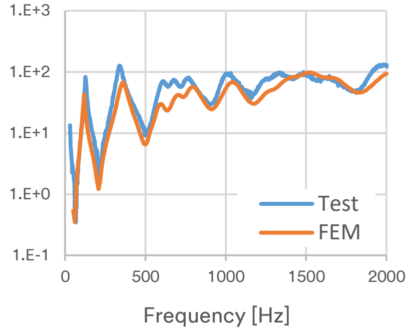


Constrained Layer Damping



Results – Test vs. FEA





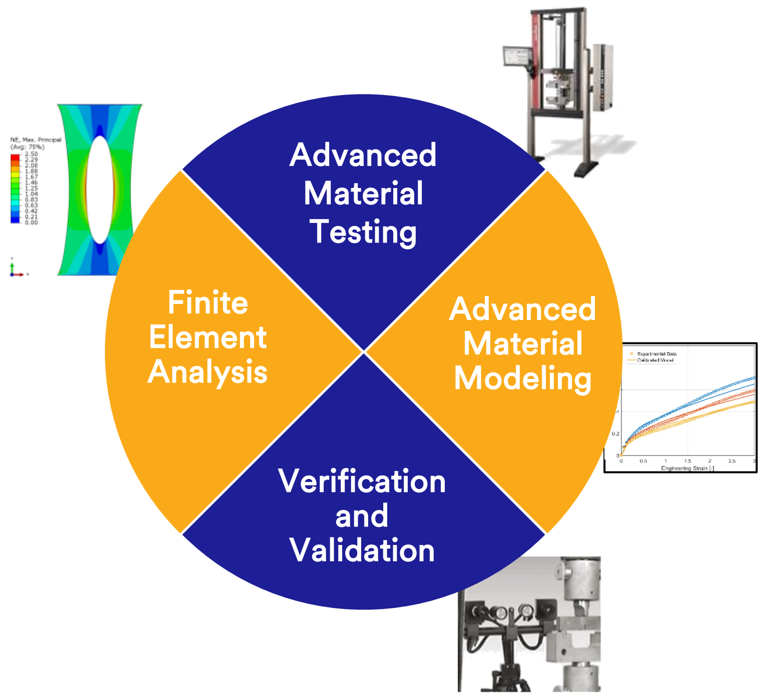
Goal I: Reduce noise effectively with constrained layer damping

Goal II: Ideally applied at the right places with the least amount of material

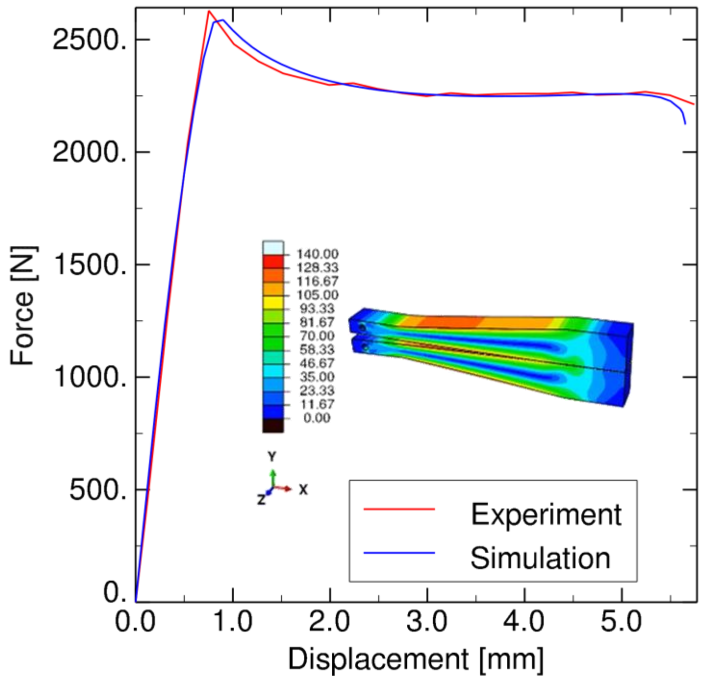
Conclusion and Summary

Summary – 3M Technology Framework

Technology Framework



Validated Material Data Card



- The choice of a suitable material data card depends on your particular application.
- *3M website:* Finite element material model for pressure sensitive adhesives (PSAs)
- We support you with questions around characterization, modeling and simulation! ***Get in touch with us!***

Thank You!

Tobias Waffenschmidt, Dr.-Ing. | Senior Specialist CAE

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