Experimental and Numerical Investigation of Shape Memory Alloy Hybrid Composites with Elastomeric Interface

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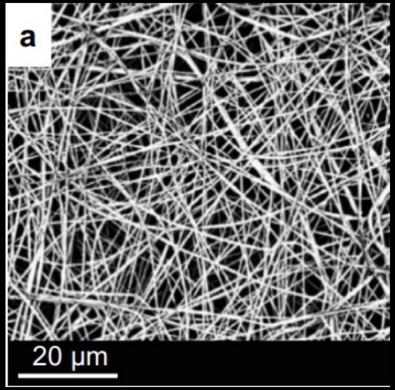
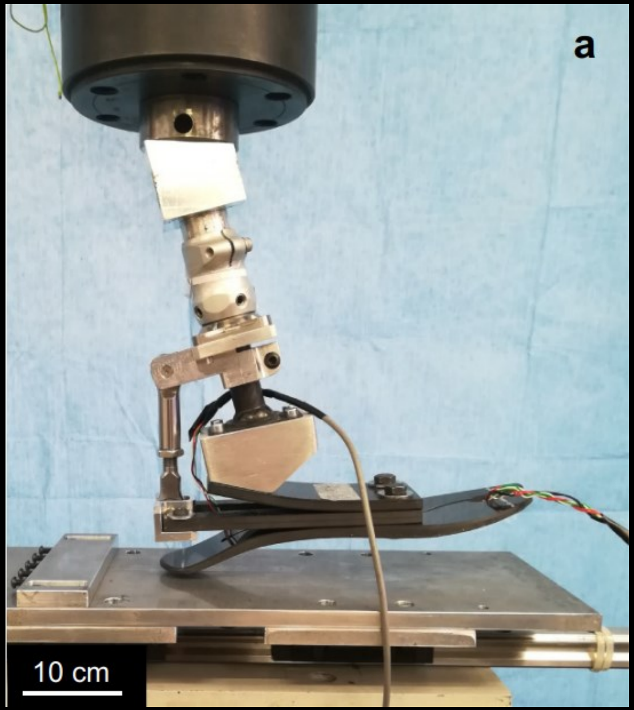
COMPOSITE MATERIALS

SMART MATERIALS





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Paolo: the student

I want to use SMA to create a mobile flap to increase the resistance force in braking

È un'idea fantastica!
Let's do it! (you do it)

Andrea: the visionary Professor

Gregorio: the SMA PhD guy

It's a bad idea,
the composite is too stiff,
the interface will break,
heating is a problem,
cooling is a problem..

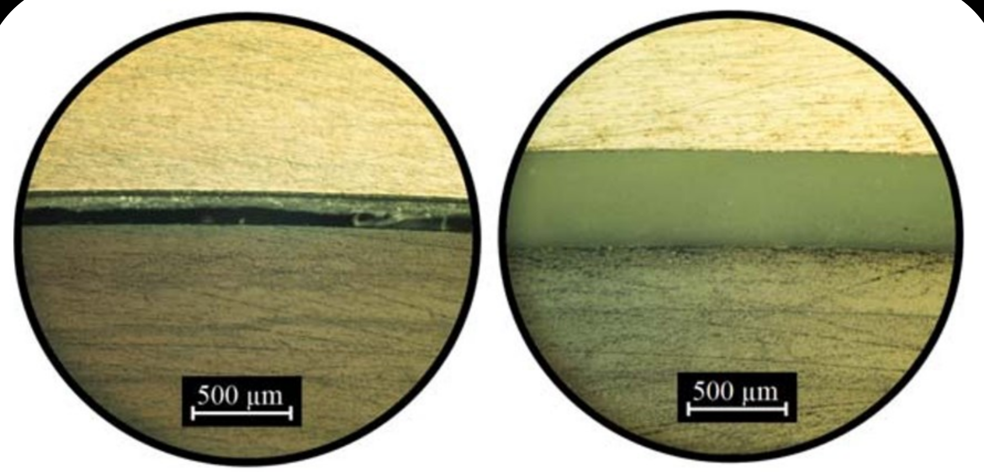
Let's use an elastomeric interface, trust me, I did 1000 time, it will work

I can help!

Giulia: the experienced in SMA FEM

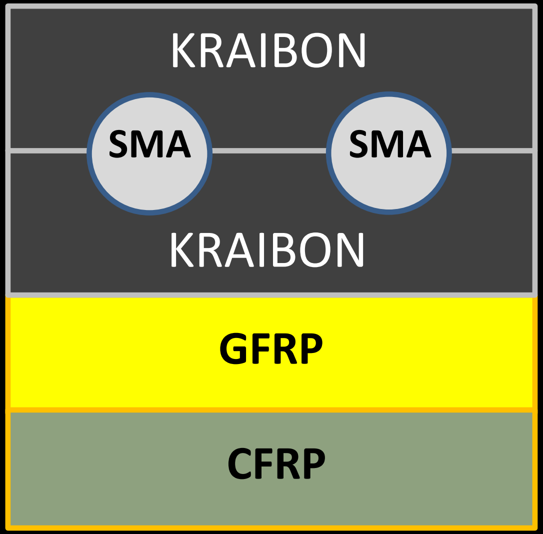
Tommaso: the experienced in composite
(Also the guy who make things work)

Povolo, M., Brugo, T. M., & Zucchelli, A. (2020). Numerical and Experimental Investigation of Al./CFRP Hybrid Tubes with Rubber-like Interlayer.



(a) Epoxy-Config. tube. (b) Rubber-Like-Config. tube.

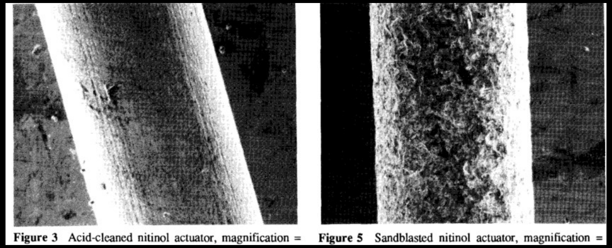
THE PROOF

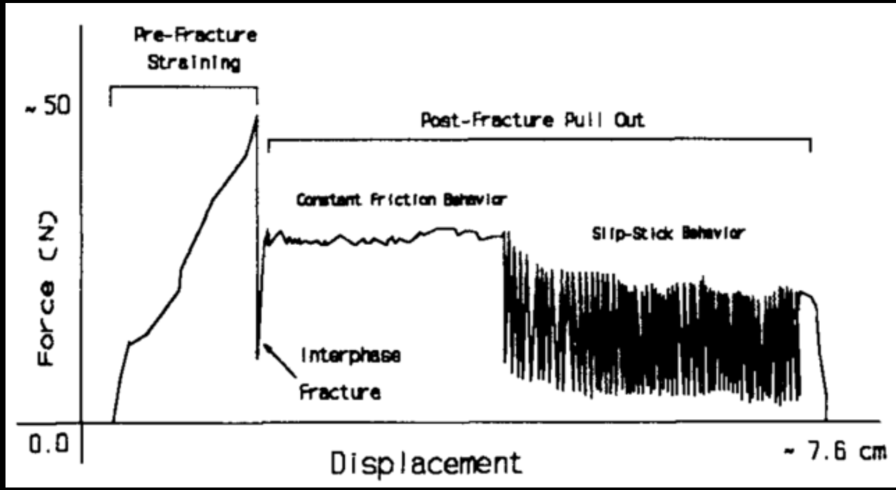


- 0.5 SMA wire (As 95°)
- 3.5% prestrain
- 6 Ampere

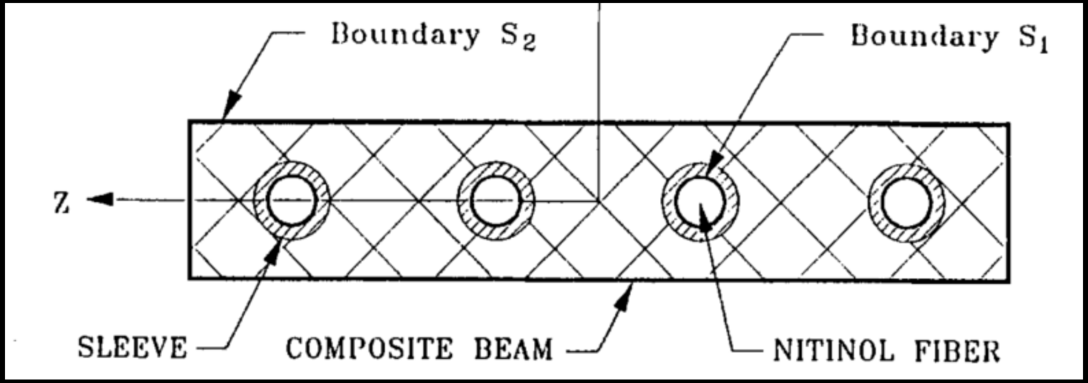
WHY IT WORKED?

STATE OF THE ART





PAINE, JONES, & ROGERS, (1992)
Nitinol actuator to host composite interfacial adhesion in adaptive hybrid composites.



Baz, Ro, (1992).
Thermo-Dynamic Characteristics of Composite Beams

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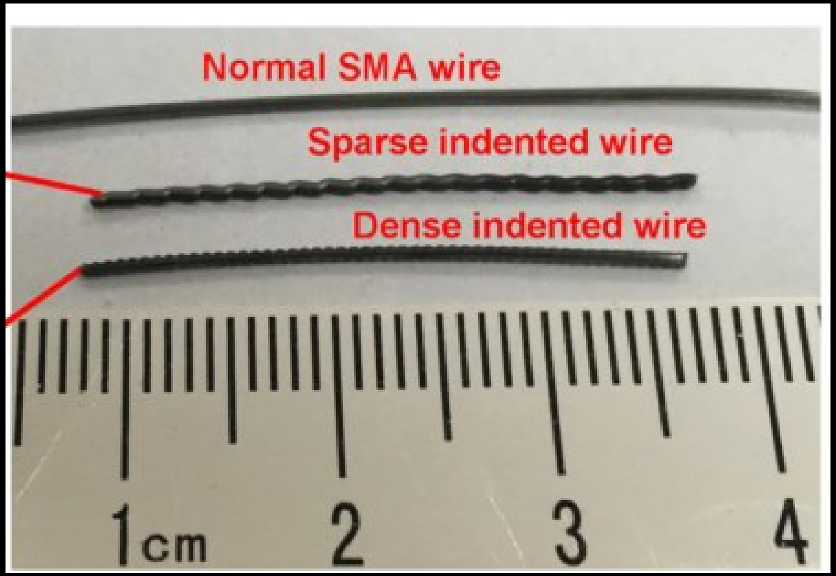
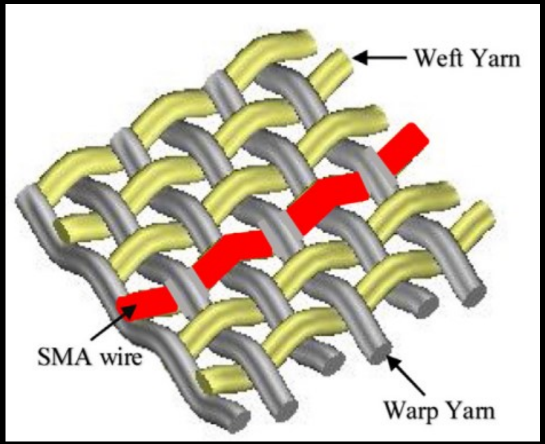
STATE OF THE ART



Yuan, Bai, Jia. (2016).
Enhancement of interfacial bonding strength of SMA smart composites by using mechanical indented method

Modifying method	Chemical etching [15]	Hand sanding [9]	Silane coupling agent [10]	Twisting method [13]
value	3%–18%	17%	91%	500%

Baitab,et al. (2020).
Tensile behavior of multilayer 3D smart woven composites embedded with SMA wires.



STATE OF THE ART

l_c : critical embedding

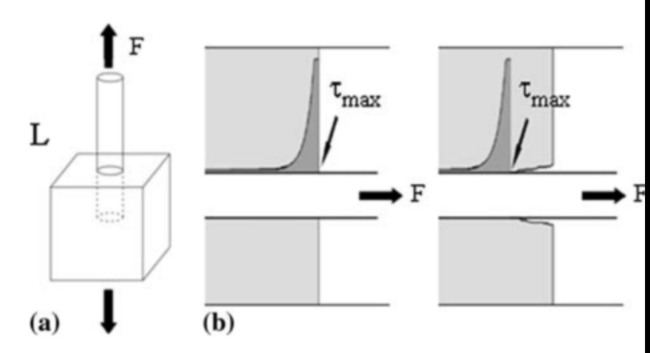
σ_{ult} : fiber tensile strenght

r : radius of the fiber

τ_y : interfacial shear strenght

Kelly and Tyson (1965)

$$l_c = \frac{\sigma_{ult} \cdot r}{\tau_y}$$



- ***Embedding length >> Critical length*** but the SMA doesn't brake

- **Mode I** is predominant: The **necking** of the SMA wire cause **debonding**

SPOILER

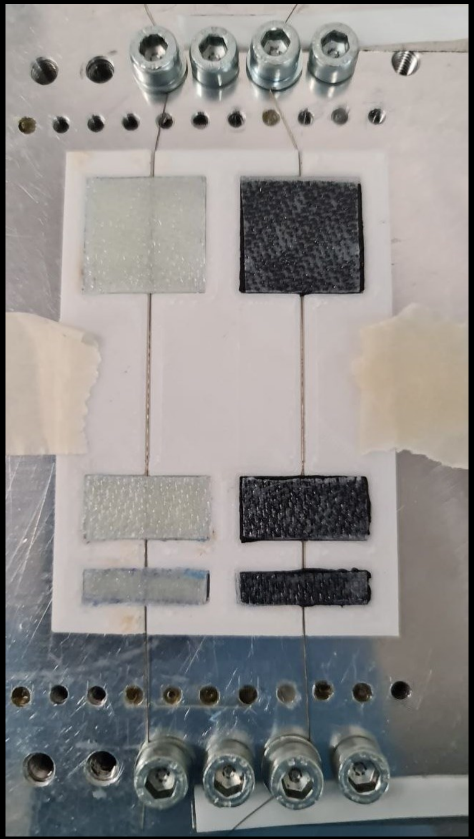
- The solution to SMA integration in composites is to eliminate **Mode I** But most of the work is to increase **interfacial shear strength**

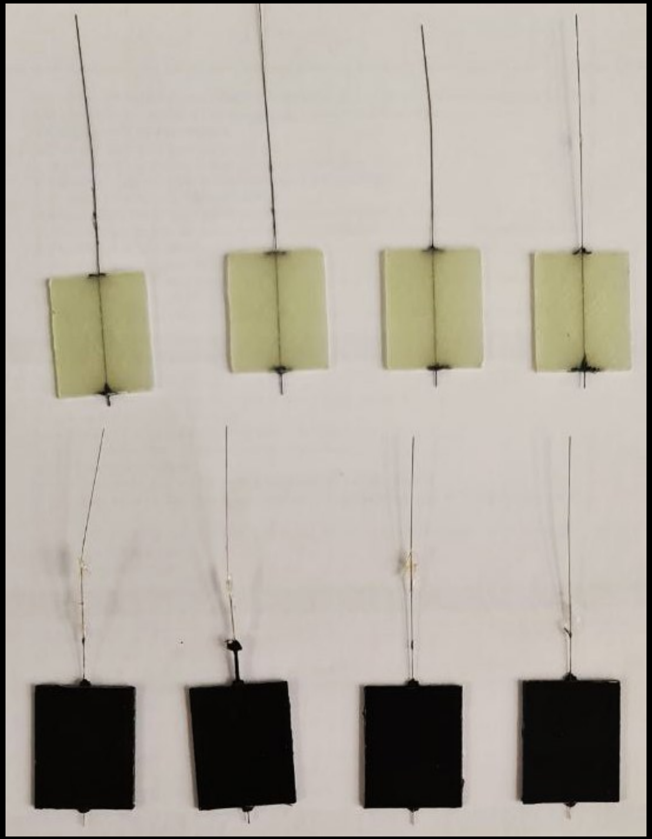
EXPERIMENTAL AND NUMERICAL INVESTIGATION

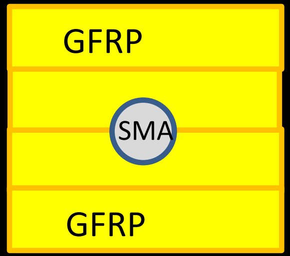
1. Manufacturing
2. Testing
3. Characterization of the materials
4. Finite element analysis

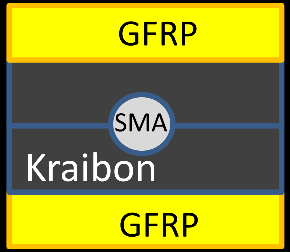
1. MANUFACTURING

Specimen with or without elastomeric interface









- 0.2 mm SMA wire (Af -25°)
- 0.22 mm GFRP prepreg
- 0.5 mm KRAIBON

- Preliminary specimen

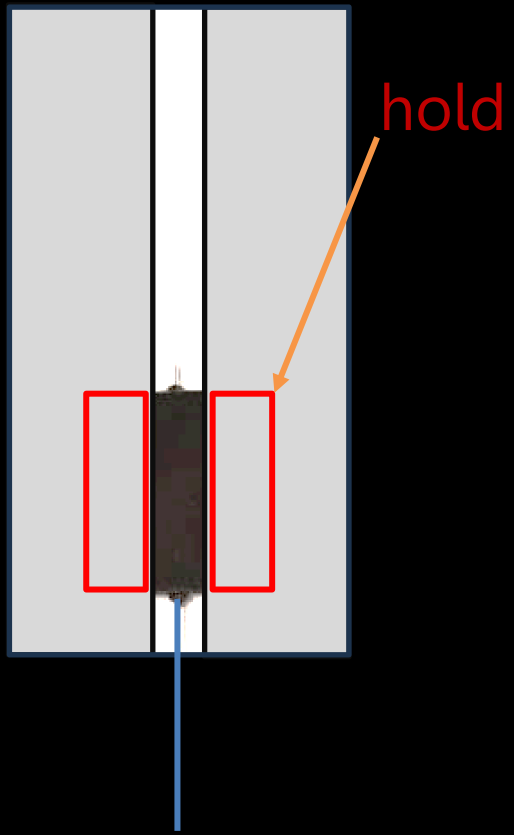
  L_embedded = [¼″ ½″ 1″]

- Final specimen

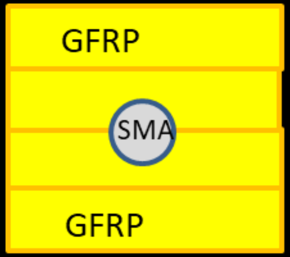
  L_embedded = ½″

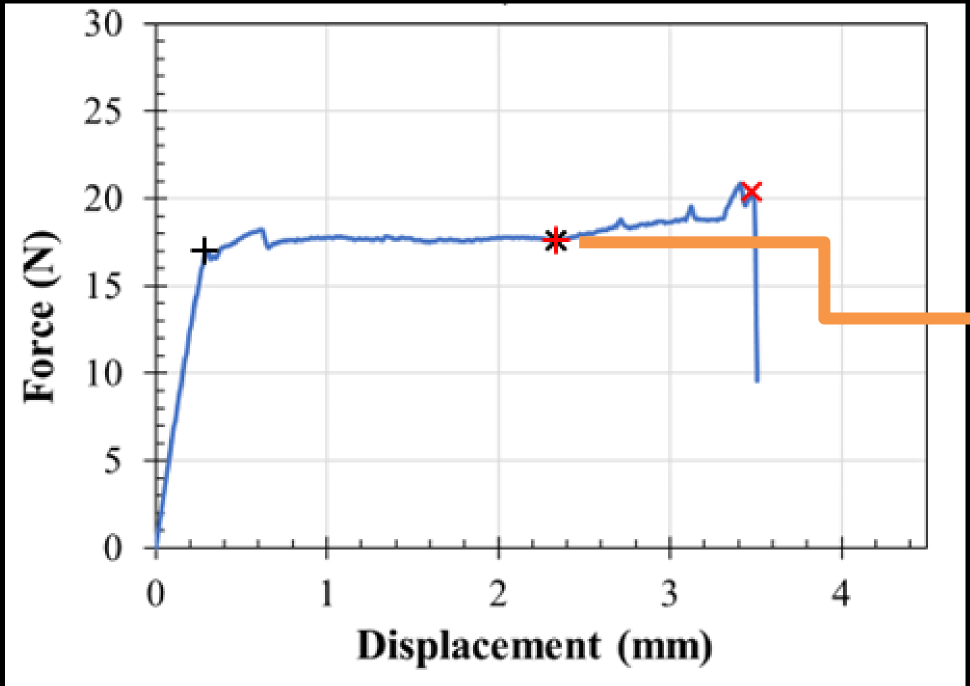
2. TESTING - METHOD

Customised Pull-out tests of different embedded length specimen



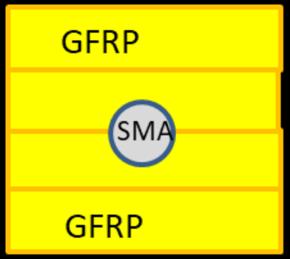
2. TESTING - RESULTS

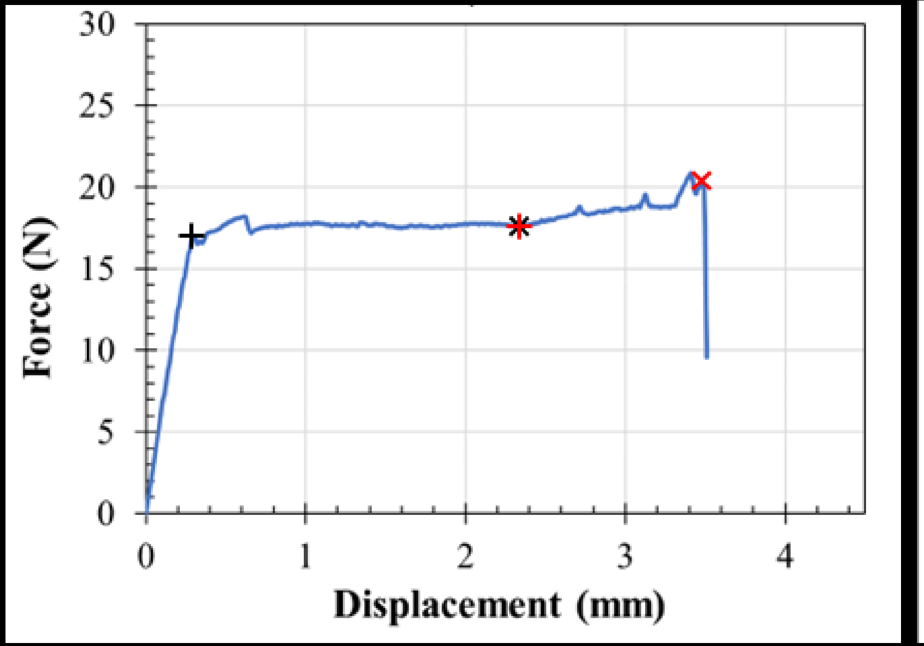


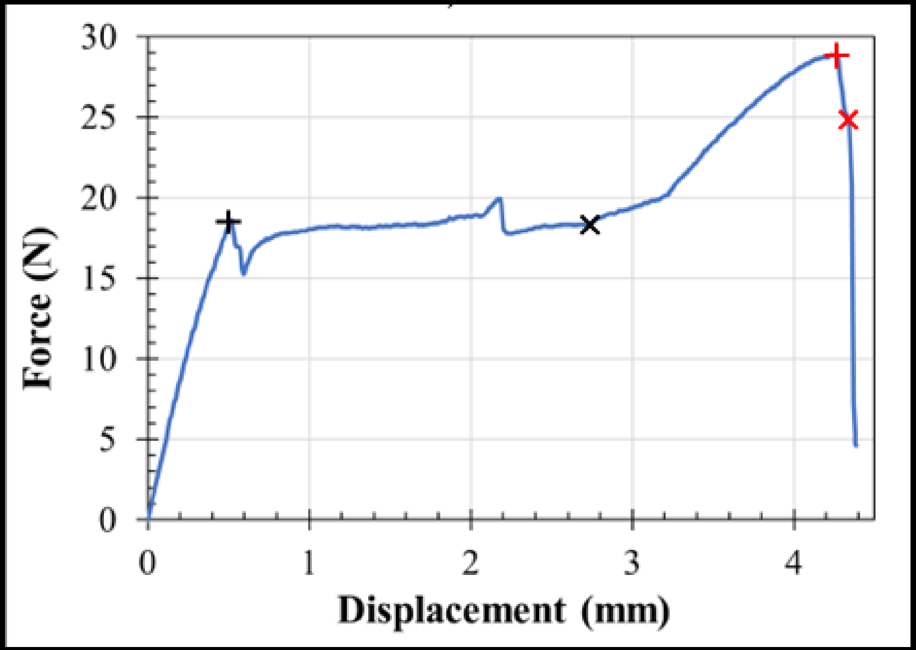


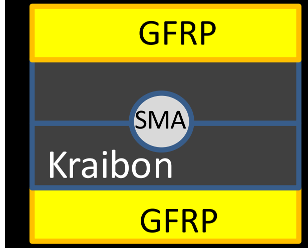
+ Initiation of Martensitic Phase Transformation (MPT) within the free wire
× Completion of MPT within the free wire and initiation within the embedded
+ Initiation of debonding
× Completion of debonding

2. TESTING - RESULTS









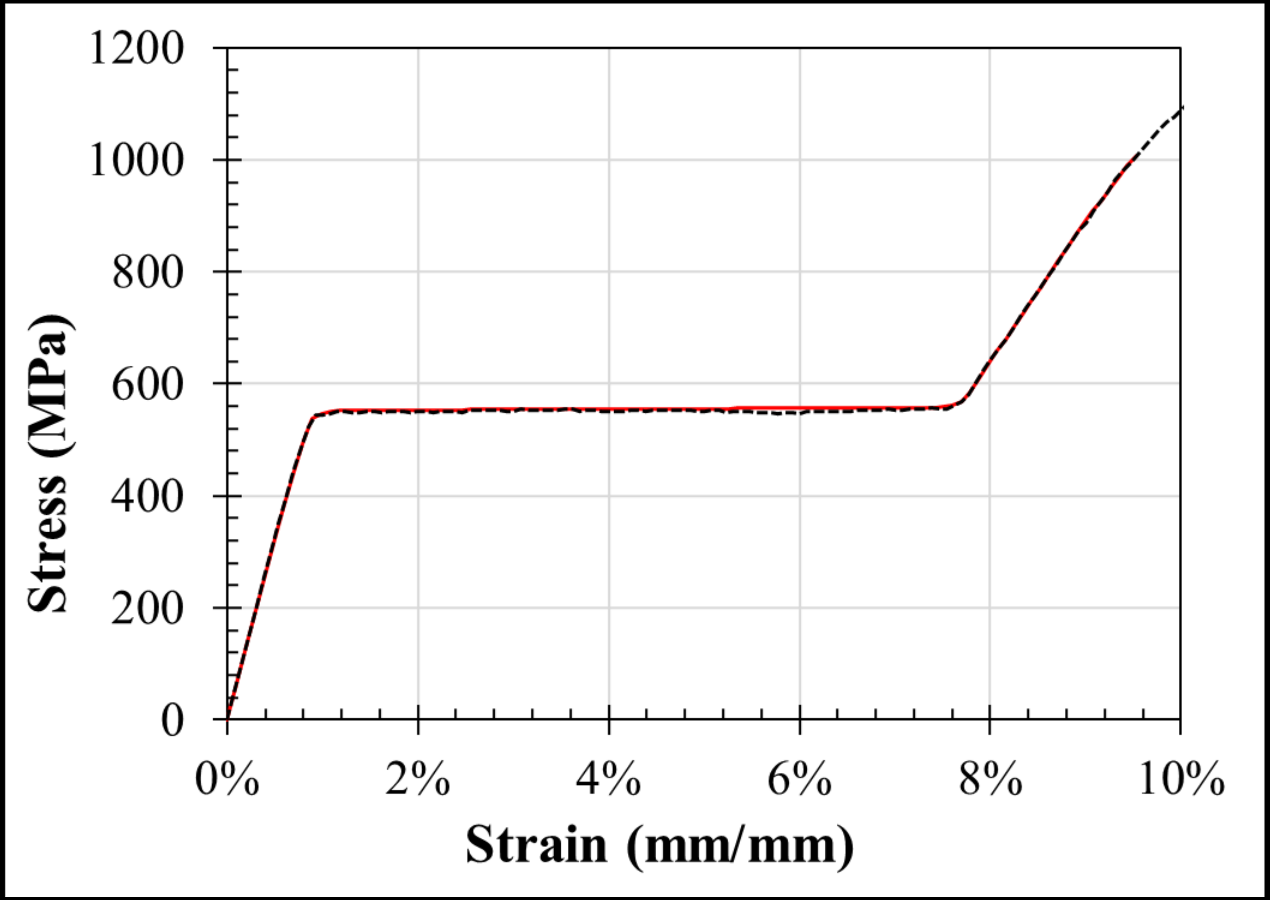
+ Initiation of Martensitic Phase Transformation (MPT) within the free wire

× Completion of MPT within the free wire and initiation within the embedded

+ Initiation of debonding

× Completion of debonding

3. CHARACTERIZATION



SMA wire tensile test (dotted line)

SMA FEM curve (red line)

NUMERICAL ANALYSIS - MODELING

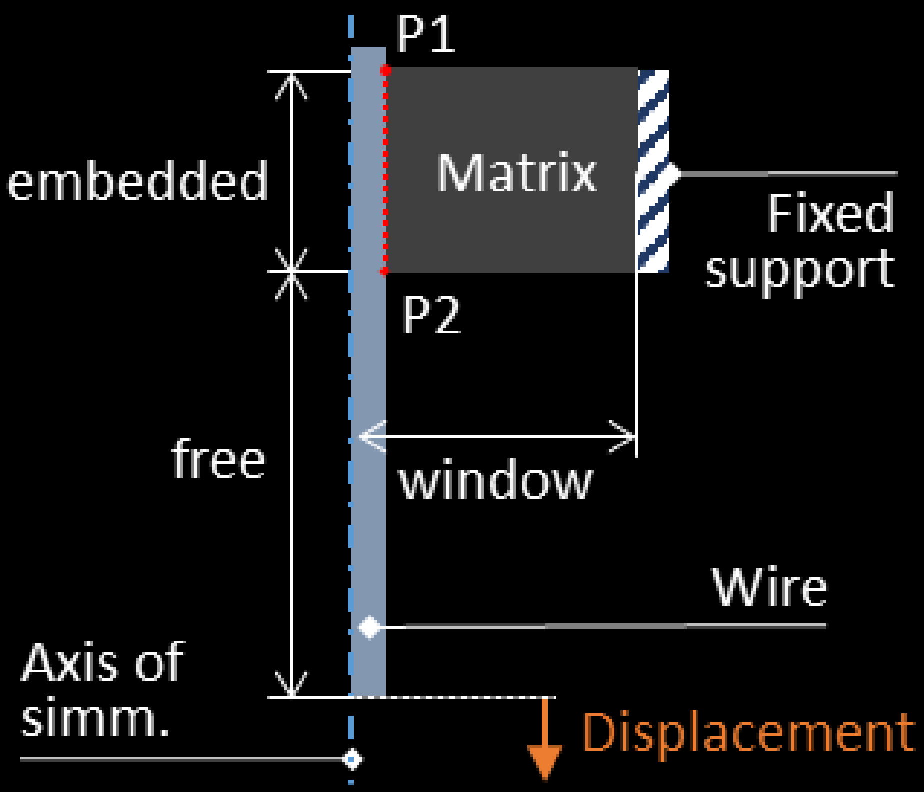
1. 3D-2D FEM validation

2. 2D ax-sym FEM

   Shared Topology: starting stress value

3. 2D ax-sym FEM with CZM

   DOE: Optimization of parameters



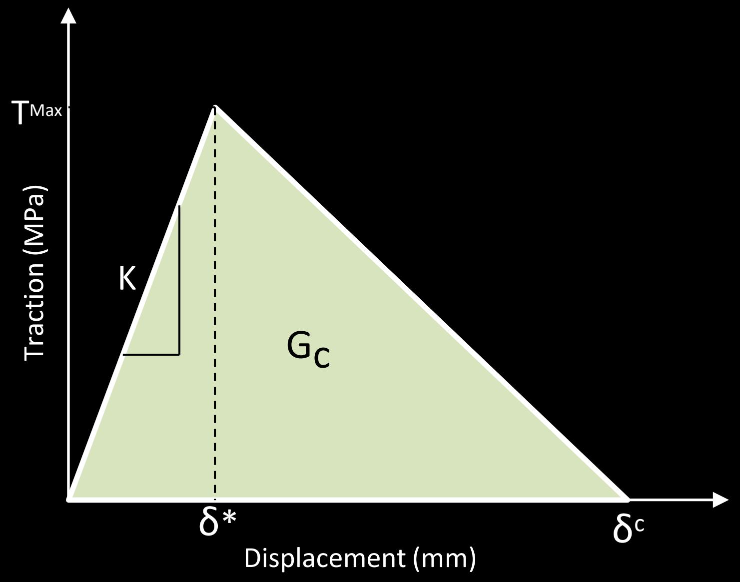
NUMERICAL ANALYSIS – SHARED TOPOLOGY

	τ *average* (MPa)	δ *t* (mm)	σ *average* (MPa)	δ **n** (mm)	R (-)	α (-)
EP	18	0.04	9	0.04	0.1	1
KR	5.75	0.87	3.5	0.004	0.1	1

First Attempt

CZM

Parameters



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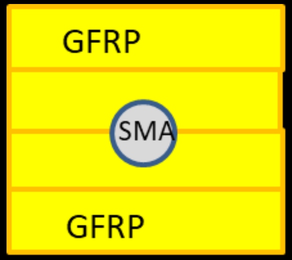
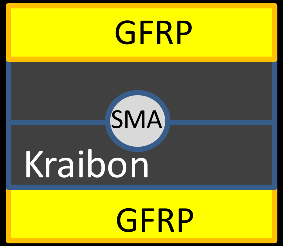
NUMERICAL ANALYSIS - DOE



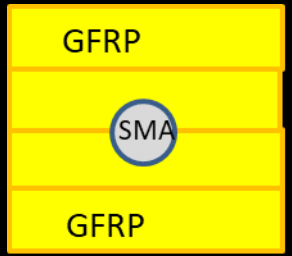
	$\tau_{average}$ (MPa)	δ_t (mm)	G_t (MPa·mm)	$\sigma_{average}$ (MPa)	δ_n (mm)	G_n (MPa·mm)	R (-)	α (-)
DOE 1	18.3 18 17.7	0.07 0.04 0.01	0.6405 0.63 0.6195 0.366 0.36 0.354 0.0915 0.09 0.0885	8	0.012	0.048	0.13 0.1 0.07	1
DOE 2	35.4 23.6 17.7 14.16 11.8	0.06 0.05 0.04 0.03 0.02	0.354	8	0.012	0.048	0.5 0.1 0.01	1
DOE 3	17.7	0.04	0.354	16 8 4	0.24 0.06 0.024 0.012 0.004	0.96 0.24 0.0964 0.024 0.016	0.1	1

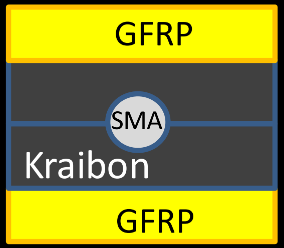
NUMERICAL ANALYSIS - DOE

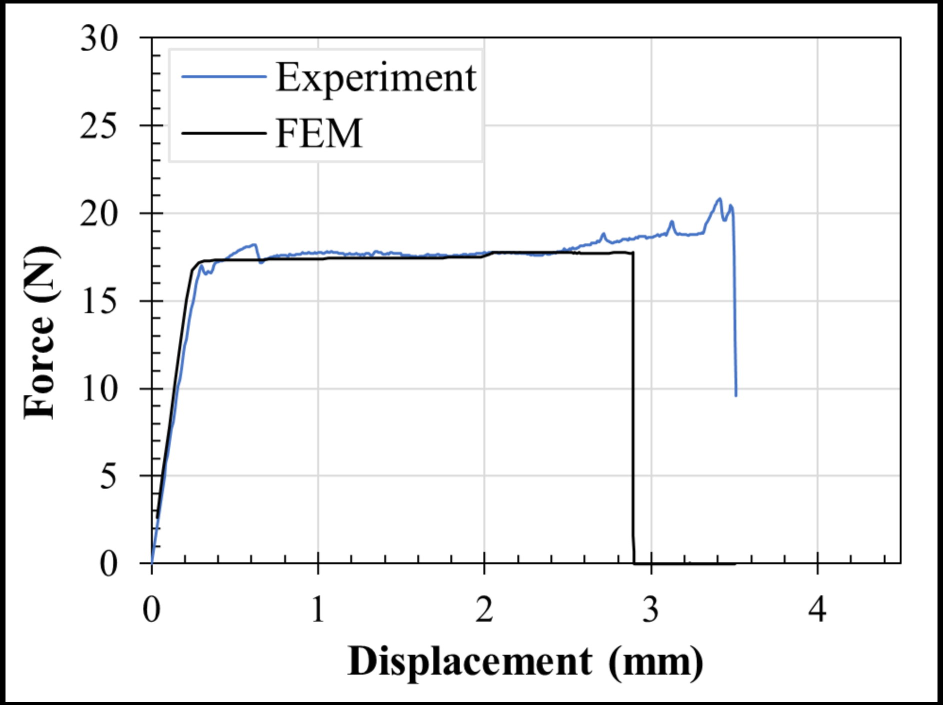


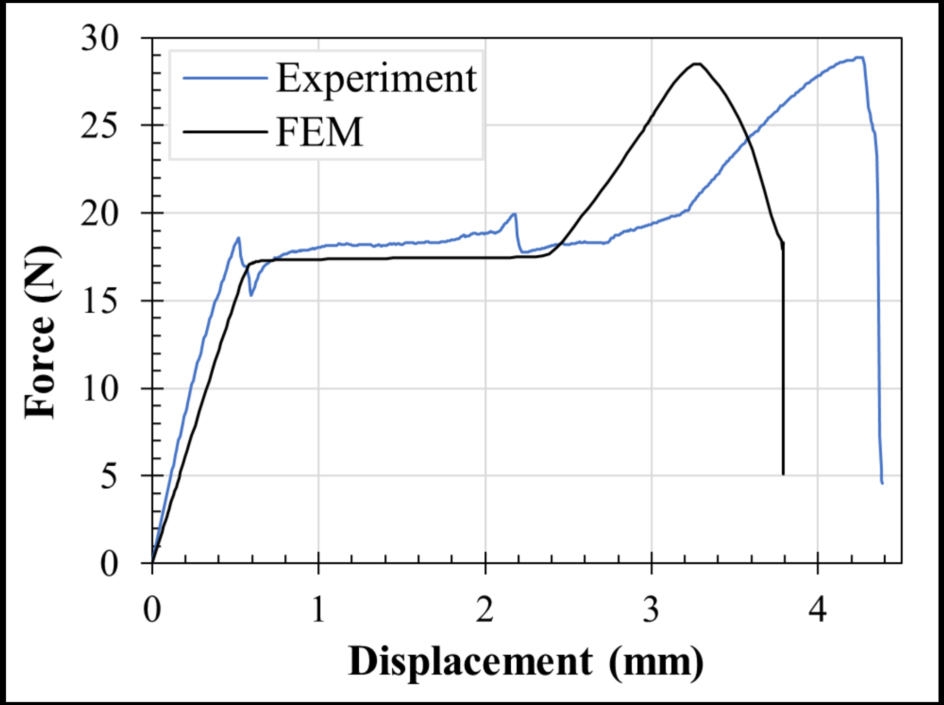
	(MPa)	(mm)	(MPa·mm)	(MPa)	(mm)	(MPa·mm)	R (-)	α (-)
DOE 1	7	1	3.5	7	0.01	0.035	0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.85	1
DOE 2	7 6 5 4 3 2	1	3.5 3 2.5 2 1.5 1 0.5	7	0.01	0.035	0.85	1

NUMERICAL ANALYSIS - RESULTS

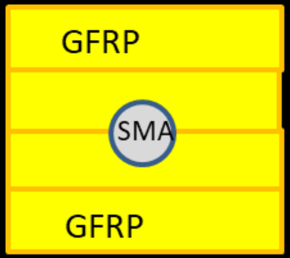


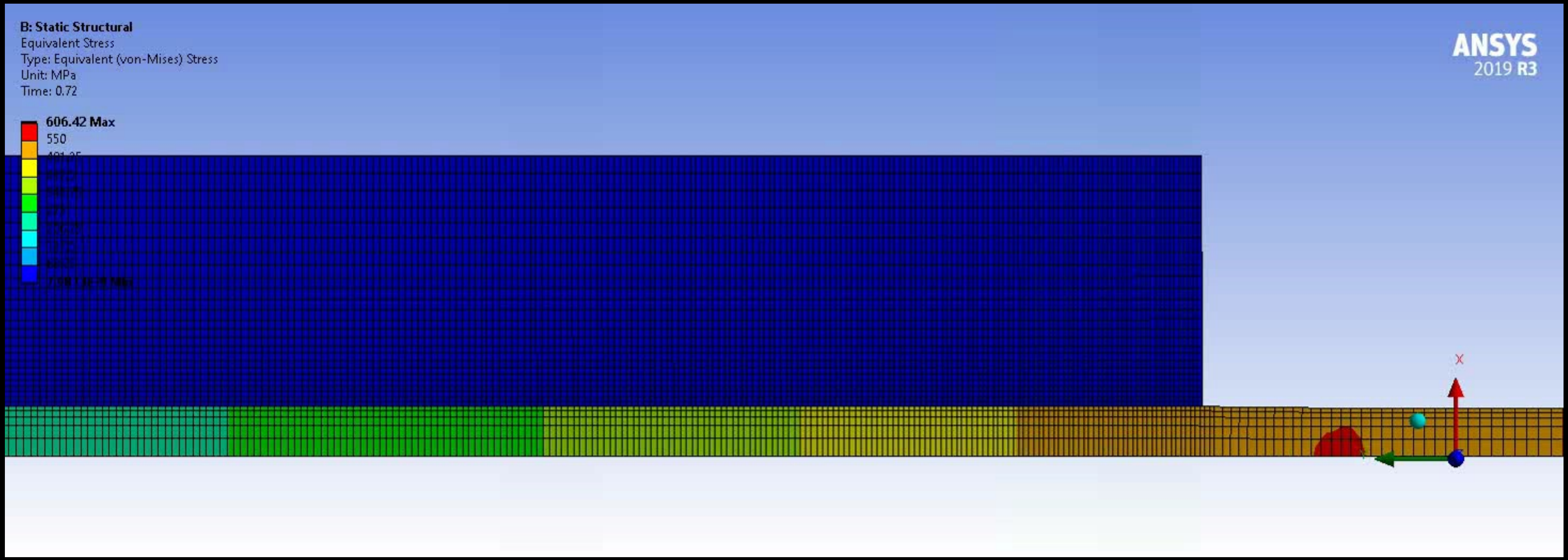






NUMERICAL ANALYSIS - RESULTS





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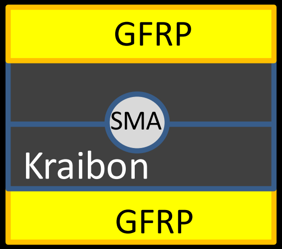
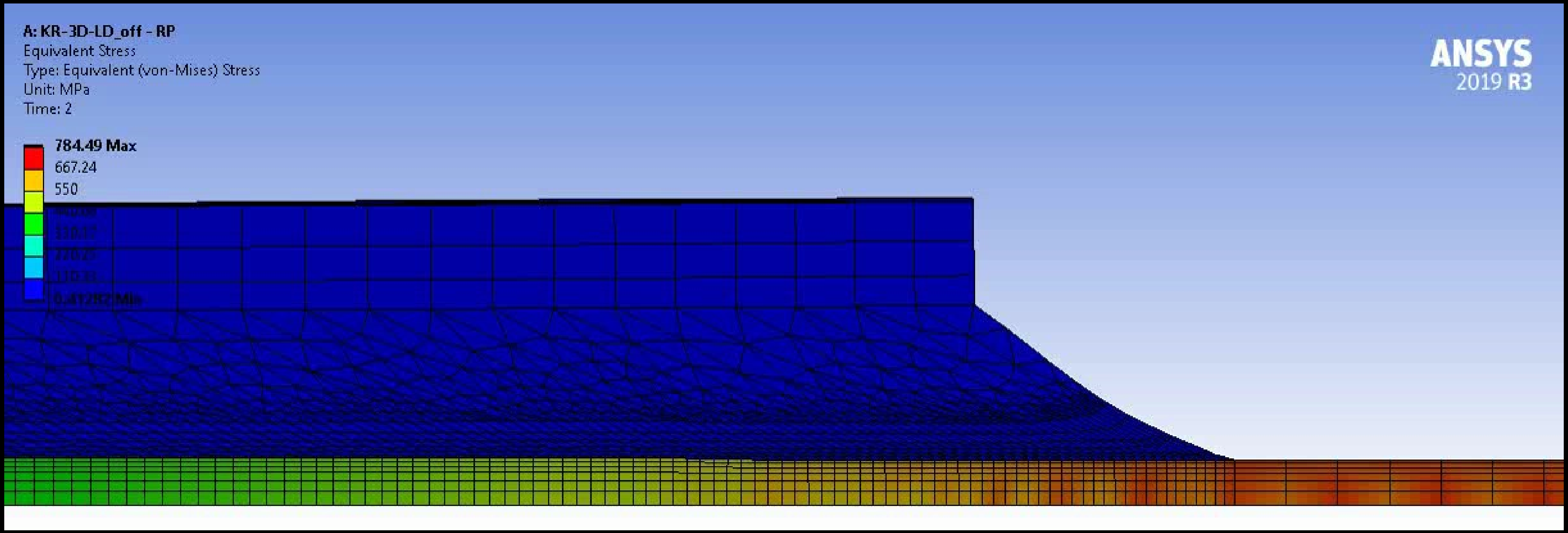
NUMERICAL ANALYSIS - RESULTS





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CONCLUSION

- The elastomeric interface can effectively be used to integrate SMA
- Other method all fail before or when the SMA MPT reach the matrix
- A method of optimization of CZM parameters have been tested

UPDATES

- Experiments with different embedding lengths
- Study of the effect of clamping in the SMA modelling
- Tensile traction/compression characterization of KRAIBON
- Study of the effect of the thermal effect
- Improved FEM modelling
- Improved DOE optimization method of CZM parameters
- …

FUTURE WORKS

- Tailoring of the elastomeric interface
- Electrospinning of the elastomeric interface
- Thermo-Mechanical Characterization of SMA and KRAIBON
- Experiments/Numerical investigation with Shape Memory Effect
- Design of new SMAHC
- …

AKNWOLEDGEMENT

Thanks to Gummiwerk KRAIBURG GmbH & Co. KG for generously donating the KRAIBON® used in this experiment;

Thanks to SAES® for sharing some information about SMA properties

And thanks to anyone who is interested in this work and who will share criticisms, comments and questions