Experimental and numerical analysis under axial and bending loading of hollow and foam filled A-profiles as stiffener concept for FRP structures for the aerospace industry

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Presentation prepared by:

Luiz Araujo
Technical Sales & New Business Development South America
Evonik Degussa Brasil Ltda.

M. Alexander Roth, Dr.-Ing.
Director ROHACELL® Americas & Vice President
Evonik Foams Inc.

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1. Introduction to stiffened shells by using A-Former
2. Experimental analysis of hollow and foam-filled A-Former
3. Numerical analysis of hollow and foam-filled A-Former
4. Conclusion
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Introduction to stiffened shells by using A-former

PMI filled A-formers:

Optimized method of stiffening FRC structures

- The most suitable and effective method for stiffening thin carbon/epoxy shells can be achieved by using A- or hat- profiles.

- PMI serves as a mandrel during the lay-up, but also as a structural member in the design of the component.

- This case history will demonstrate that PMI sandwich cores can be used for thickness – and weight – reduction of a shell element.

Introduction to stiffened shells by using A-former

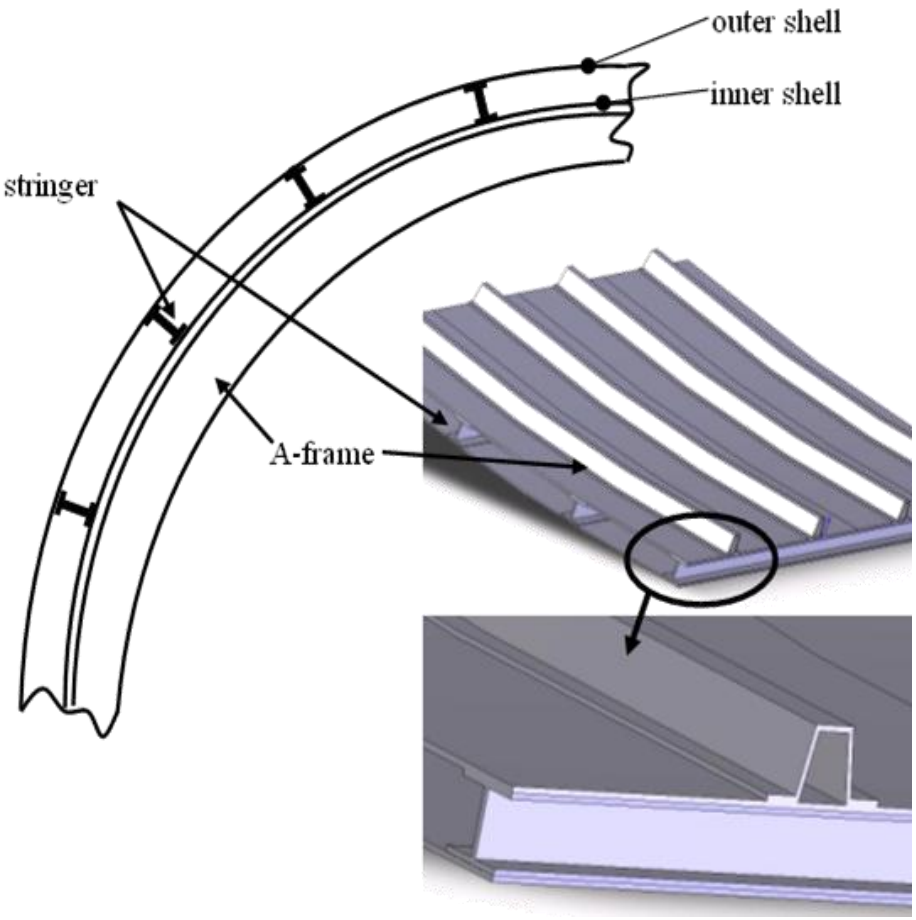
Application: Pressure Bulkheads Airbus A340-500 / A340-600 / A380

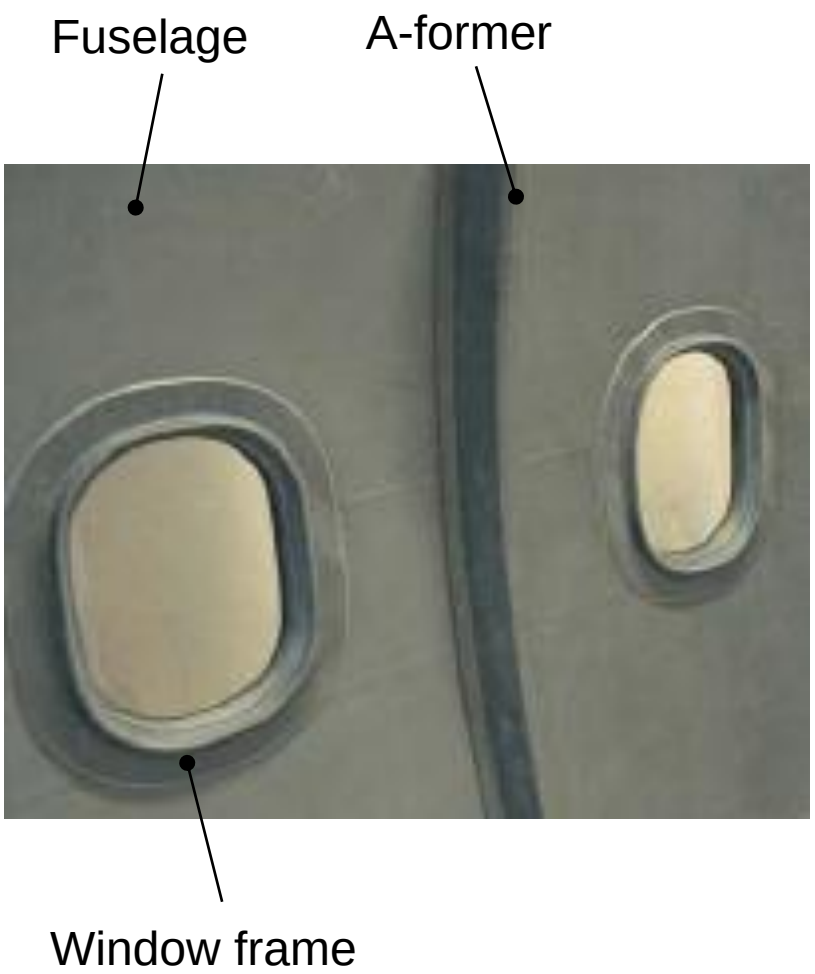
- **Material for stringer: ROHACELL 71 WF-HT used as mandrel**
- **Manufacturing process: autoclave co-curing**

180°C (356°F) / 0.35MPa (50 psi) / 2hrs

Introduction to stiffened shells by using A-former

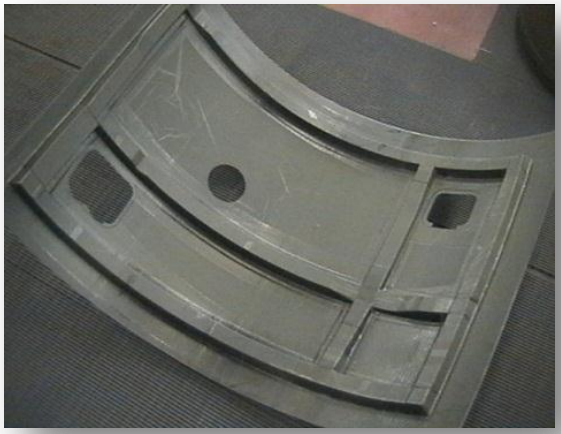
Application: Fuselage according the SOFI-concept





Introduction to stiffened shells by using A-former

Application: Engine Cowling Airbus A320 / Bombardier BR710 / Gulfstream G550



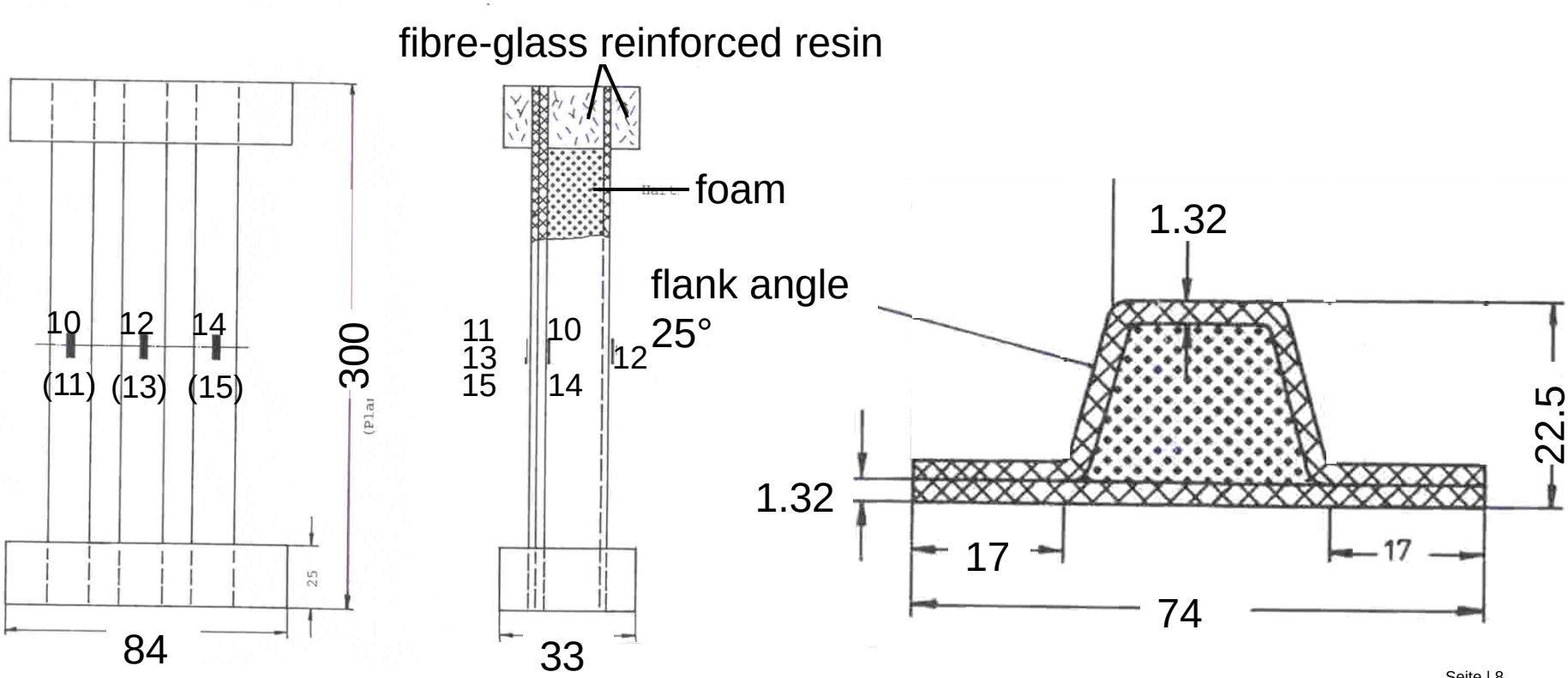
Experimental analysis of hollow and foam-filled A-former

- Buckling occurs in the compression loaded areas before reaching the actual compression resistance.
- Improvement of buckling resistance of a shell can be achieved by stiffening profiles bonded to the shell.
- PMI - filled profile is stabilized by the structural performance of the core, and will maintain its geometry and its strength properties until the yield load.
- The main structural loadings for the core are tensile and compression perpendicular to the sidewalls of the profile.

Experimental analysis of hollow and foam-filled A-former

The paper of Heinz Ames and Dr.Manfred Rather, DORNIER evaluates the behavior of a hollow and foam-filled A- or hat- profile under static compression load, focusing on weight and cost optimization by implementing a more cost effective manufacturing method.

Test specimen:



Experimental analysis of hollow and foam-filled A-former

Material:

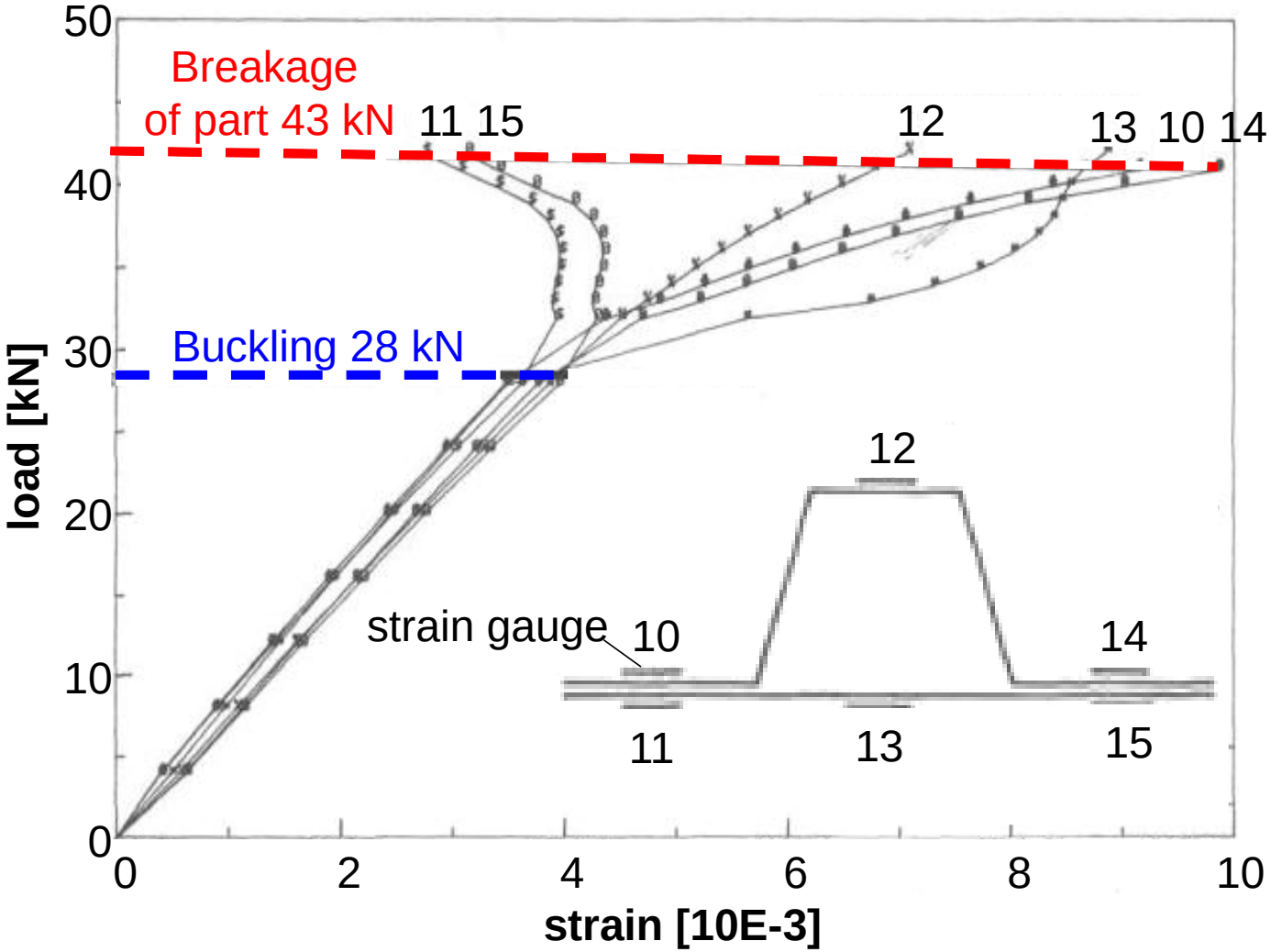
Laminate: CF and S-GF-Prepreg (DoL186/177/63)
Core material: ROHACELL® 110 WF

Lay-up of laminate:

	GFK	–	±45	–	0,1	
	CFK	–	0/90	–	0,2	
	SFK	–	±45	–	0,26	
"S" —·—	CFK	–	0/90	–	0,2	—·— "S"
	SFK	–	±45	–	0,26	
	CFK	–	0/90	–	0,2	
	GFK	–	±45	–	0,1	
					1,32	

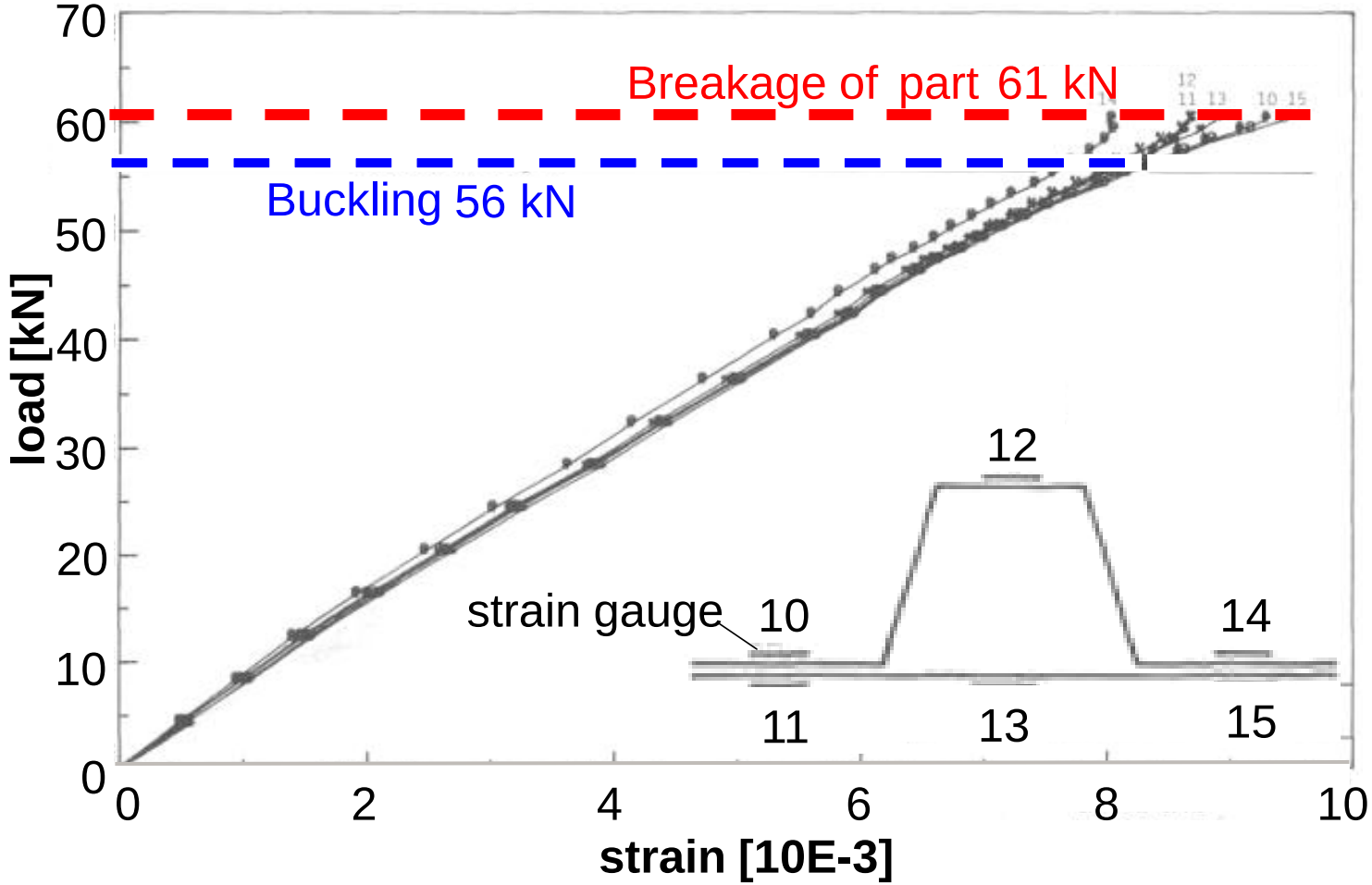
Experimental analysis of hollow and foam-filled A-former

Load-/strain-diagram of hollow A-former



Experimental analysis of hollow and foam-filled A-former

Load-/strain-diagram of PMI-filled A-former



→ **Breaking load is increased up to + 41%**

→ **Stability is increased up to + 108%**

Numerical analysis of hollow and foam-filled A-former

Development of a full parametrical FE model with the aid of input-files and the ANSYS programming language (APDL)

- Geometry
- Material data
- Lay-up
- Boundary conditions (e. g. bearing, loading etc.)

Static Load ($F_{max.}$ = 1000 N per loading point)

- Analysis of the stiffness
- Analysis of the strength according Tsai-Wu Criteria

Non-linear buckling analysis

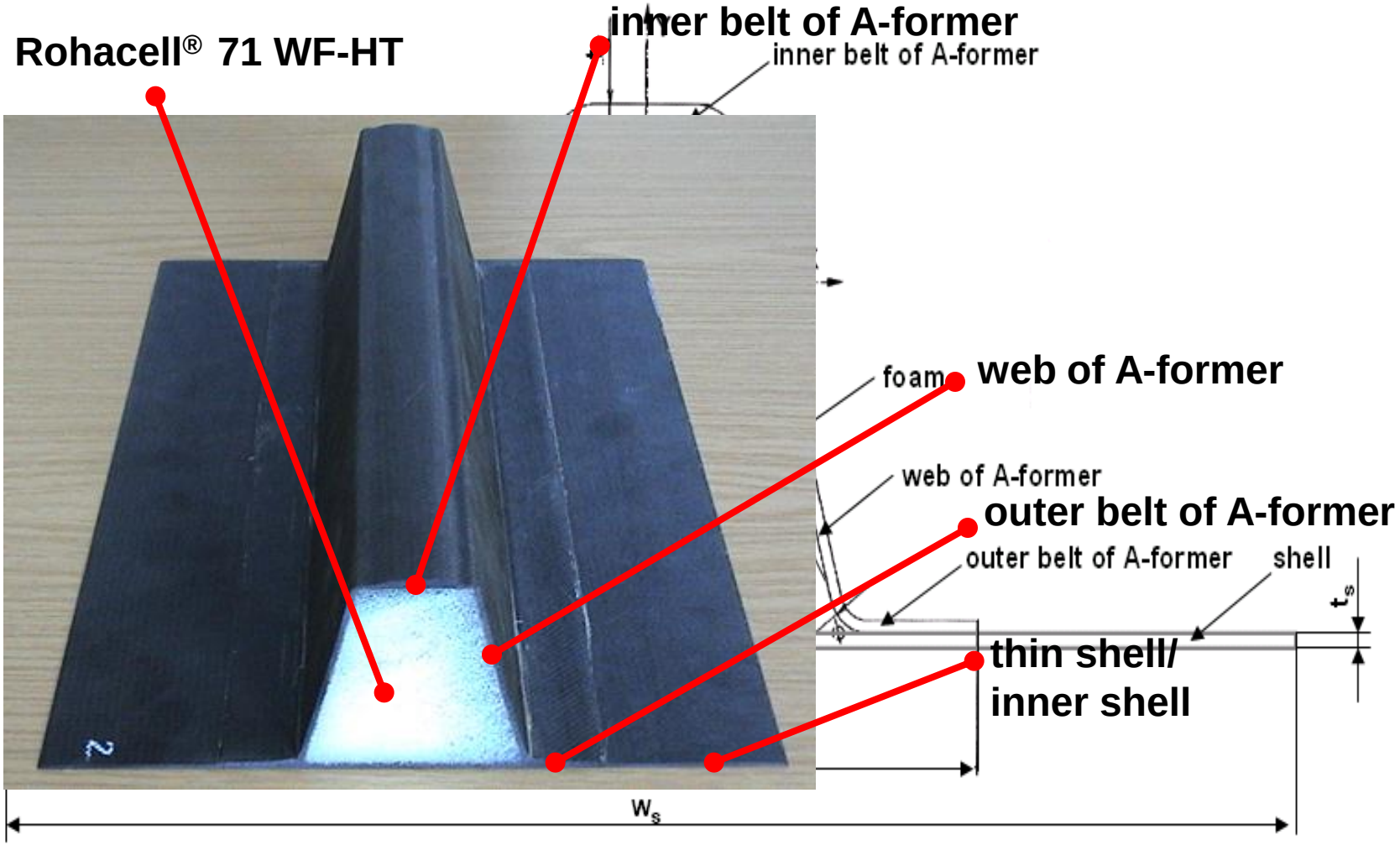
- One variant of an A-former
- Reduction of the laminate thickness of the foam-filled A-former to reach the same buckling behavior as the hollow variant

Axial compression load analysis

- One variant of hollow and foam-filled A-former

Numerical analysis of hollow and foam-filled A-former

Geometry of thin shell stabilized by PMI-foam-filled A-former



Numerical analysis of hollow and foam-filled A-former

Geometry of A-former:

geometry		variant 1
width of A-former	w_{total}/mm	120.00
width of inner belt	w_{if}/mm	35.00
width of outer belt	w_{of}/mm	25.00
total high	h_{total}/mm	80.00
width of inner shell	$w_{innershell}$/mm	240.00
length	l/mm	720

Laminate thickness and lay-up of A-former:

laminate thickness [mm]	variant 1	Material (Fabric, Tape)	angle [°]
inner belt of A-former	4.65	$(((\pm F2/(T)_3)_2/\pm F2/(T/T/\pm F2/T)_3/T/\pm F2/((T)_3/\pm F2)_2)$	$(((\pm 45/(0)_3)_2/\pm 45/(0/0/\pm 45/0)_3/0/\pm 45/((0)_3/\pm 45)_2)$
outer belt of A-former	1.9	$(\pm F2)_9$	$(\pm 45)_9$
web of A-former	1.9	$(\pm F2)_9$	$(\pm 45)_9$
shell	2.422	$(\pm F2/(T)16/\pm F2)$	$(\pm 45/(0)_2/(90)_2/(0)_3/\pm 45/(0)_3/(90)_2/(0)_2/\pm 45)$

Numerical analysis of hollow and foam-filled A-former

Material properties

→**Foam Core:** PMI foam: **Rohacell® 71 WF-HT**

Elastic modulus: 105 MPa

Poisson's ratio: 0.375

→**Face sheets:** Carbon fibre reinforced plastics (CFRP)

HTA-977/2	E_{11}	E_{22}	E_{33}	G_{12}	G_{13}	G_{23}
	MPa	MPa	MPa	MPa	MPa	MPa
Fabric	53423	53423	9100	5200	4200	4200
Tape	130000	8000	8000	5200	5000	3400

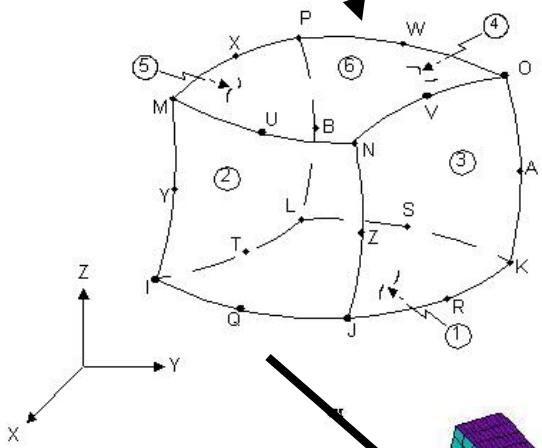
HTA-977/2	ν_{12}	ν_{23}	ν_{13}
	1	1	1
Fabric	0.035	0.464	0.464
Tape	0.3	0.5	0.01846

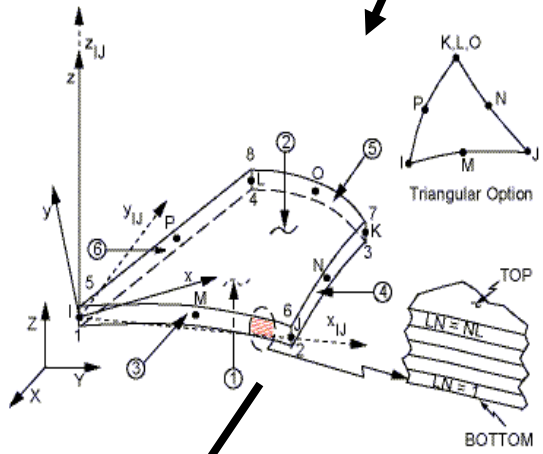
Index 1: direction of load; 2: direction of contraction

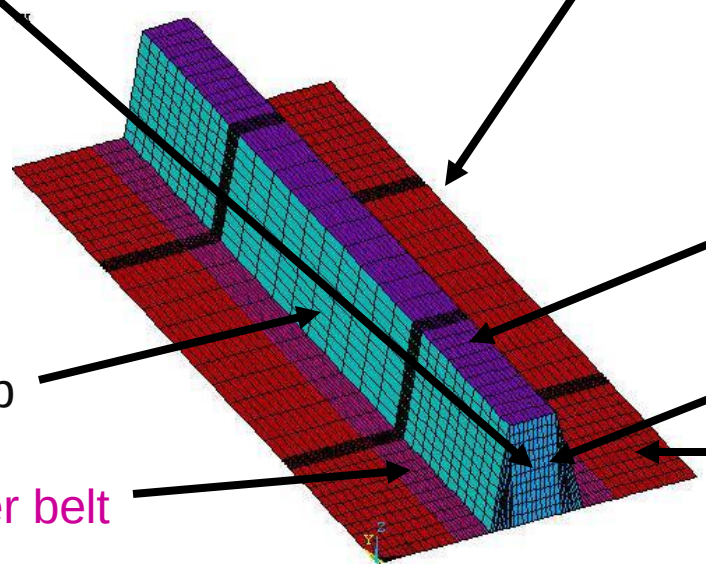
Numerical analysis of hollow and foam-filled A-former

Used element-types

- the laminate is represented by element-type SHELL 99 and the core by SOLID 95



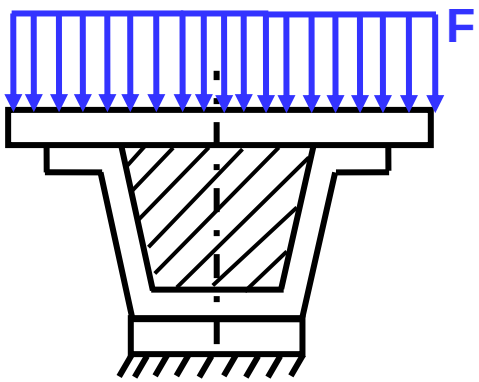




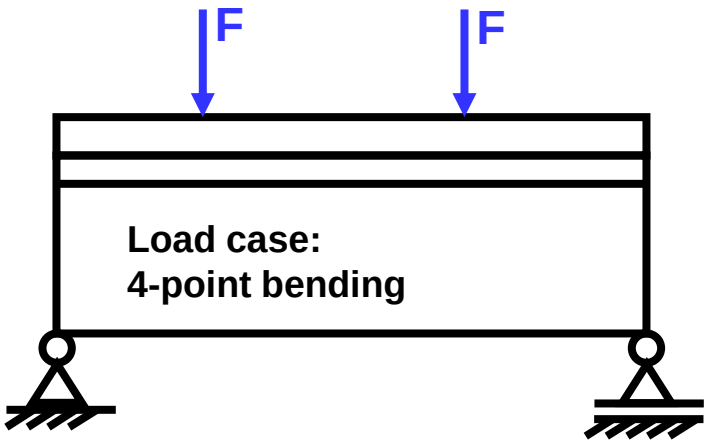
Numerical analysis of hollow and foam-filled A-former

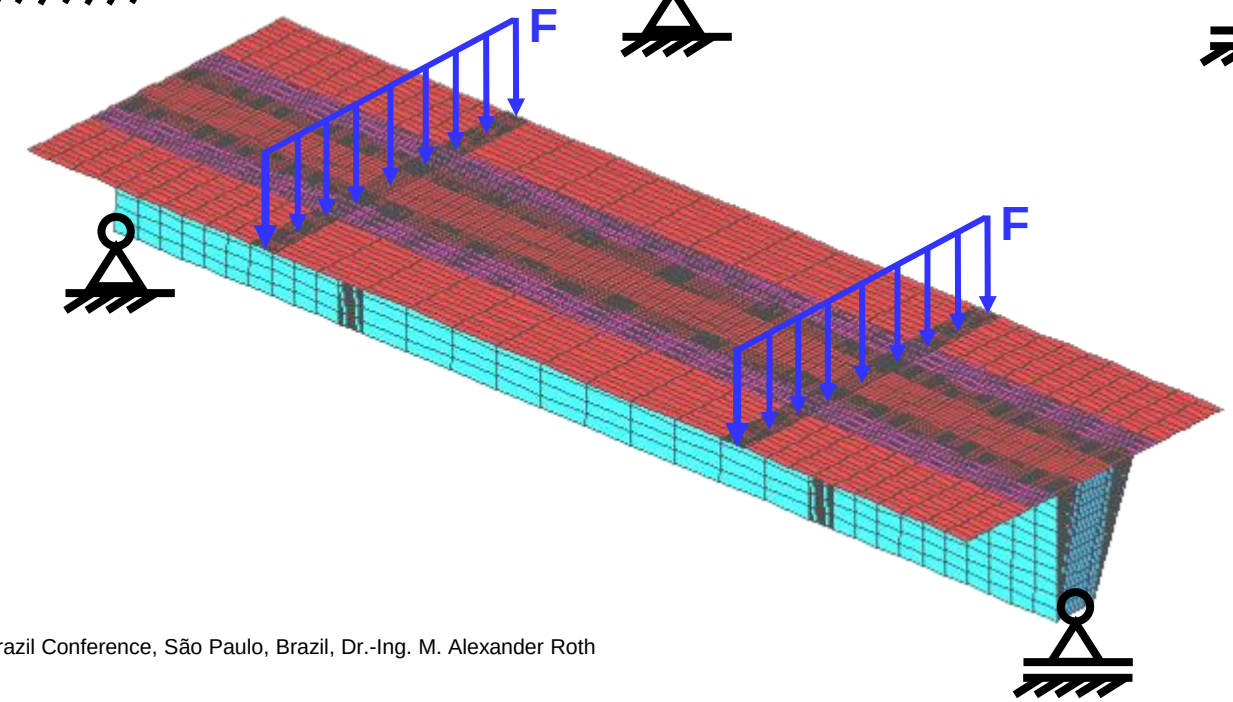
Load case and boundary conditions

front view of load case



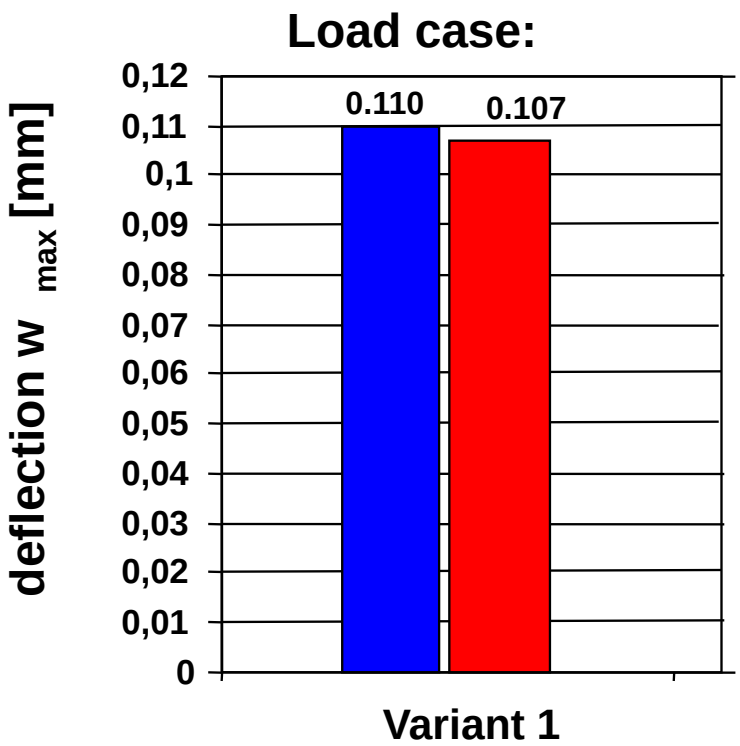
side view of load case





Numerical analysis of hollow and foam-filled A-former

Analysis of the stiffness



Hollow A-former

Foam-filled A-former

percentage increase:

2.8%

Numerical analysis of hollow and foam-filled A-former

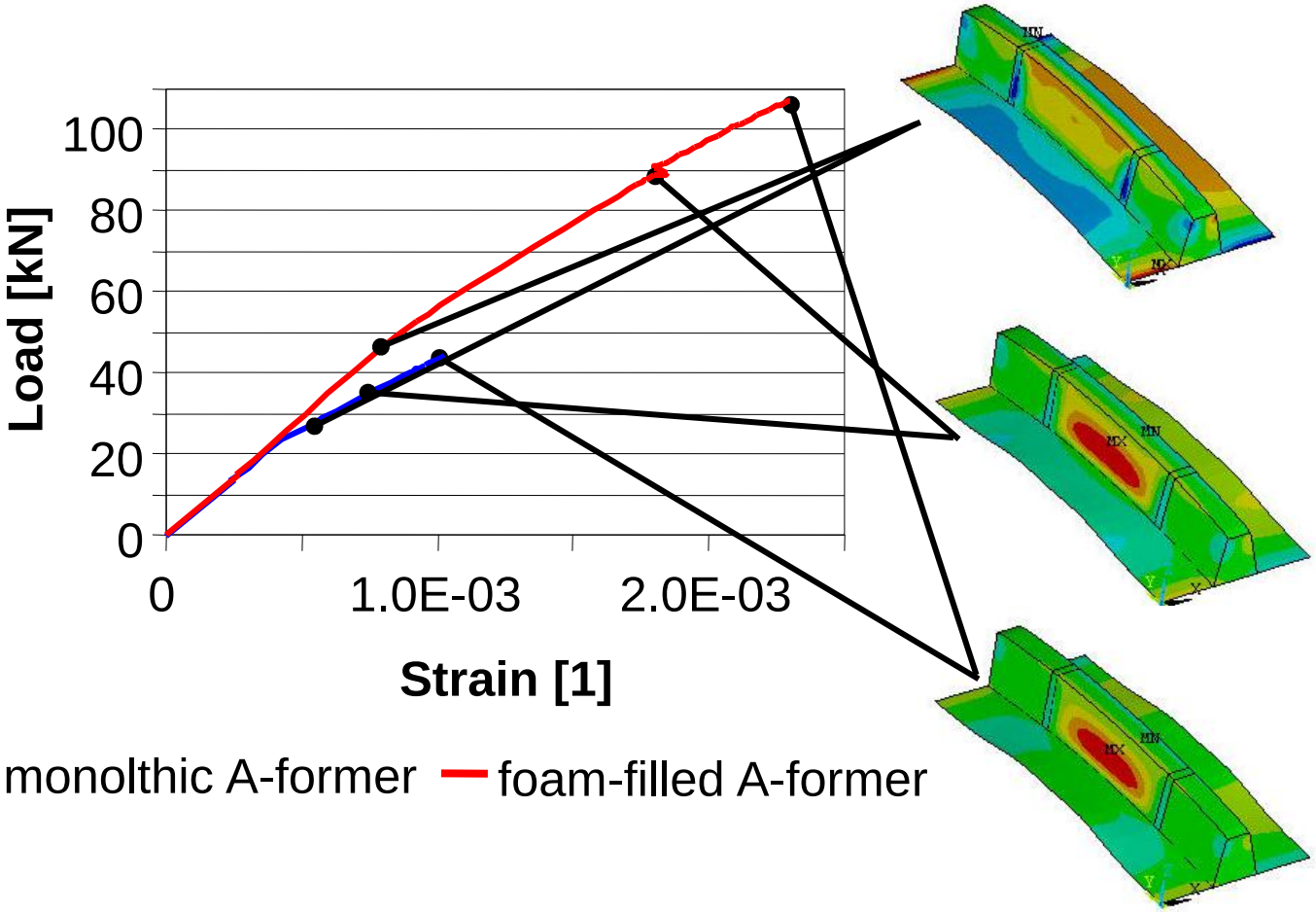
Analysis of the strength according to Tsai-Wu criteria

Variant	Percentage increase of the maximum effort of the CF-EP-laminate by using a foam core to stabilize the thin shell [%]		
	Inner belt of A-former	Web of A-former	Outer belt of A-former & thin shell
1	1.7	**13.6**	1.2

→ Improvements are especially achieved in the web of the A-former.

Numerical analysis of hollow and foam-filled A-former

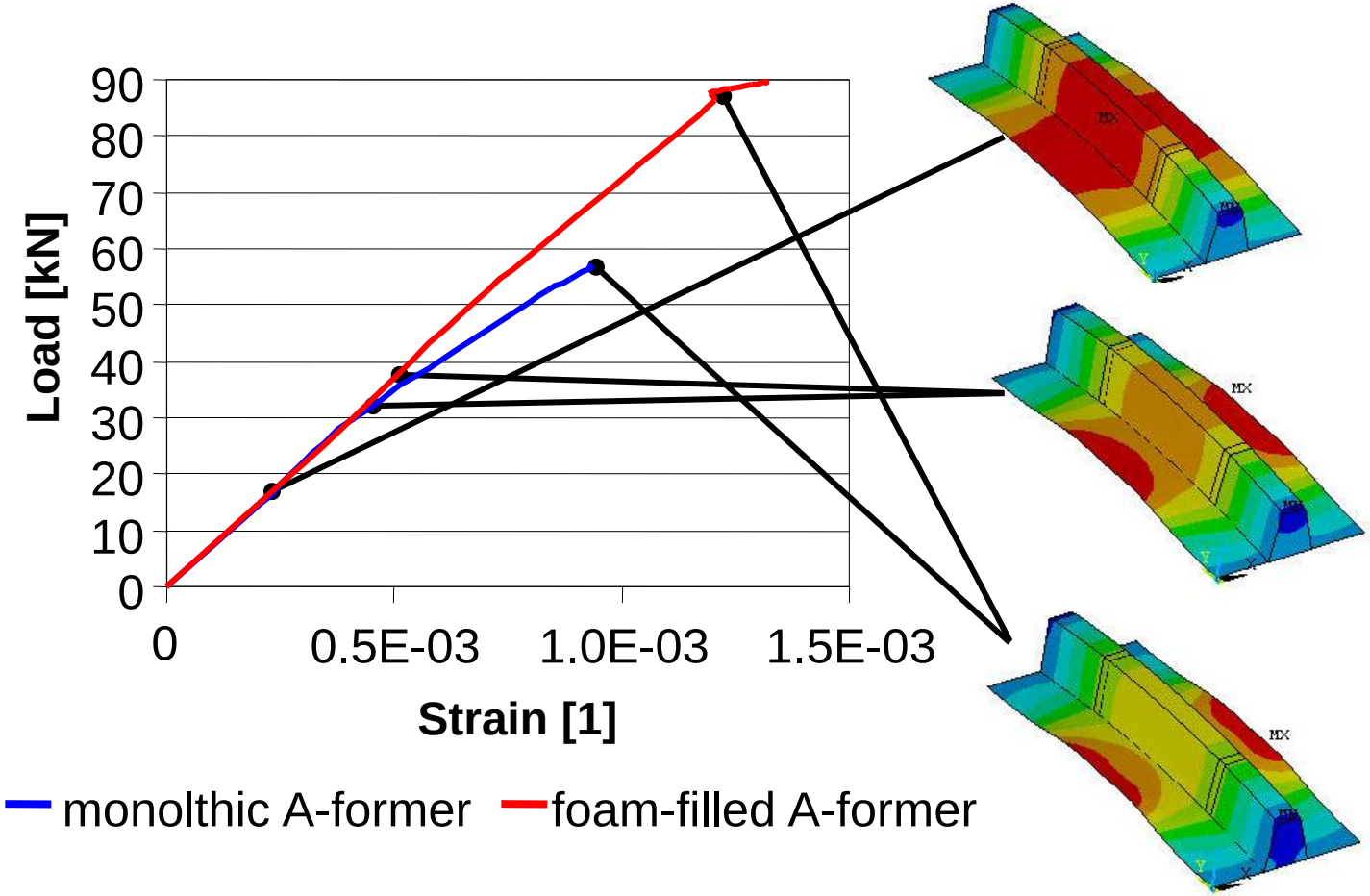
Non-linear buckling analysis: Load-/strain diagram of A-former variant 1/ web



→ Increased buckling load up to <u>69%</u> in the web area of the A-formers by using a PMI-foam to stabilize the thin face sheet.

Numerical analysis of hollow and foam-filled A-former

Non-linear buckling analysis: Load-/strain diagram of A-former variant 1/inner shell



→ Increased buckling load up to <u>10%</u> in the area of the thin shell.

Numerical analysis of hollow and foam-filled A-former

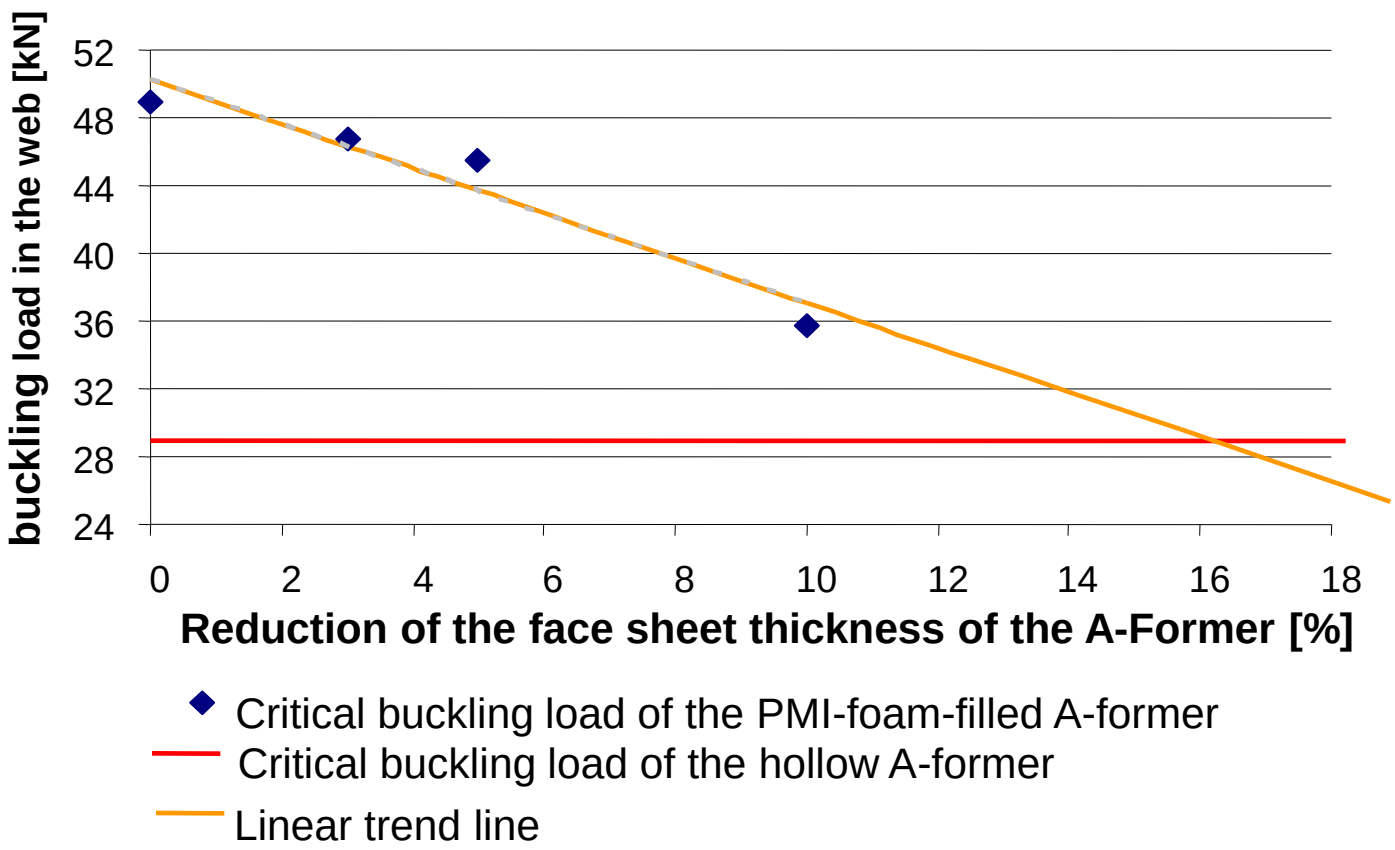
Non-linear buckling analysis

Variant 1	buckling load in the web of the A-former [kN]		
	hollow	foam-filled	Percentage increase [%]
web	28.9	49.0	**69.6**
inner shell	31.7	34.9	**10.1**

→Increased buckling load up to <u>69%</u> in the web area and <u>10%</u> in the inner shell.

Numerical analysis of hollow and foam-filled A-former

Analysis of a complete stiffened thin shell by using a hollow and a foam-filled A-former according to geometry of variant 1



Numerical analysis of hollow and foam-filled A-former

Analysis of a complete stiffened thin shell by using a hollow and a foam-filled A-former according to geometry of variant 1

Findings:

→ Reduction of the laminate thickness of the A-former up to 17% (= 2 layers)

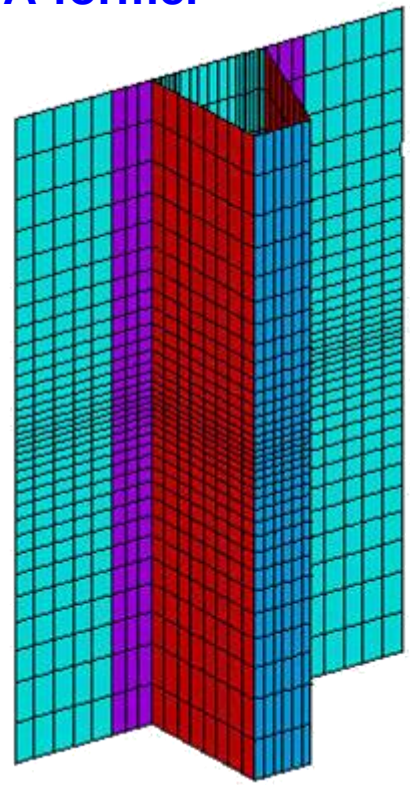
→ Weight reduction of the complete structure up to 9% in comparison to a foam-filled A-former, where the stabilizing effect due to the foam core is not taken into account.

Numerical analysis of hollow and foam-filled A-former

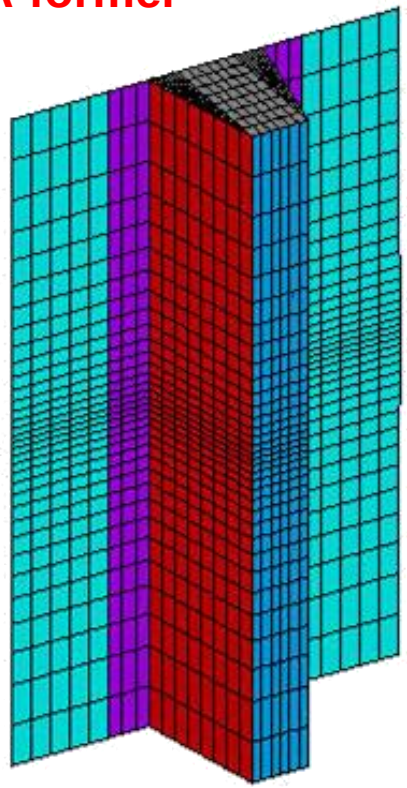
Analysis of axial compression loading

Variants

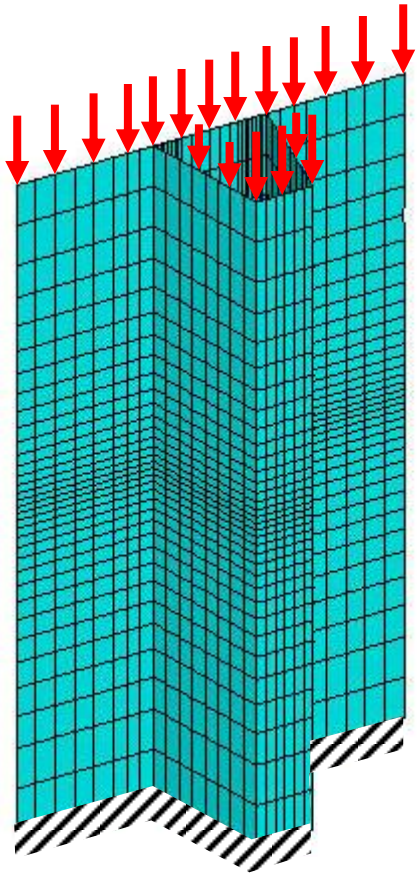
hollow A-former



PMI foam-filled A-former

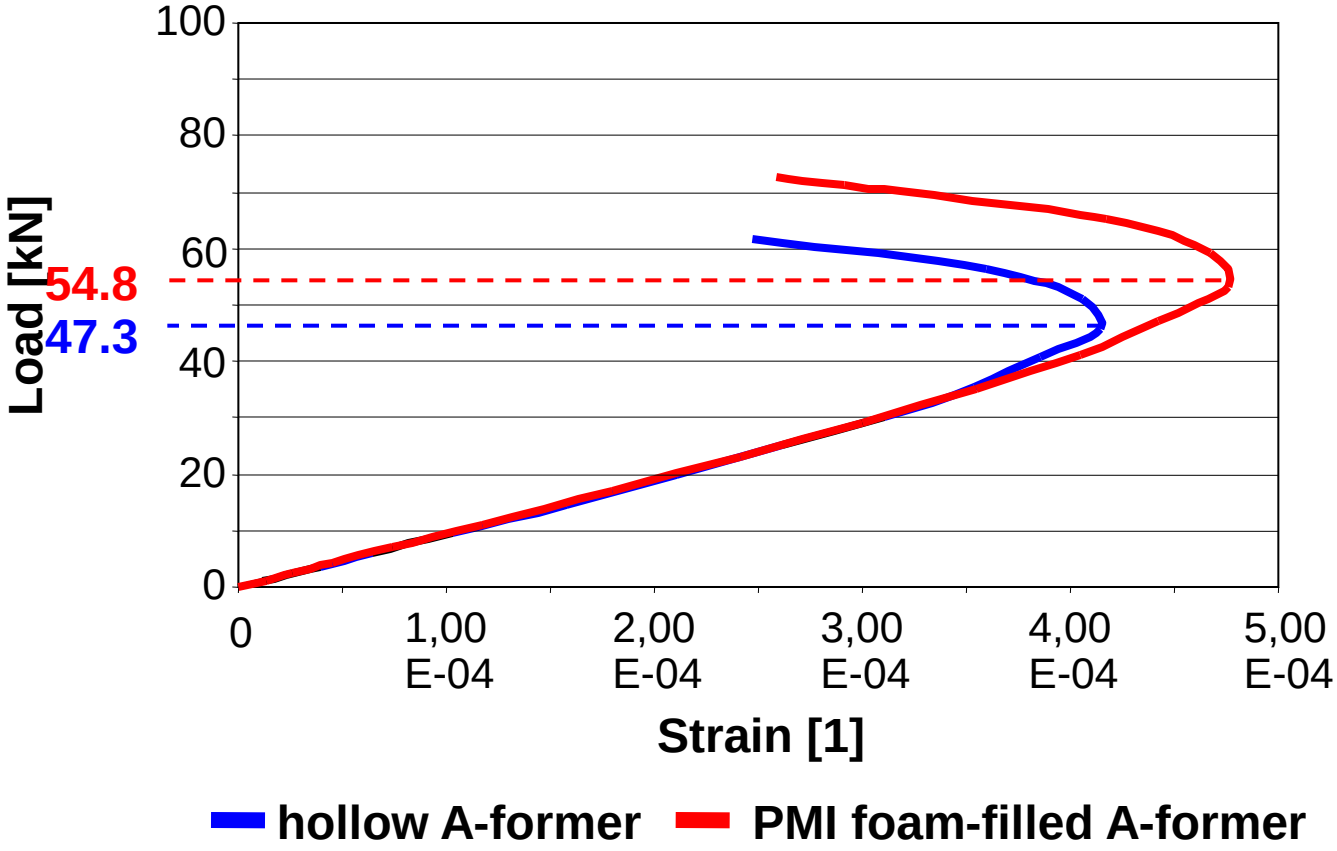


Load Case



Numerical analysis of hollow and foam-filled A-former

Axial compression load analysis



→ Increased buckling load up to <u>16%.</u>

Conclusion

Results of the experimental analysis (Dornier investigation)

- Strength and durability of a carbon epoxy shell can be significantly improved by using an A–former stabilized by a structural ROHACELL® core.
- The ROHACELL® - stabilized structure greatly out-performs the hollow stiffener by far, because the failure caused by stability is moved almost to the yield strength.
- This makes it possible to design the stiffened profile with minimized wall thickness resulting in a significant weight reduction.
- The achievable level of optimization depends on the actual design / geometry of the stiffened profile.
- Breaking load is increased up to 41%
- Stability is increased up to 108%

Conclusion

Results of the numerical analysis

Advantages by using an foam-filled A-former:

- Structural and mechanical advantages regarding buckling effects
- Good laminate quality, good reproduction of the geometry of the A-hat, no dimpling effects, reduced process steps

Findings:

- Increased stiffness up to 5%
- Increased strength up to 18%
- Stabilizing effect of the thin face sheets of the A-former especially in the area of the web due to rigid foam core → Increased buckling load up to 69%
- Due to the stabilizing effect it's possible to reduce the thickness of the A former up to 17% or 2 layers, i. e. decreased weight of the whole structure up to 9%

Conclusion

Final Result:

- The stabilizing effect of the thin face sheets as a result of the foam core have to be taken into account to reduced the **laminate thickness, the weight**, as well as **the production costs** and **production time** of foam-filled A-formers.

Further works:

- Experimental testing of foam-filled and hollow A-formers under 4-point-bending and axial compression loading.
- Validation of the numerical results with the aid of the experimental tests.

Thank you very much for your Attention!!!

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