Cohesive Zone debonding : Evaluation of interfacial adhesion strength of NiTi-PMMA composite and simulation validation

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Konference COMSOL Multiphysics 2026, 27.-29/5/2026

Lednice, Czech Republic

Co-funded by the European Union

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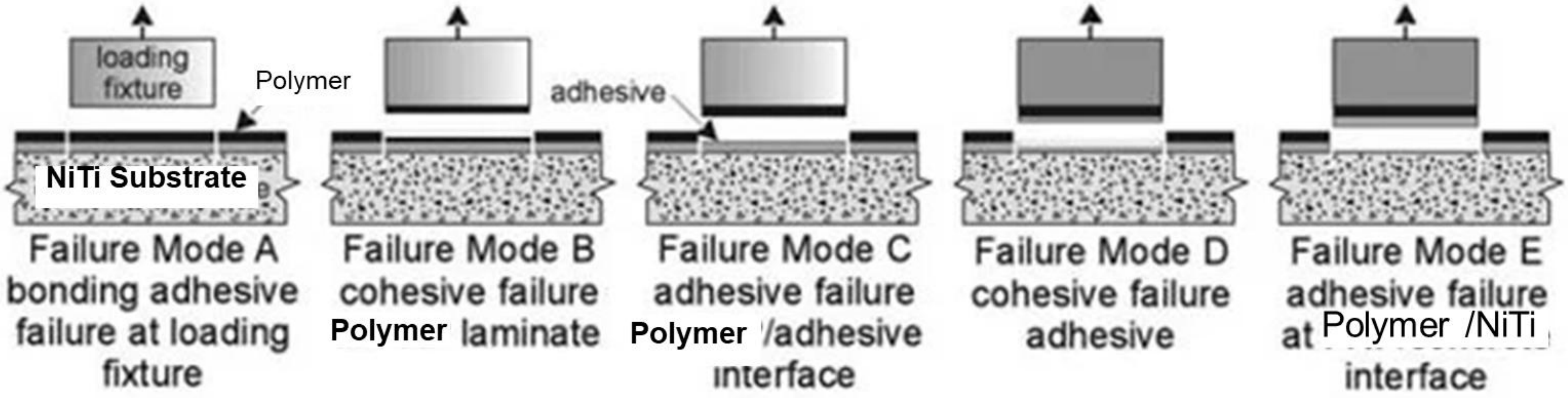
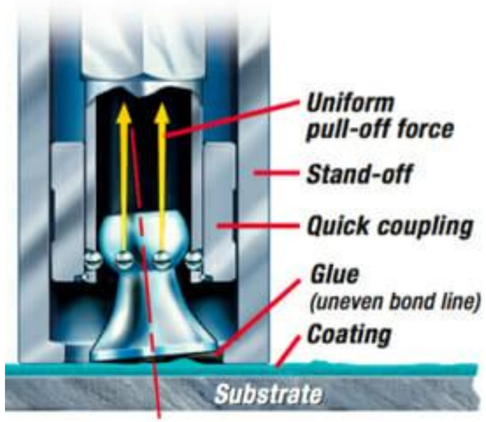
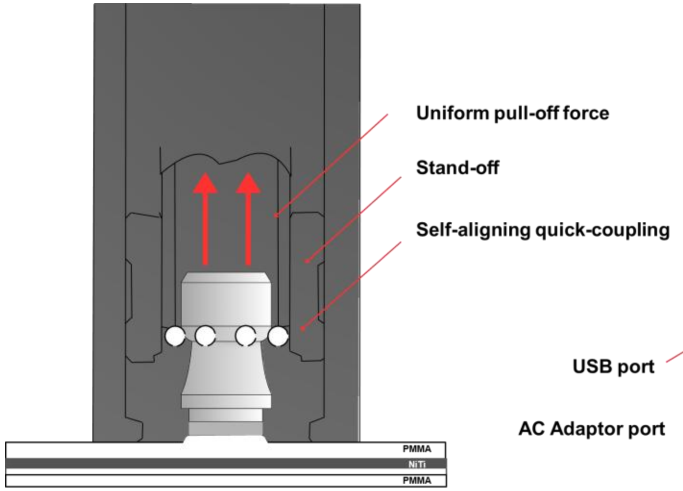
Overview : Mode of failure

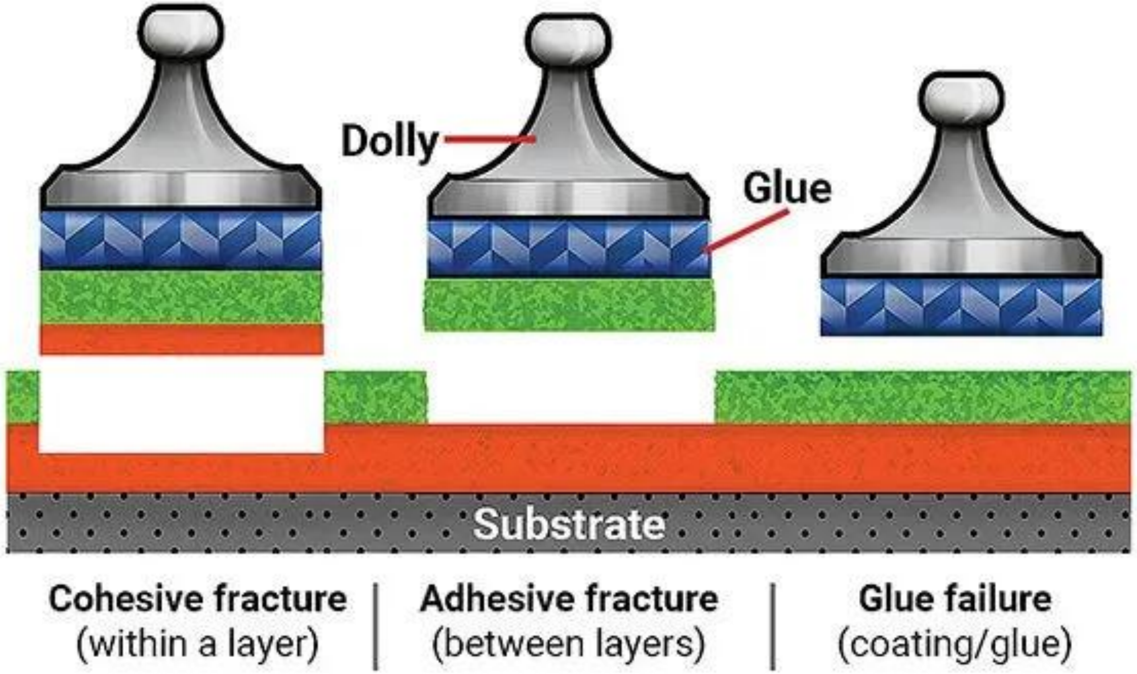




Failure modes for pull-off test (ASTM D7522)

Experimental Set up for pull off test to determine interfacial strength





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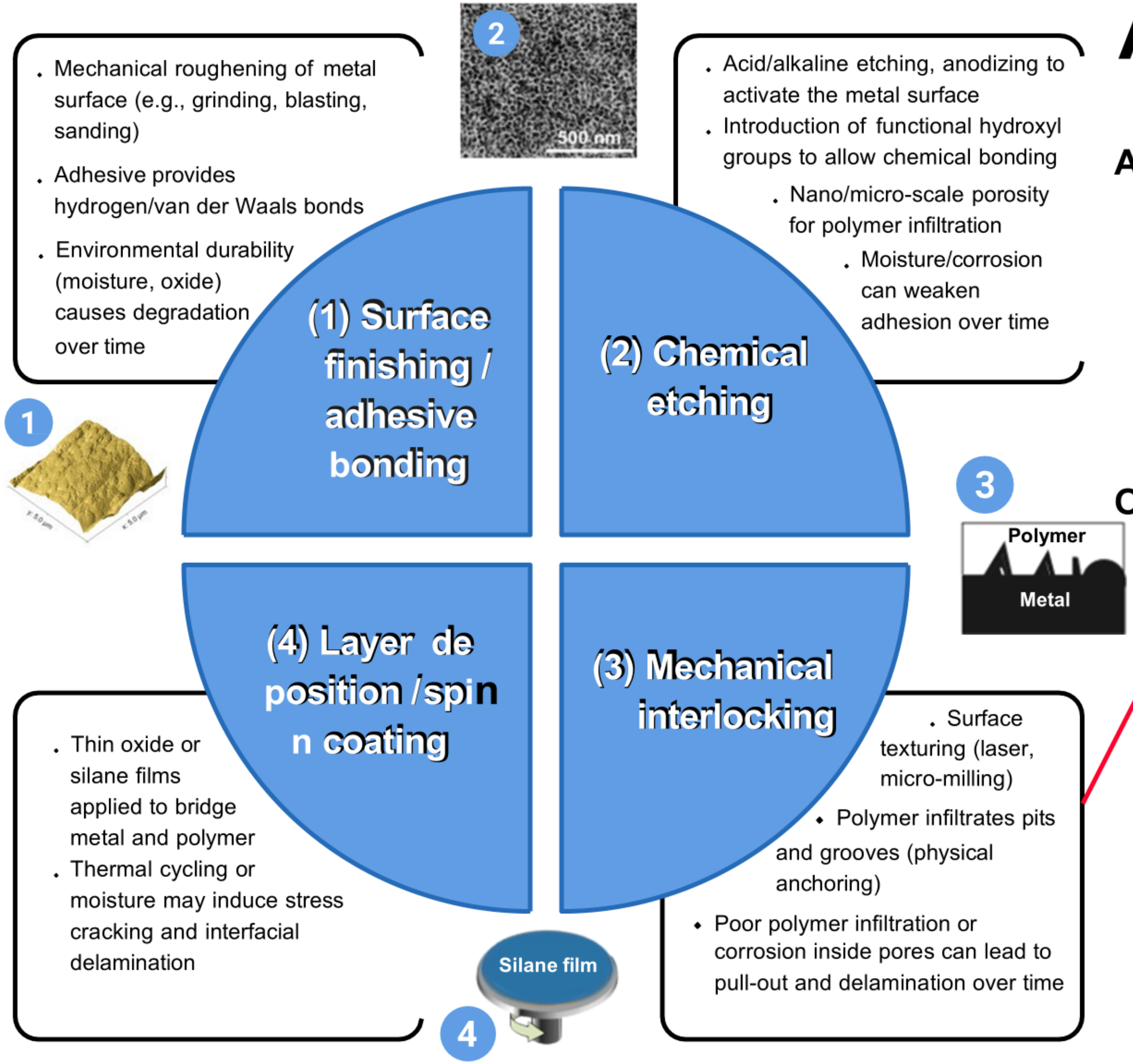


Aim and objective

Aim:

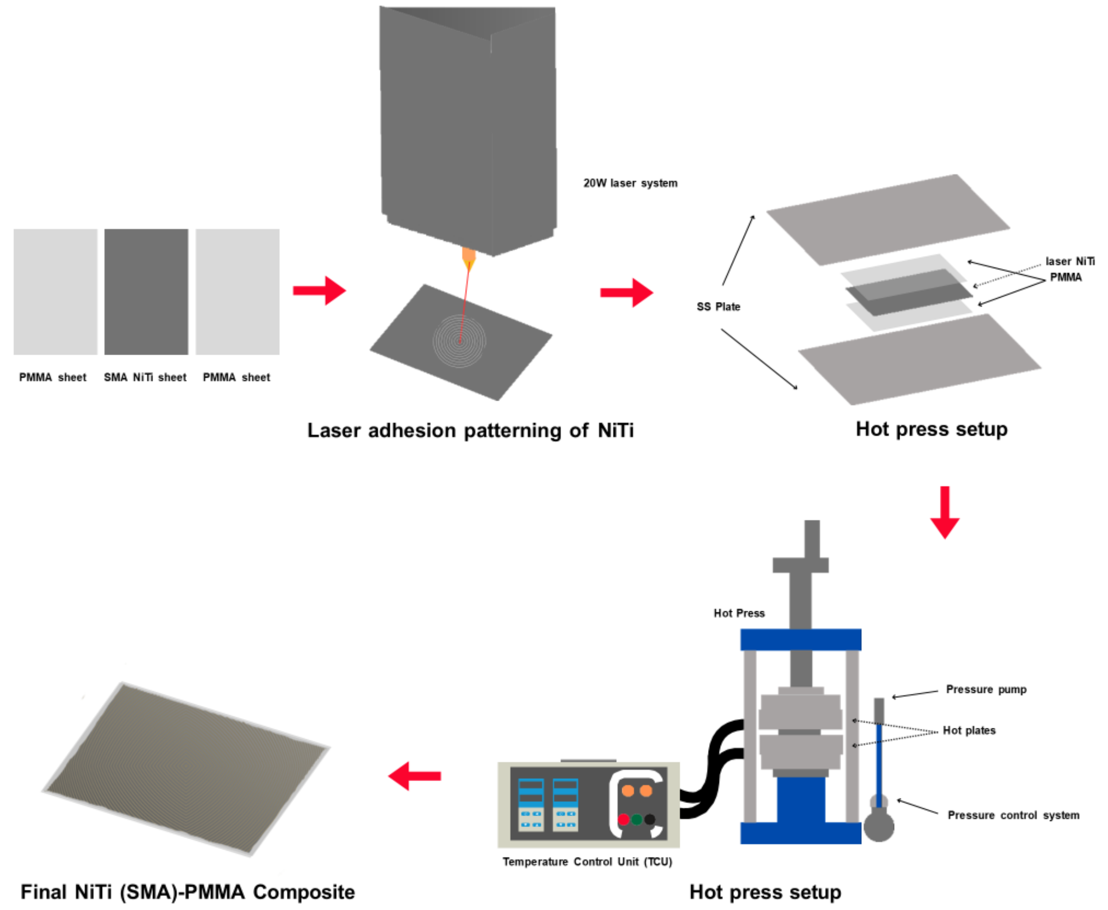
- To establish the interfacial adhesion of the metal-polymer surface in the composite
- To examine the adhesion strength of NiTi-PMMA composite by implementing a pull-off test on the composite surface.

Objectives:

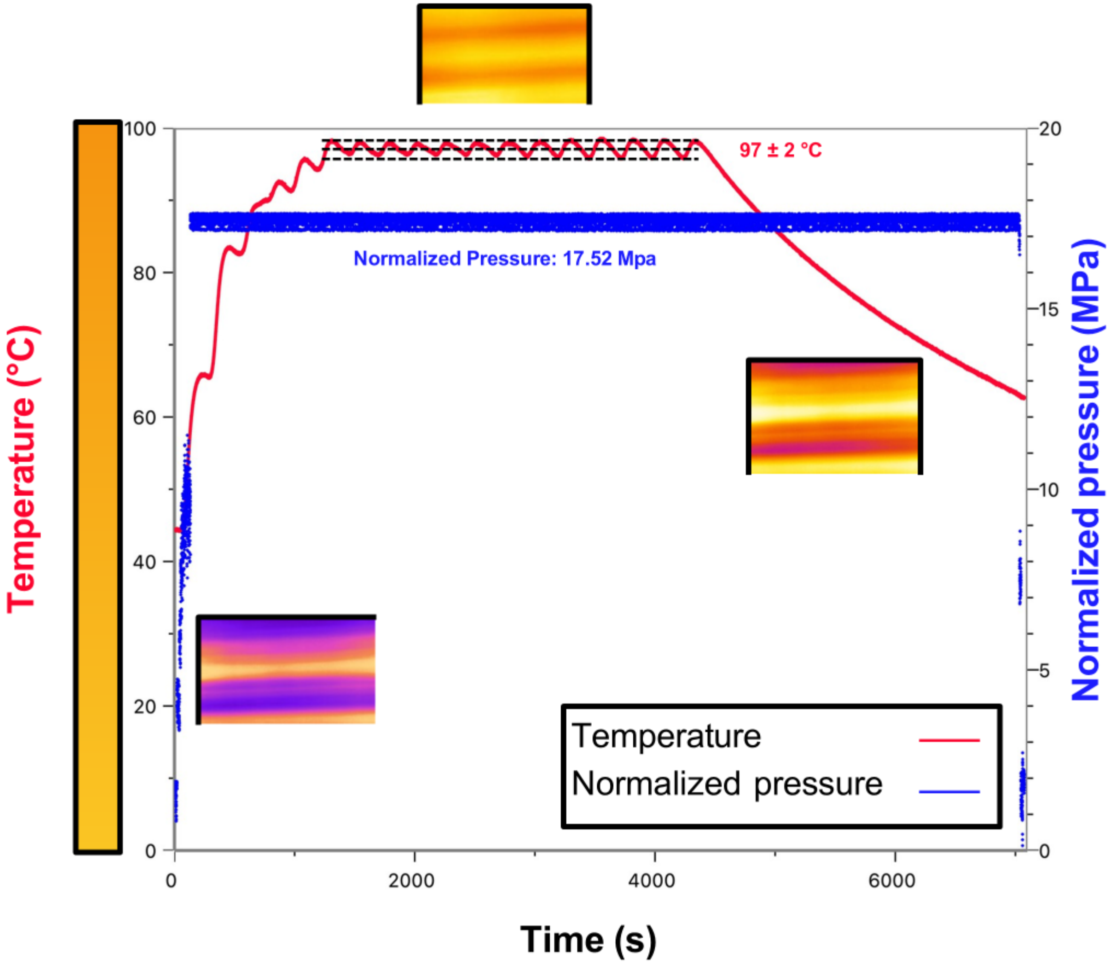
- Mechanical interlocking: create NiTi-PMMA composites for better adhesion with different laser patterns and hot press
- Implement a pull-off test using the PosiTest AT-A automatic adhesion tester
- Compare the maximum strength (MPa) required to pull off PMMA from composite
- Evaluate the mode of failure of the composite

Fabrication of composite by laser surface pattern and hot press system

Fabrication process



Temperature and pressure profile v.s. time



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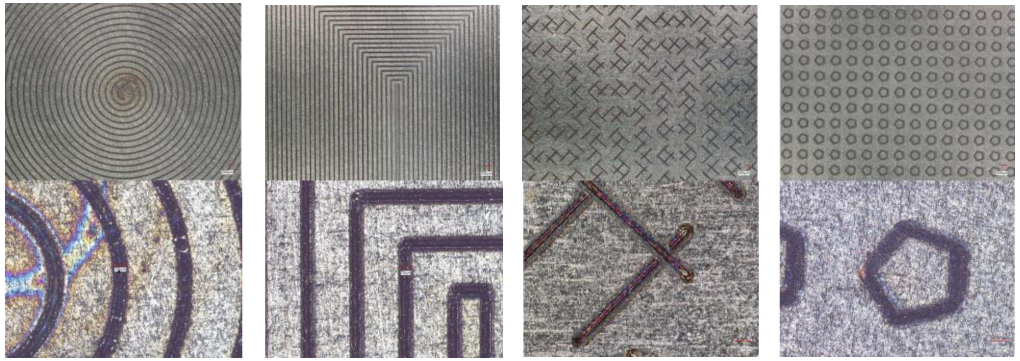
Various laser surface patterns for adhesion

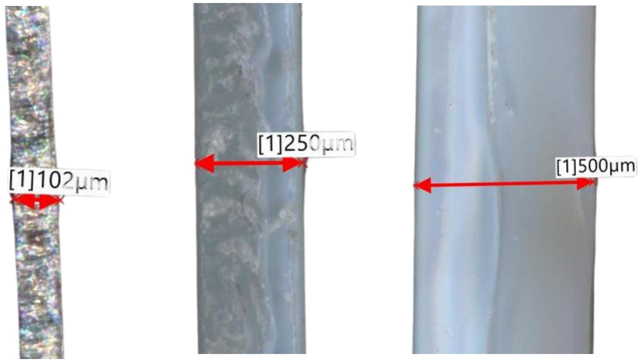
100 µm

NiTi surface with four different laser patterns

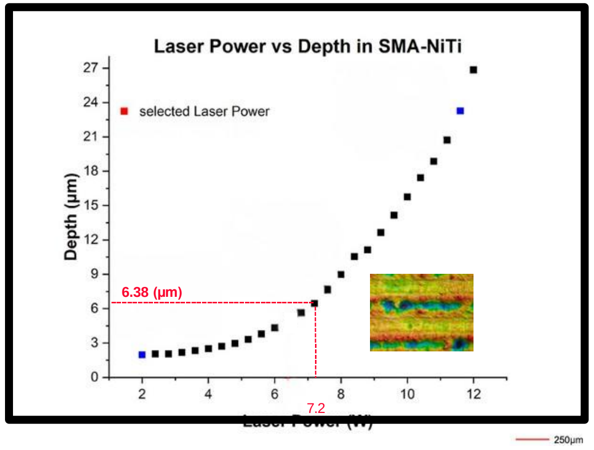


A - Spiral | B- Square | C - Cross | D - Dot

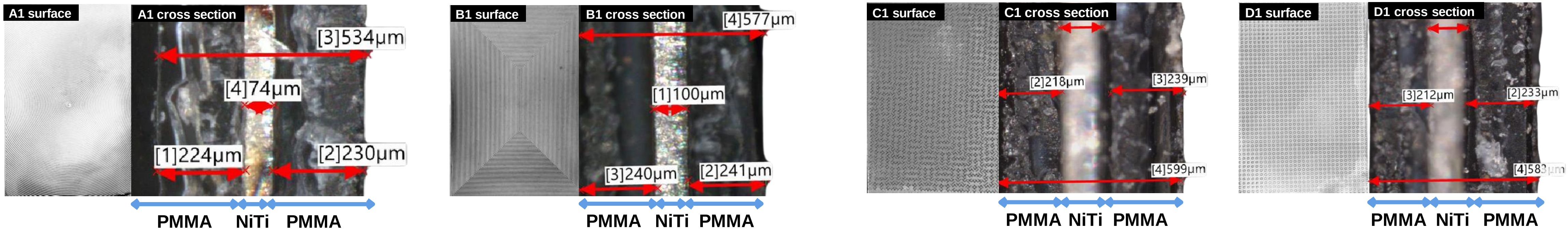
Cross section surface of NiTi, PMMA



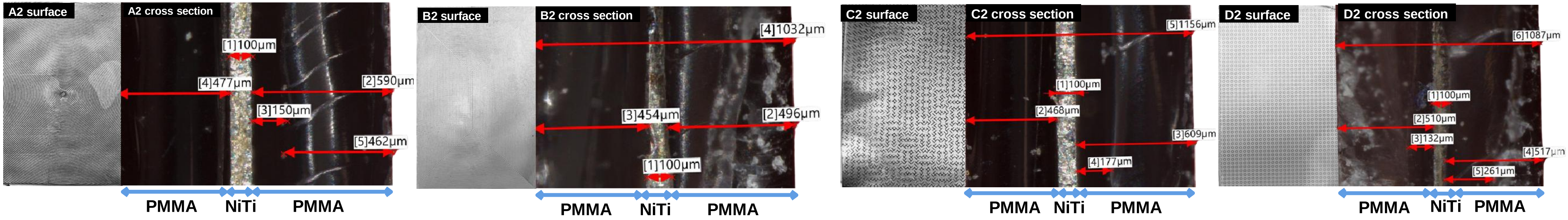
NiTi (100 µm) | 1- PMMA (250 µm) | 2- PMMA (500 µm)



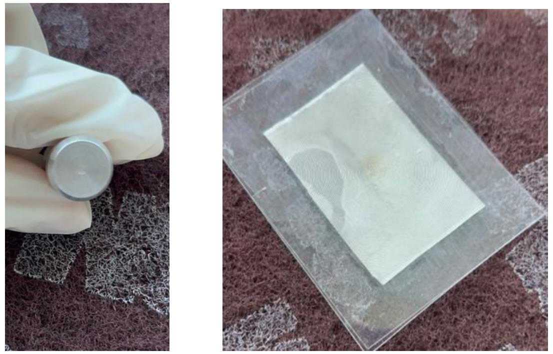
Surface and cross section of the composite: PMMA (250 µm) - NiTi (100 µm) - PMMA (250 µm), overall thickness of the composite: 600 ± α µm



Surface and cross section of the composite: PMMA (500 µm) - NiTi (100 µm) - PMMA (500 µm), overall thickness of the composite: 1100 ± α µm

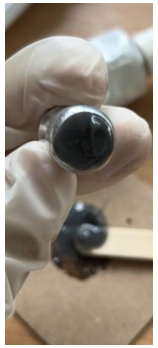


Adhesion Pull-off test



Abrasion of dolly and composite surface

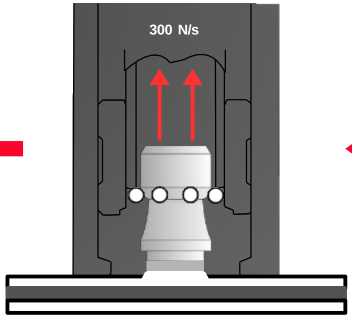
Mix epoxy part A and part B



Application on dolly surface

Cure at room temperature for 24~48 hours

Attach actuator onto dolly

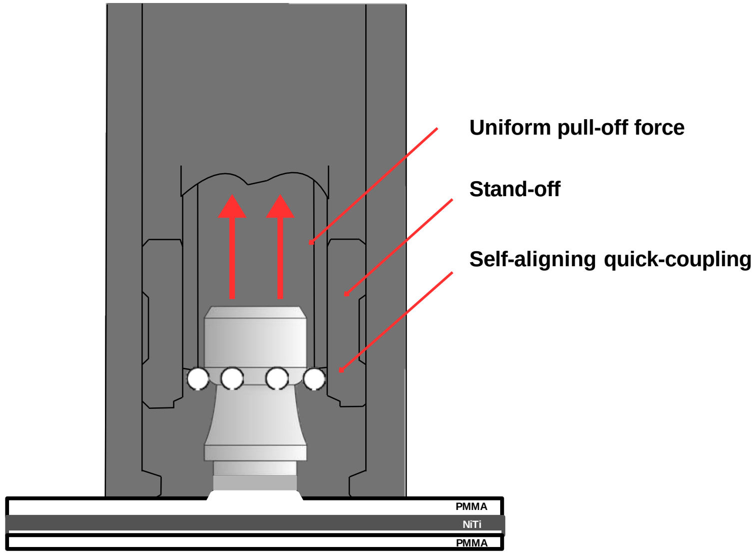


Dolly pulled off

Composite and dolly surface after the pull-off test

Pull-off parameters

- Maximum force: 7550 N
- Pull rate: 300 N/s
- Dolly: 10 mm



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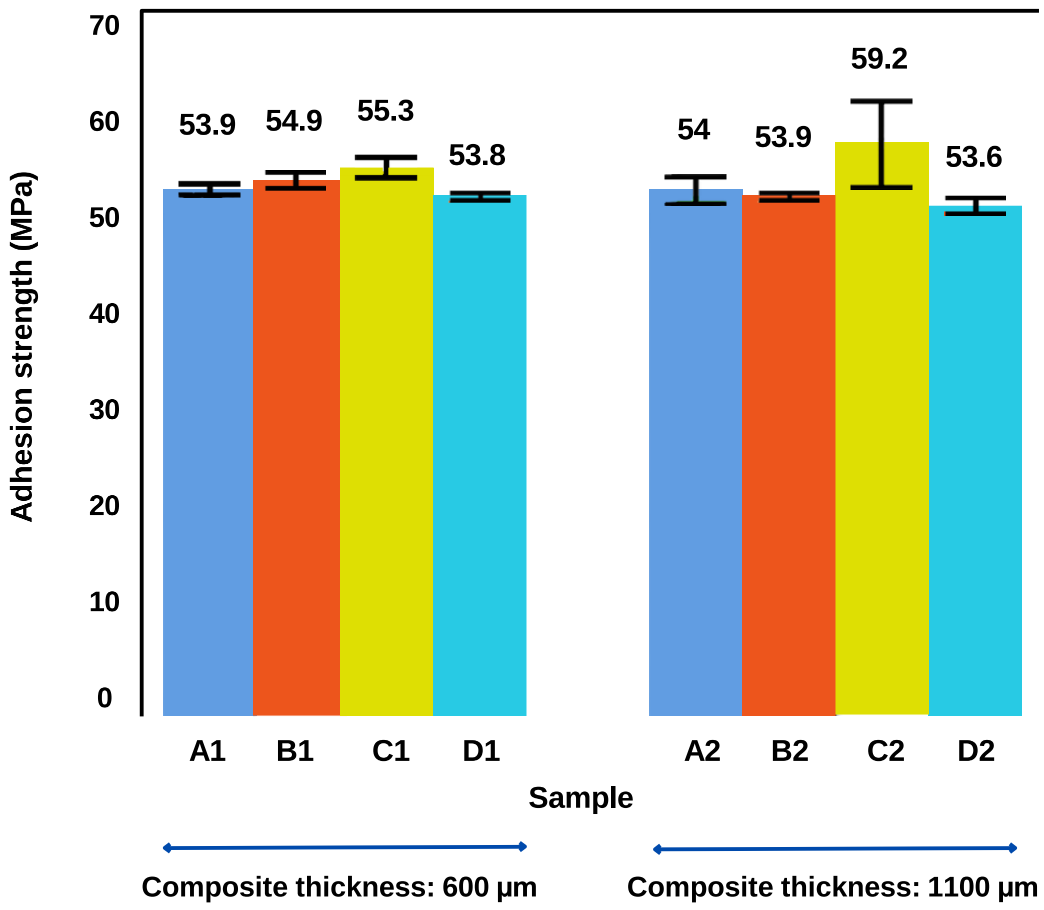
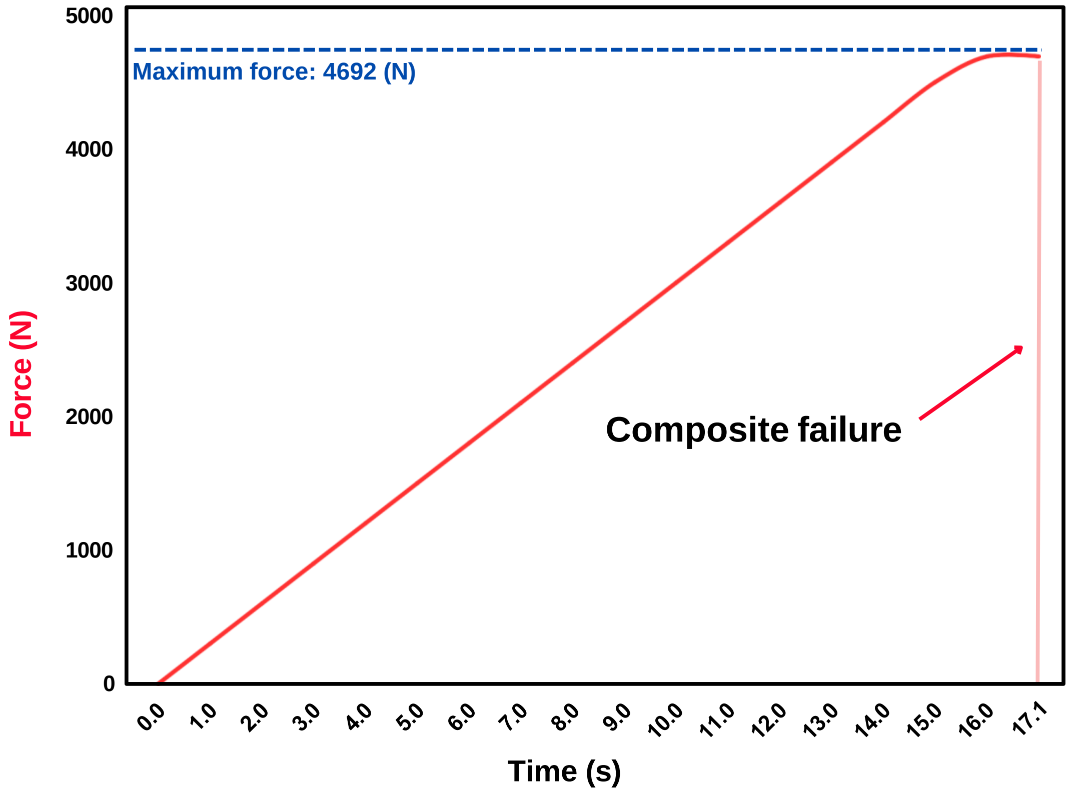
Adhesion strength of composite in pull-off test

Adhesion strength across samples



Pull-off test graph (Force (N) v.s. Time (s))



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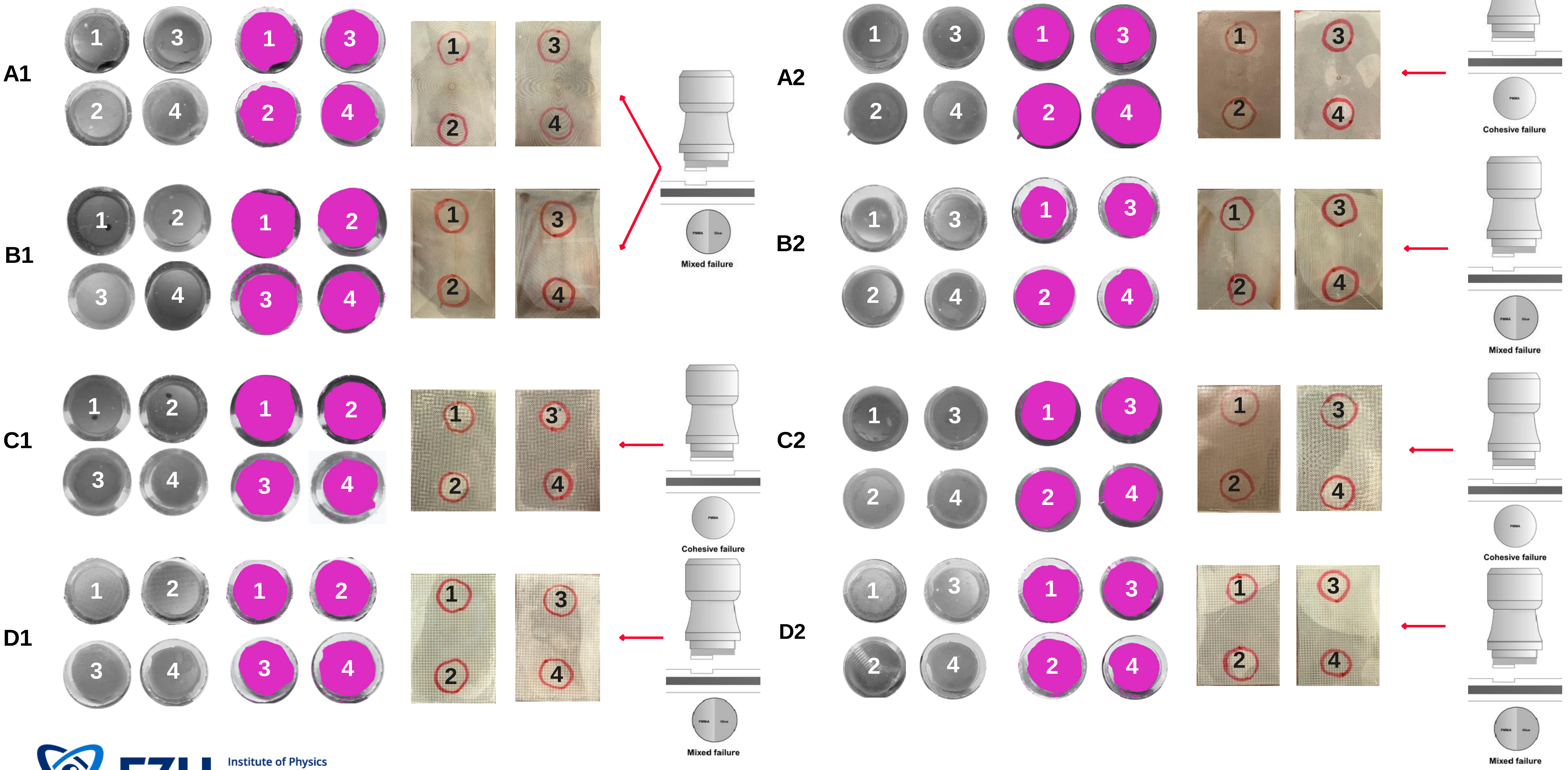
Failure mode: surface observation (both dolly and composite)



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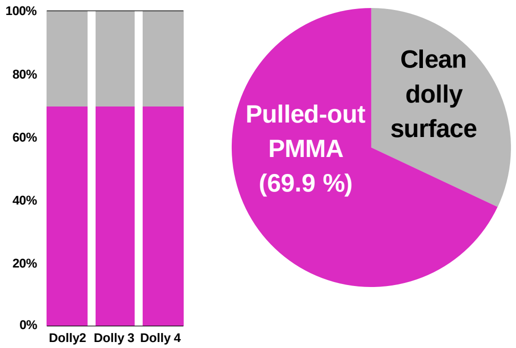
Summary of the pull-off test (Adhesion strength and failure mode)

A1

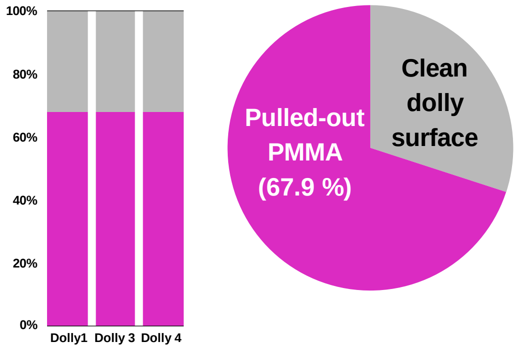
Adhesion strength: 53.9 MPa



The value for dolly 1 was taken our since it was deemed to deviate significantly from the others.

B1

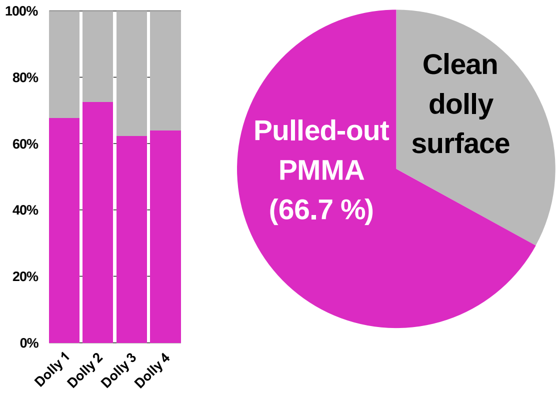
Adhesion strength: 54.9 MPa



The value for dolly 2 was taken our since it was deemed to deviate significantly from the others.

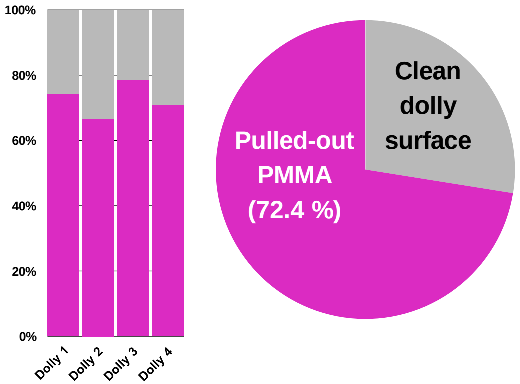
C1

Adhesion strength: 55.3 MPa



D1

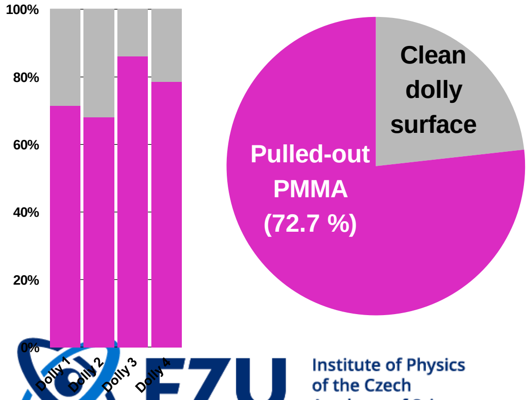
Adhesion strength: 53.8 MPa



Composite thickness: 600 μm

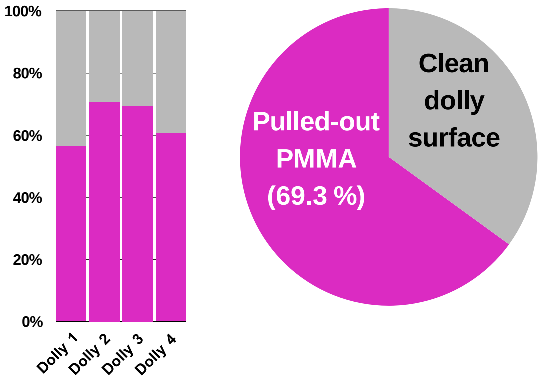
A2

Adhesion strength: 54 MPa



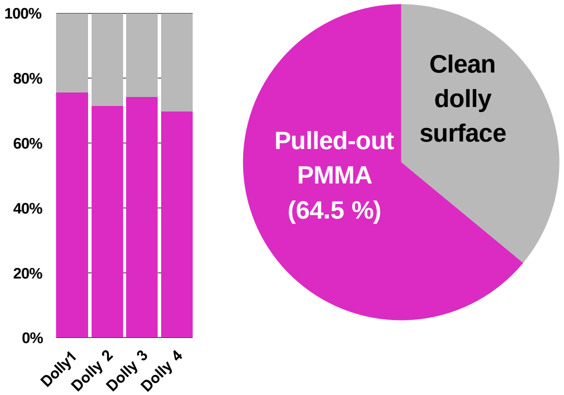
B2

Adhesion strength: 53.9 MPa



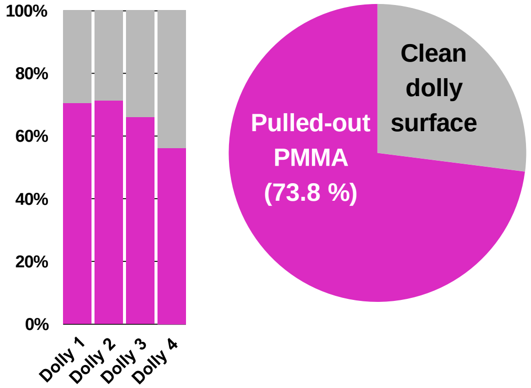
C2

Adhesion strength: 59.2 MPa



D2

Adhesion strength: 53.6 MPa



Composite thickness: 1100 μm

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Conclusion

- Sample C2 with the crossed laser pattern and PMMA thickness of 500 µm exhibited the highest maximum pressure of approximately 59.2 MPa.

- Mixed/cohesive failure was observed throughout the pull-off tests, indicating that the adhesion between the NiTi and PMMA interface is stronger than the cohesion within PMMA.

- In failure mode, it is possible to observe that the less pull out of PMMA from dolly surface signify higher interfacial strength.

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Mixed-Mode Debonding of a Laminated Composite

Interfacial failure by delamination or debonding can be simulated with a Cohesive Zone Model (CZM). This example shows the implementation of a CZM with a bilinear traction-separation law. It is used to predict the mixed-mode softening onset and delamination propagation in a composite material.

lb	102[mm]	0.102 m	Length
wb	25.4[mm]	0.0254 m	Width
hb	2*1.56[mm]	0.00312 m	Thickness
cl	34.1[mm]	0.0341 m	Initial crack length
pn	1e6[N/mm^3]	1E15 N/m³	Penalty stiffness
sigmat	65[MPa]	8E7 Pa	Normal tensile strength
sigmas	50[MPa]	1E8 Pa	Shear strength
Gct	0.969[kJ/m^2]	969 J/m²	Critical energy release rate, tension
Gcs	1.719[kJ/m^2]	1719 J/m²	Critical energy release rate, shear
alpha	2.284	2.284	Exponent of the Benzeggagh and Kenane (B-K) criterion
disp	0	0	Displacement parameter
mm	0.5	0.5	Mode mixity ratio
ll	lb/2*(0.5*sqrt(3*(1-mm)/mm)+1)/(3-0.5*sqrt(3*(1-mm)/mm))	0.044596 m	Lever length
lr	8*((6*mm+sqrt(3*mm*(1-mm)))/(3+9*mm+8*sqrt(3*mm*(1-mm))))	2.1436	Load ratio middle/cracked edge

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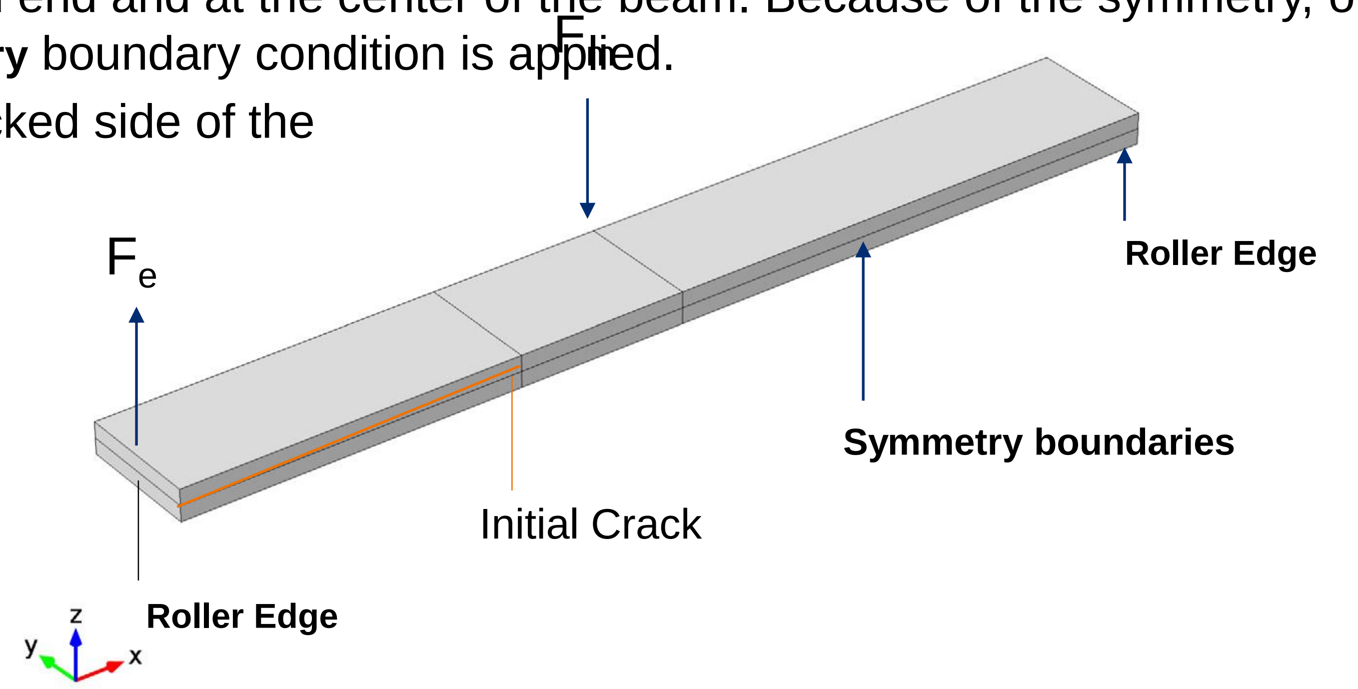
Transversely isotropic

Density	2050	kg/m³
Young's modulus	{30, 3.1}	GPa
Poisson's ratio	{0.42, 0.35}	1
Shear modulus	20 [GPa]	N/m²

It consists of a beam cracked along a ply interface halfway through its thickness. The initial crack length is c_l. The beam
is supported at the outermost bottom edges. A mixed-mode bending load is produced as the result of forces applied to the top edges at the cracked end and at the center of the beam. Because of the symmetry, only half of the beam is modeled and a **Symmetry** boundary condition is applied.

A pulling force F_e is acting on the cracked side of the beam. At
the center, a force F_m pushes down.



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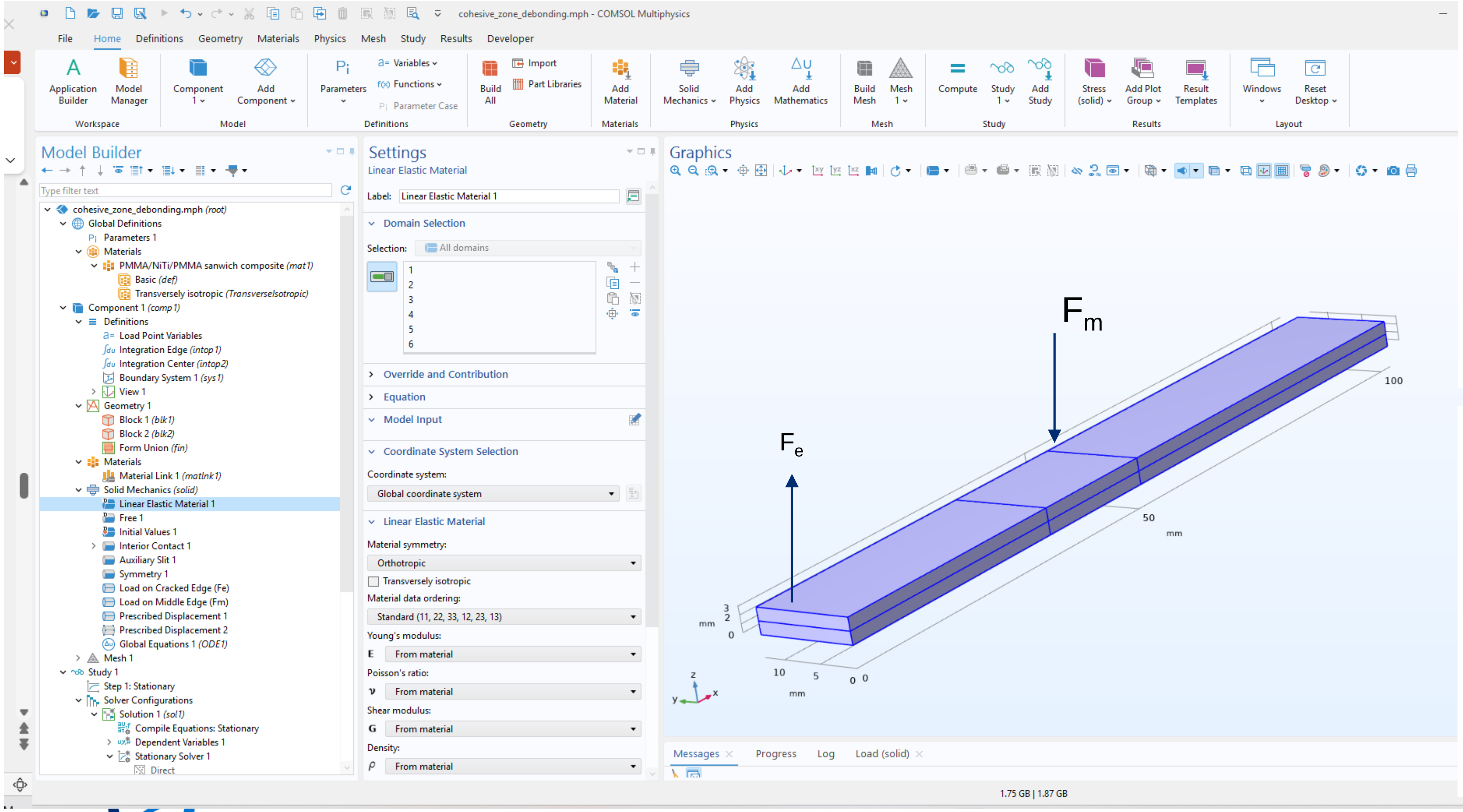
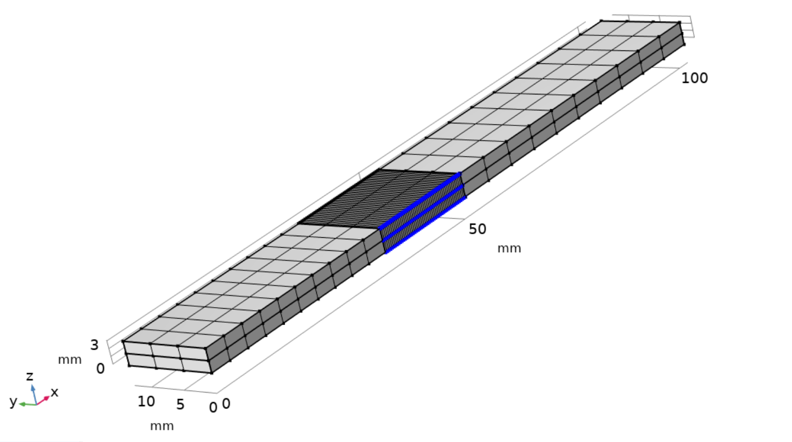
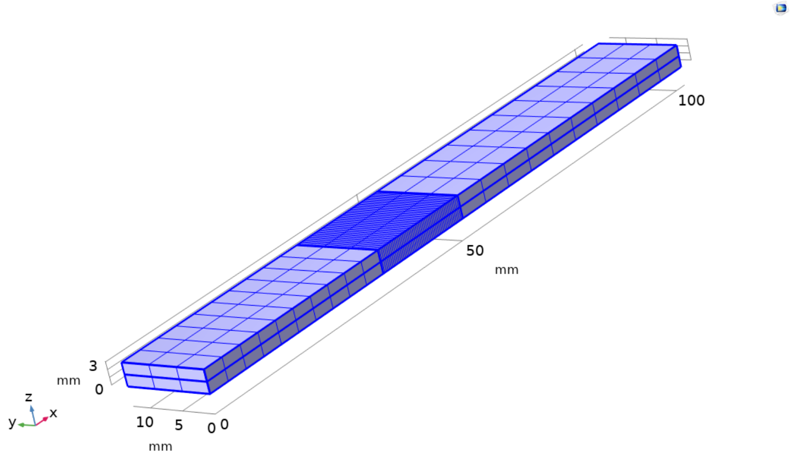
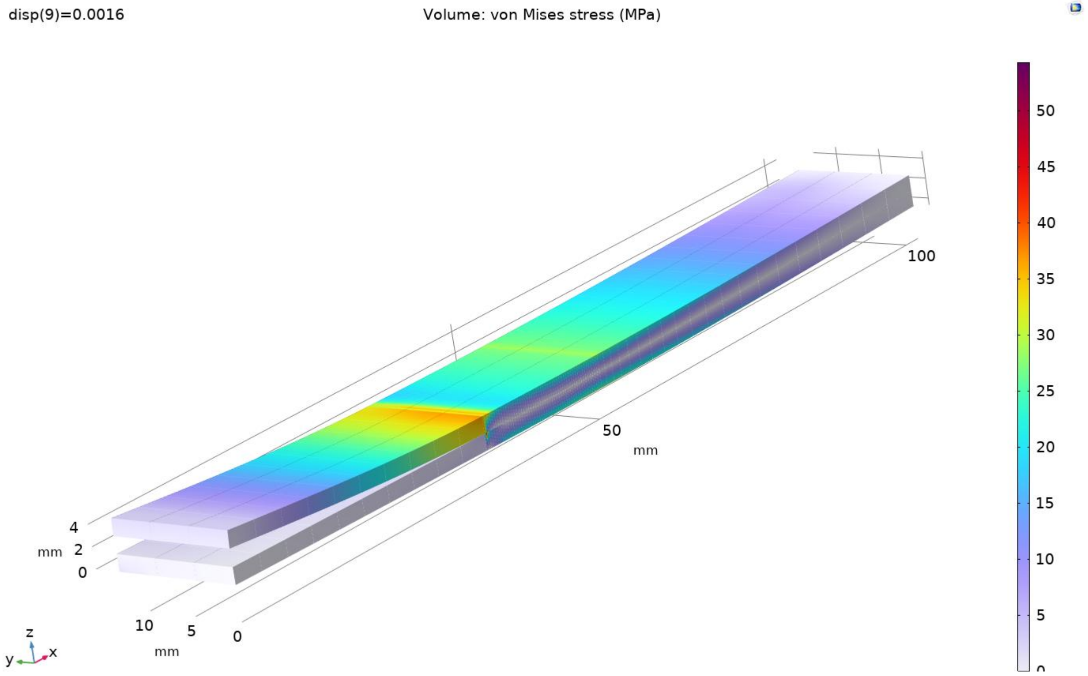
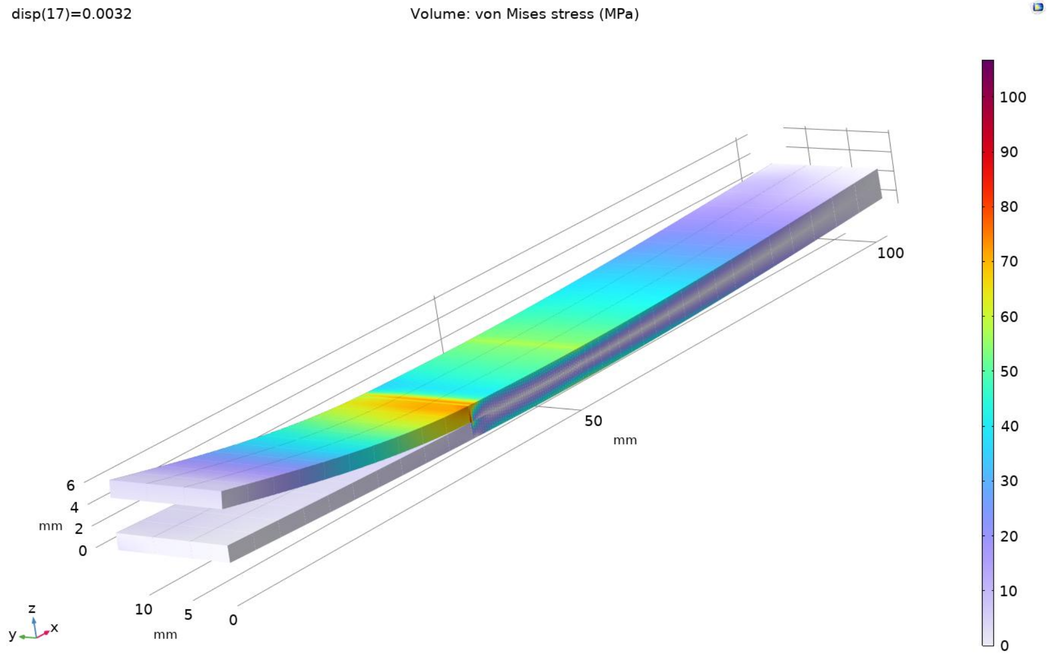
Interfacial failure by delamination or debonding is one of the main failure modes of laminate structures. Such failures can be simulated with a cohesive zone model (CZM). A key ingredient of a cohesive zone model is a traction-separation law that describes the softening in the cohesive zone near the delamination tip. This example shows how to model debonding using the decohesion model in COMSOL Multiphysics. The capabilities of the CZM to predict mixed-mode softening and delamination propagation are demonstrated in a model of the mixed-mode bending of a composite.

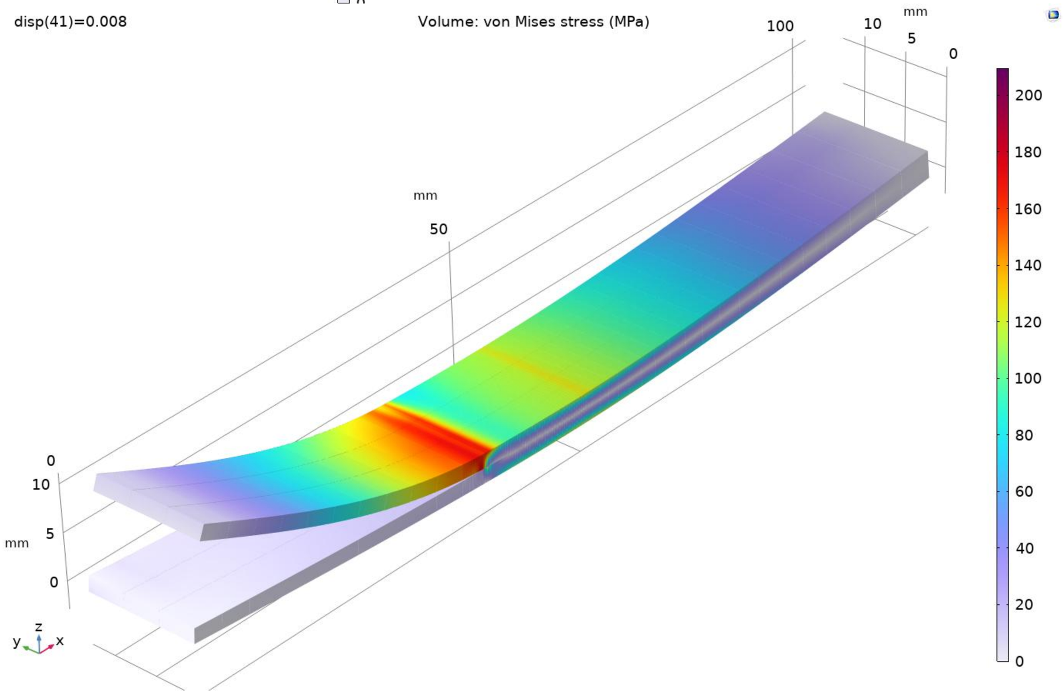


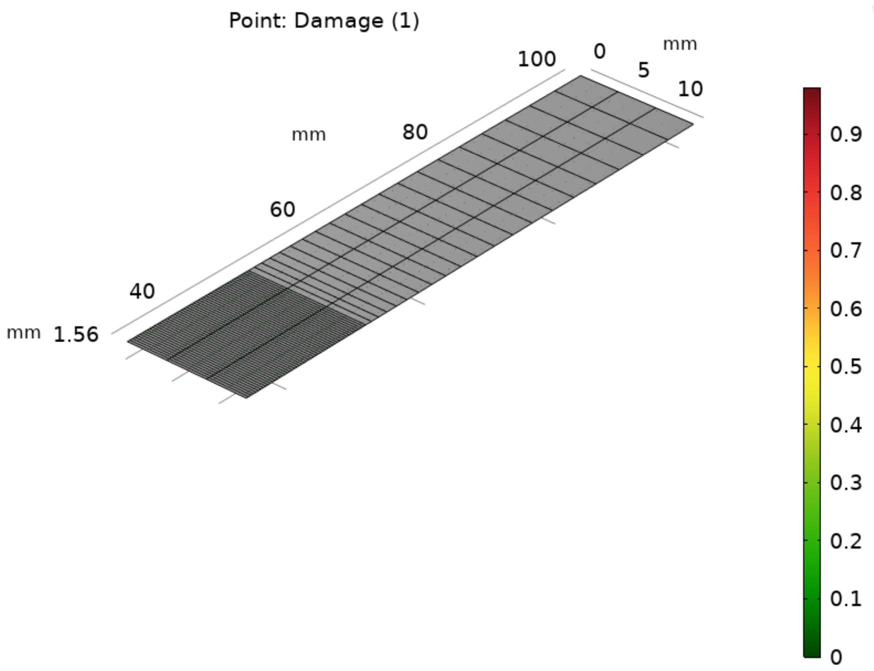


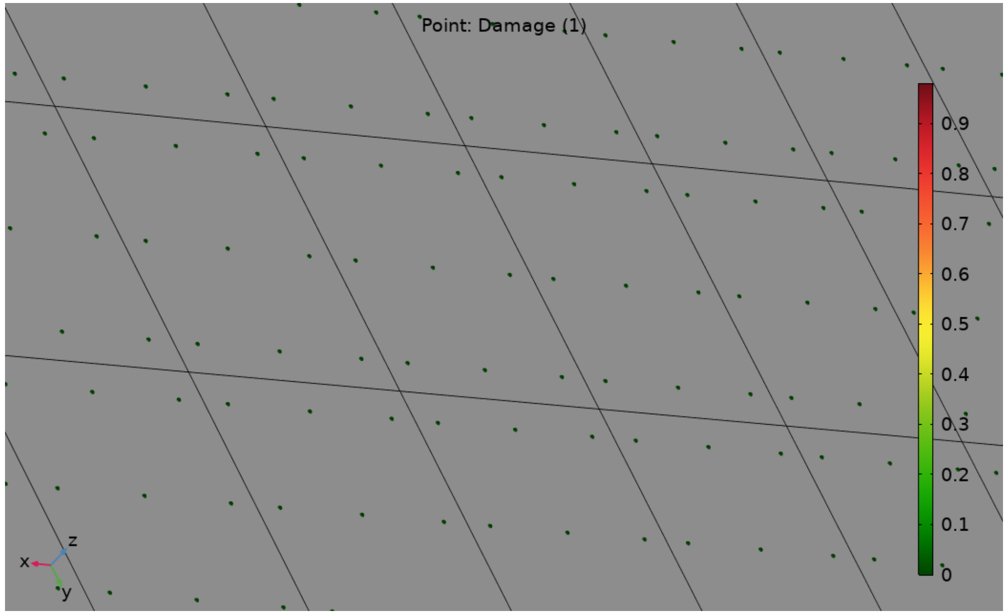


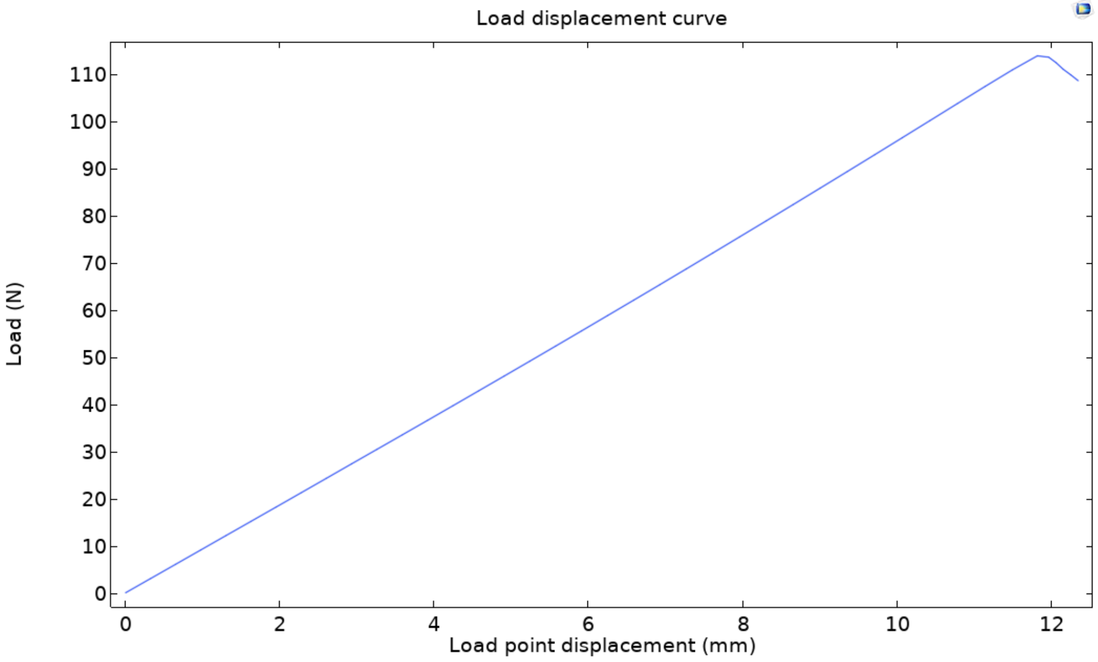

disp(9)=0.0016
Volume: von Mises stress (MPa)
50
45
40
35
30
25
20
15
10
5
100
50
mm
4
2
0
mm
10
5
0
mm


disp(17)=0.0032
Volume: von Mises stress (MPa)
100
90
80
70
60
50
40
30
20
10
0
100
50
mm
6
4
2
0
mm
10
5
0
mm


disp(41)=0.008
Volume: von Mises stress (MPa)
200
180
160
140
120
100
80
60
40
20
0
100
10
5
0
mm
mm
50
0
10
5
0
mm







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The maximum load that the beam with the initial crack can carry is exceeded and delamination occurs. After exceeding a peak load, the load decreases until the displacement reaches around 11 mm. This point approximately corresponds to when the crack reaches the center of the specimen. Thereafter, the load starts to increase again, but with a much lower stiffness than before delamination.

To implement a cohesive zone model in COMSOL Multiphysics, add an **Adhesion** subnode with a **Decohesion** subnode to the **Interior Contact** node

the simulation must be displacement controlled. This is obtained by using a global equation, in which the distributed load is controlled by the sweep parameter, which is the displacement at the free edge.

Since no large relative deformations of the laminates are expected, the **Interior Contact** node is utilized to model the behavior between laminates.

Thank you

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Name of the project: Ferroic Multifunctionalities
Registration number: CZ.02.01.01/00/22_008/0004591

Co-funded by the European Union

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