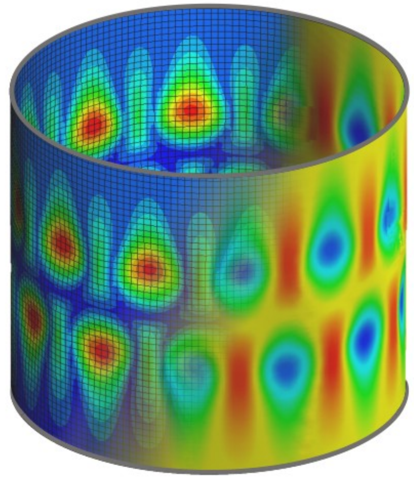
Spring-In – Simulation in Fiber-Composite Manufacturing



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DLR Deutsches Zentrum für Luft- und Raumfahrt e.V. in der Helmholtz-Gemeinschaft

Institute of Composite Structures and Adaptive Systems

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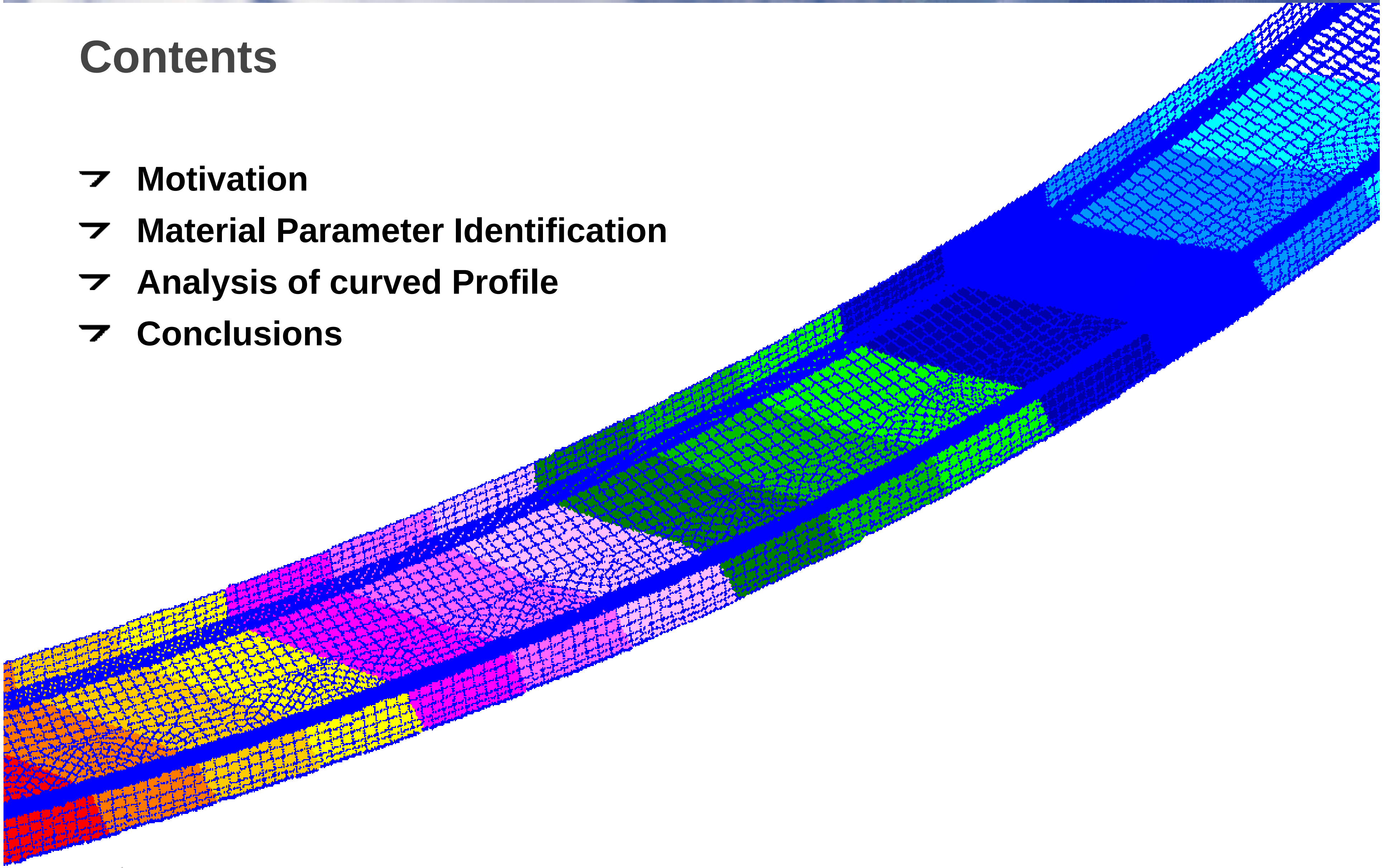


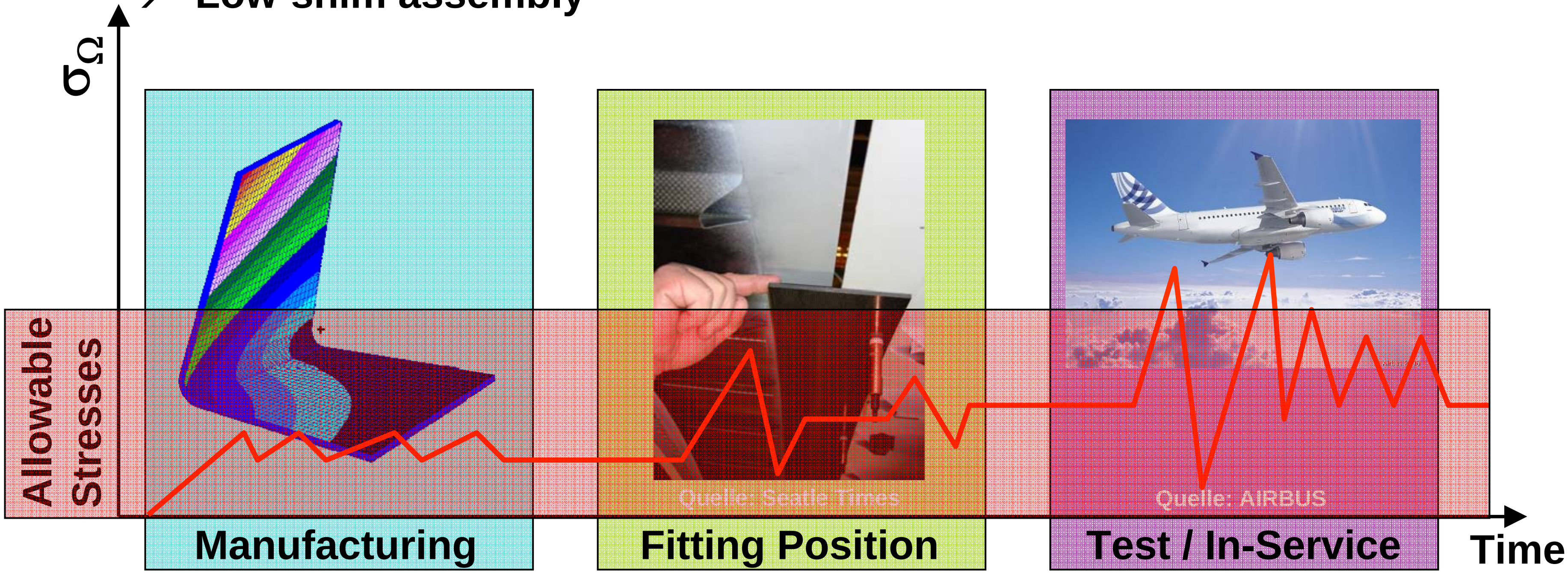
Motivation

- High production rate (≥ 30AC / month)
- Extreme competition on world market (low earnings / AC)
- Part production costs and component assembly costs

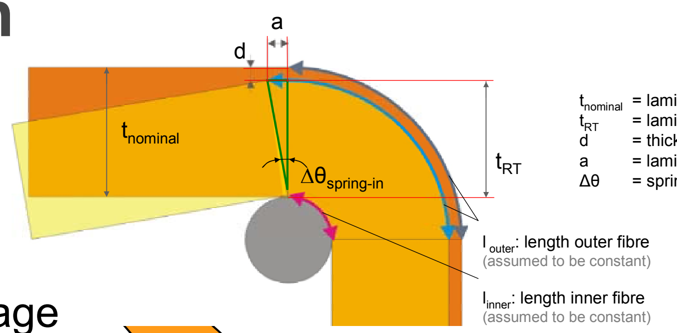
  → **Minimize rejection rate (max. reproducibility)**

  → **Minimize cycle times (optimal usage of technical equipment)**

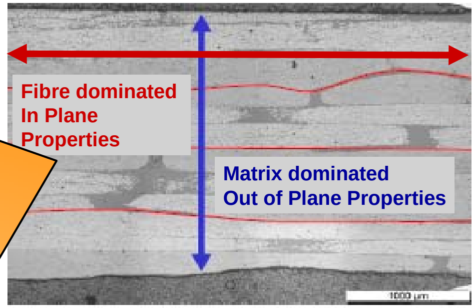
  → **Low-shim assembly**

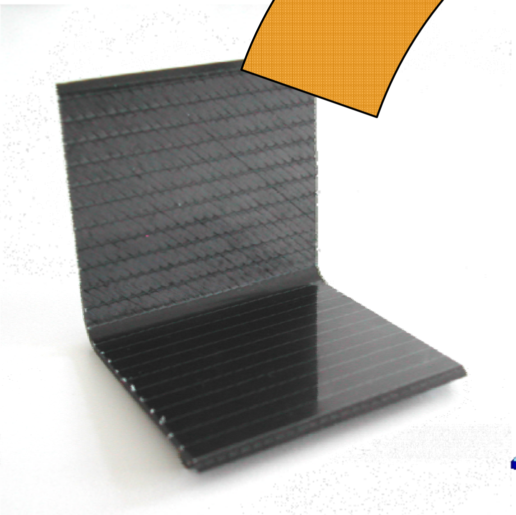


Motivation – General Approach

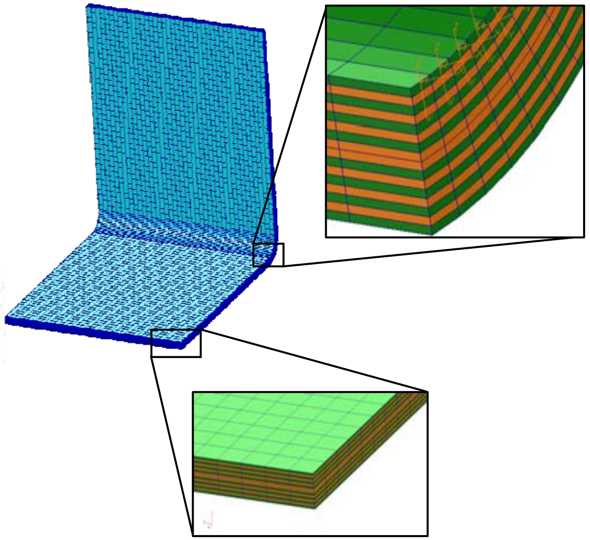


Determination of shrinkage parameters using FEM (Nastran) and test results

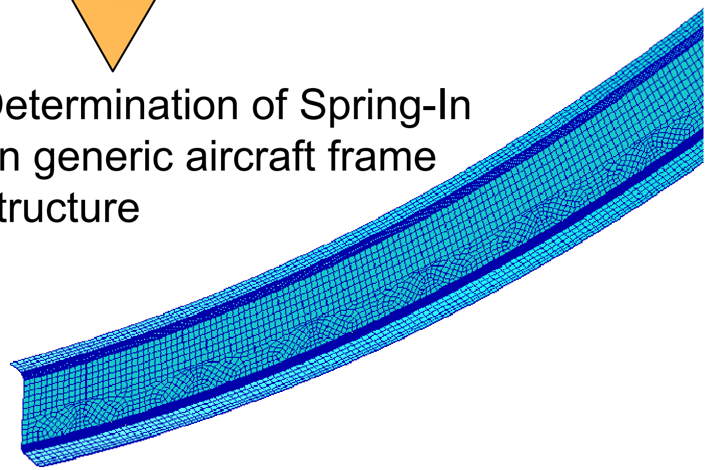




Experimental determination of Spring-in on L-profile under different process cycles



Determination of Spring-In on generic aircraft frame structure

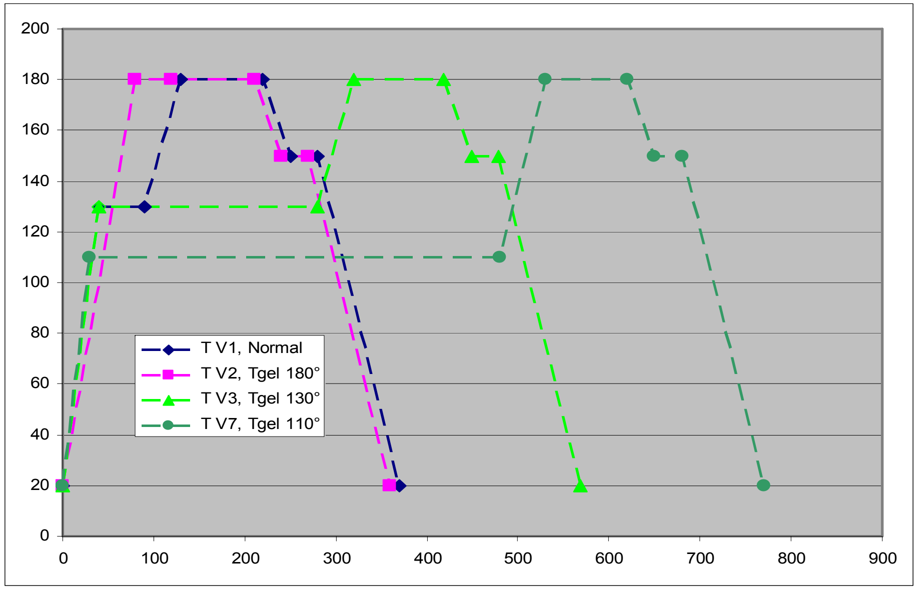


Step 1: Experimental Determination of Spring-In

Invar RTM mould with integrated thermocouples

Reproducable manufacturing using heatable press

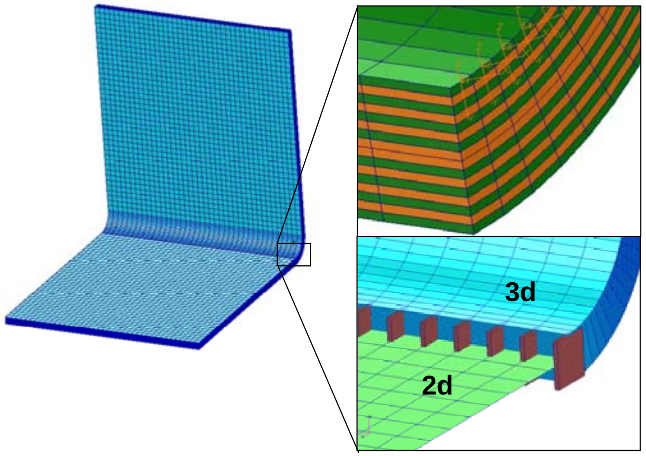
Measurement of spring-in angle



Variation of process parameters (variation of gel point)

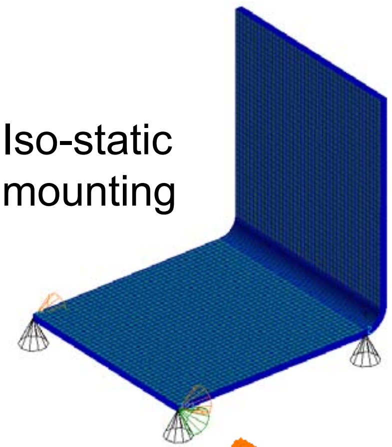
Fiber:	HTS
Matrix:	RTM6
Laminate:	$[4*(\pm45)]_s$

Step 2: Material Parameter Identification

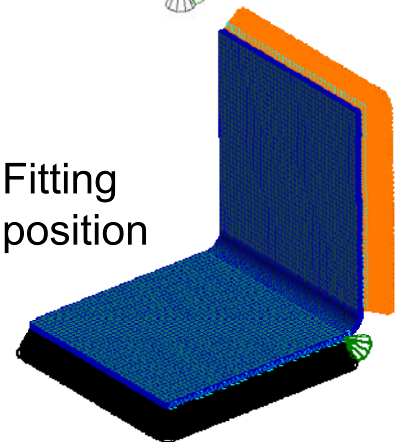


Layerwize modeling with solid elements [HEX8]
(3 elements per single ply)

Iso-static mounting



Fitting position

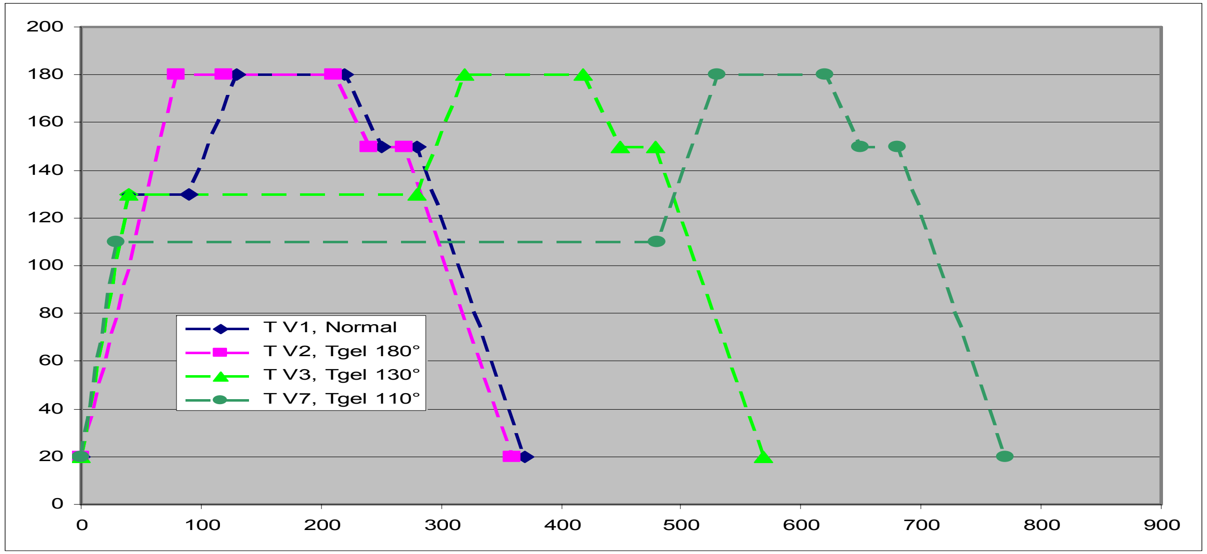


Determination of **modified CTE** of a unidirectional single ply

1. α_F =const, α_M adjusted $\alpha_M = \alpha_{MT} + \alpha_{MC}$
2. Calculation of homogenized properties of unidirectional single ply using ESAComp3.4
3. Linear-static FEM simulation of L-profile with modified CTE of unidirectional single plies
4. Matching with experimentally determined Spring-In angles by variation of α_{MC}
5. Validation analyses for different fiber-volume-fractions

Step 2: Material Parameter Identification

1. Variation of fiber-CTE α_{F11} from literature survey leads to negligible changes of the Spring-In angle



2. Matching with experimental results for minimal Spring-In

3. Matrix CTE α_{MT} through parameter variation (assumption: thermal part only)

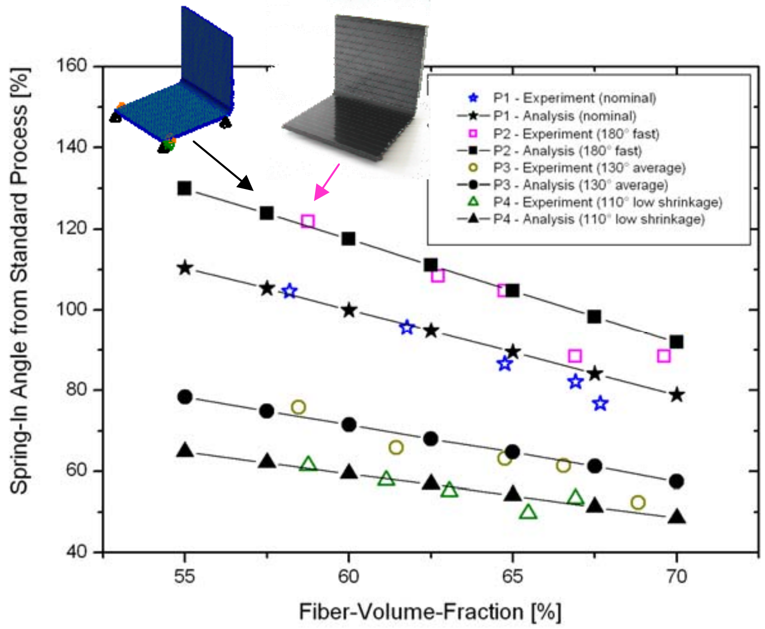
α_{F11}	α_M	Disp. [mm]	Disp. at x_1 [mm]	Disp. at x_2 [mm]	Δx [mm]	β [deg]
$-0.38\cdot10^{-6}$	$40.0\cdot10^{-6}$	0.590	0.0473	0.5828	0.5355	0.495
$-0.38\cdot10^{-6}$	$50.0\cdot10^{-6}$	0.704	0.0574	0.6957	0.6383	0.590
$-0.38\cdot10^{-6}$	$57.2\cdot10^{-6}$	0.786	0.0646	0.7765	0.7719	0.658
$-0.38\cdot10^{-6}$	$62.0\cdot10^{-6}$	0.841	0.0694	0.8310	0.7616	0.704
$-0.38\cdot10^{-6}$	$69.0\cdot10^{-6}$	0.921	0.0765	0.9100	0.8335	0.770
$-0.38\cdot10^{-6}$	$80.0\cdot10^{-6}$	1.047	0.0876	1.0340	0.9464	0.875

Step 2: Material Parameter Identification

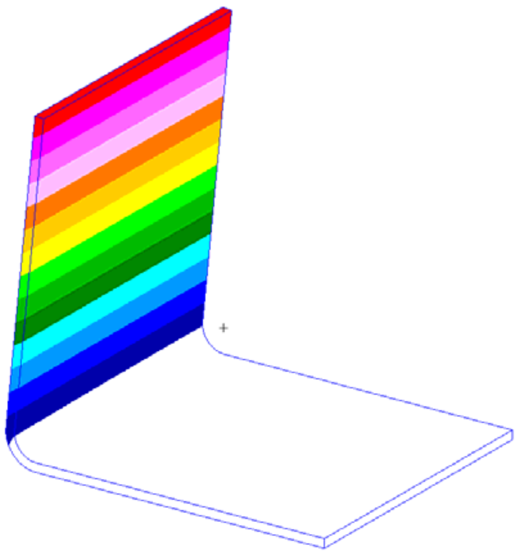
- Good correlation between experimental results and analysis for the different fiber-volume-fractions

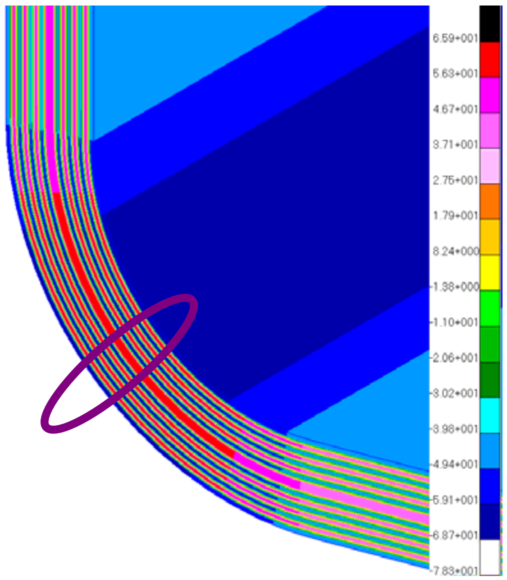
- Analytical results lead to lower Spring-In angles

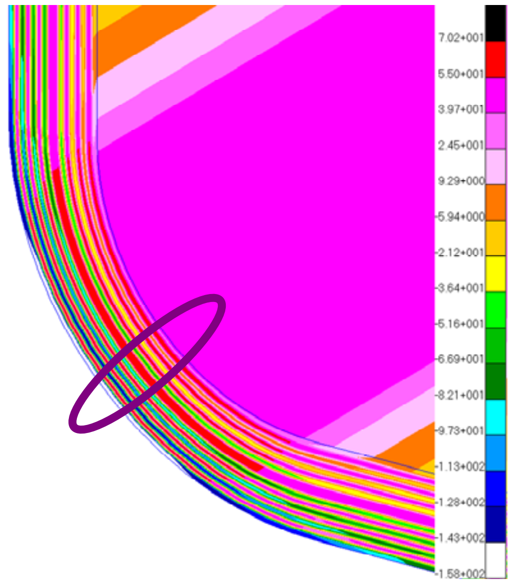
$$\Delta\theta = \theta \cdot \left[\frac{(\alpha_T - \alpha_R) \cdot \Delta T}{1 + \alpha_R \cdot \Delta T} \right]$$



Step 2: Material Parameter Identification







Displacements in iso-static mounting

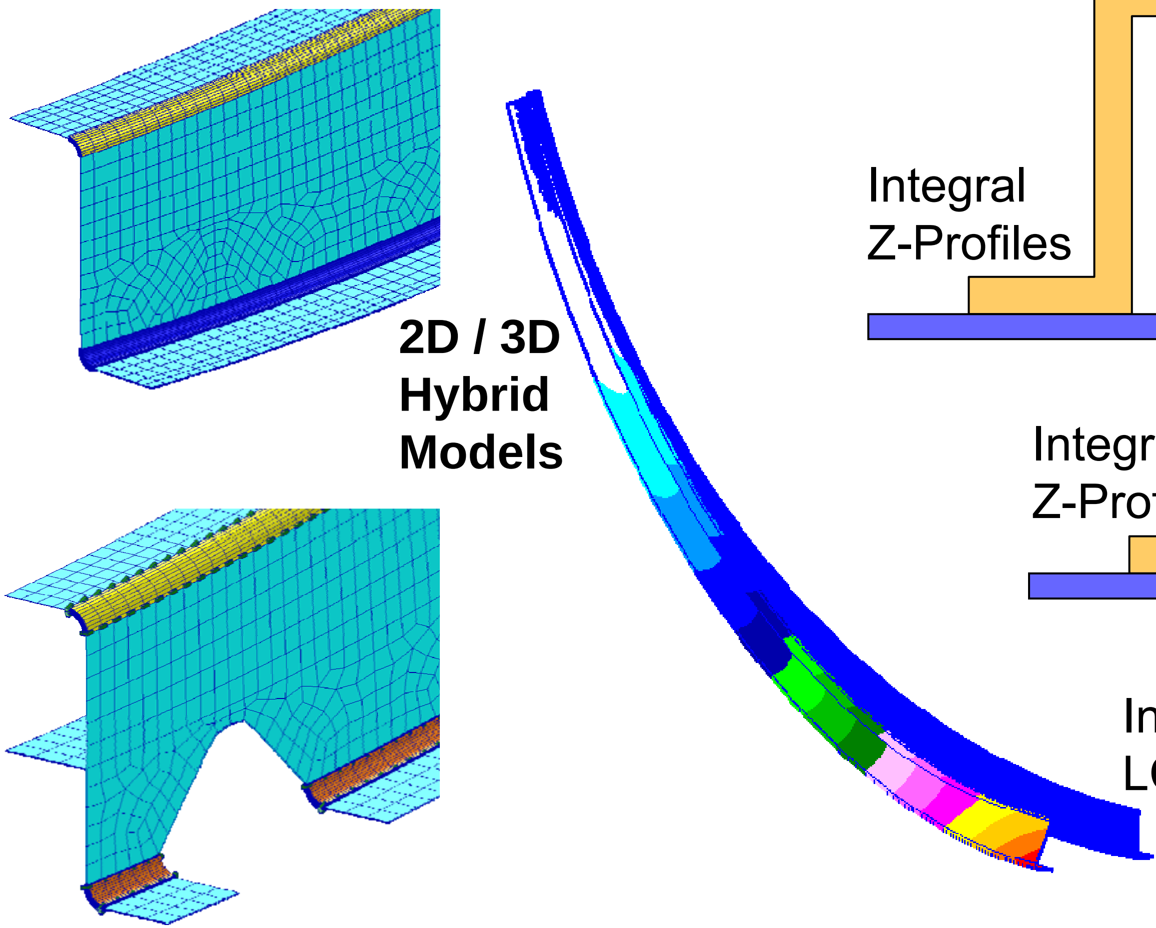
Stresses under iso-static mounting

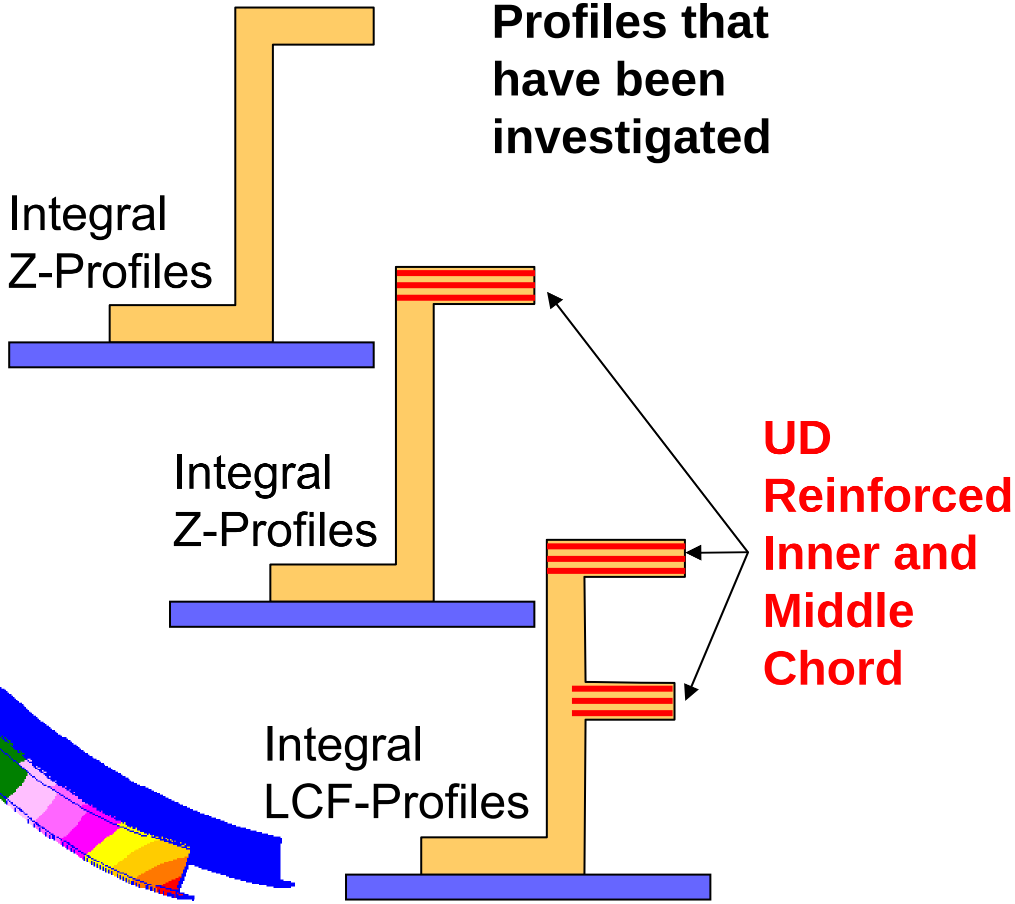
Max. Pressure: -68 N/mm²
Max. Tension: +68 N/mm²

Stresses in fitted position

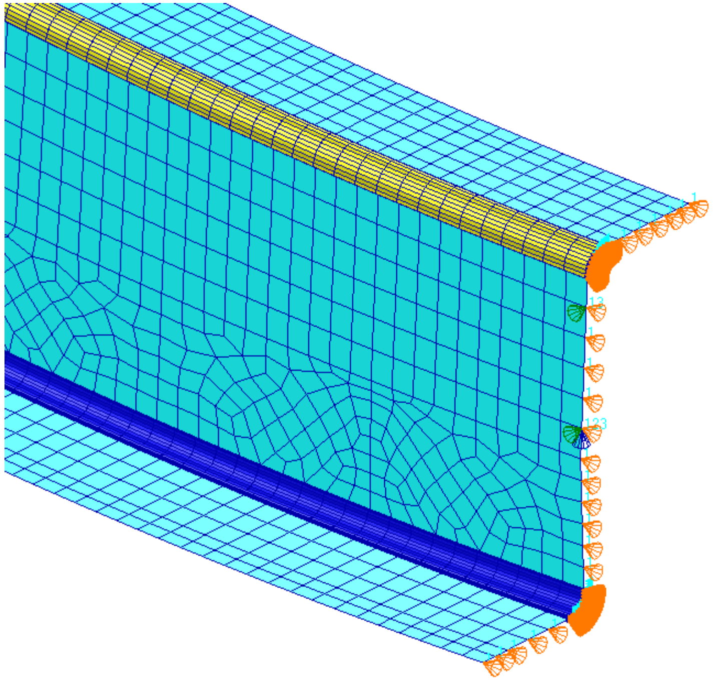
Max. Pressure: -158 N/mm²
Max. Tension: +70 N/mm²

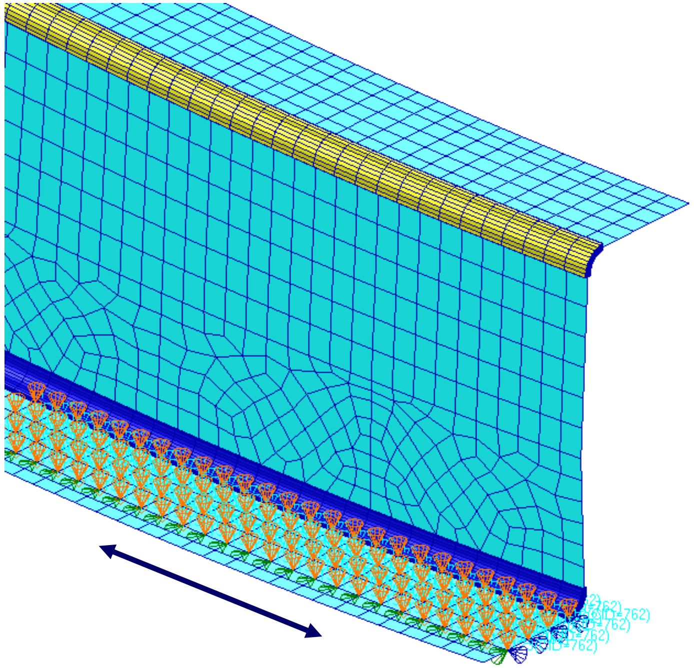
Step 3: Profile Analysis





Step 3: Profile Analysis – Boundary Conditions





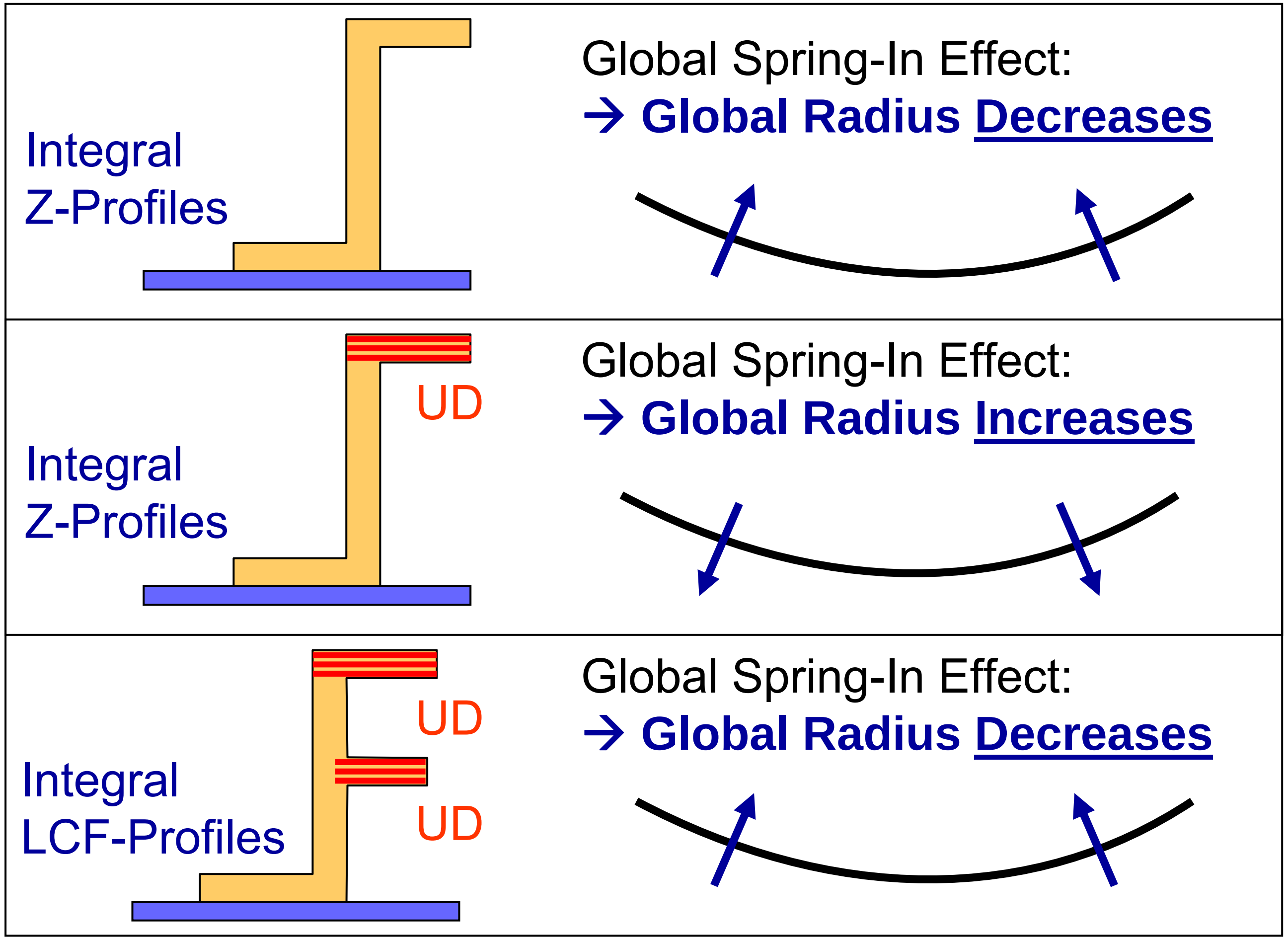
Iso-static mounting on free edge

→ Global Spring-In angle
→ Residual stress analysis

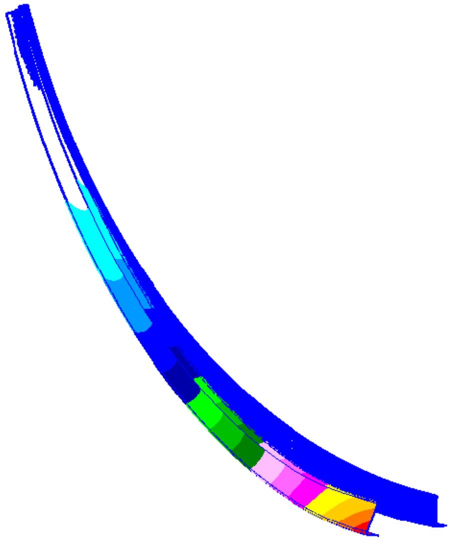
Mounted in fitting position

→ Stress analysis

Step 3: Profile Analysis – Simulation Results



Step 3: Z-Profile Analysis – Displacements and Stresses



Nominal frame radius r_{nom} = 1975.0mm
Measured radius r_{mes} = 1963.5mm

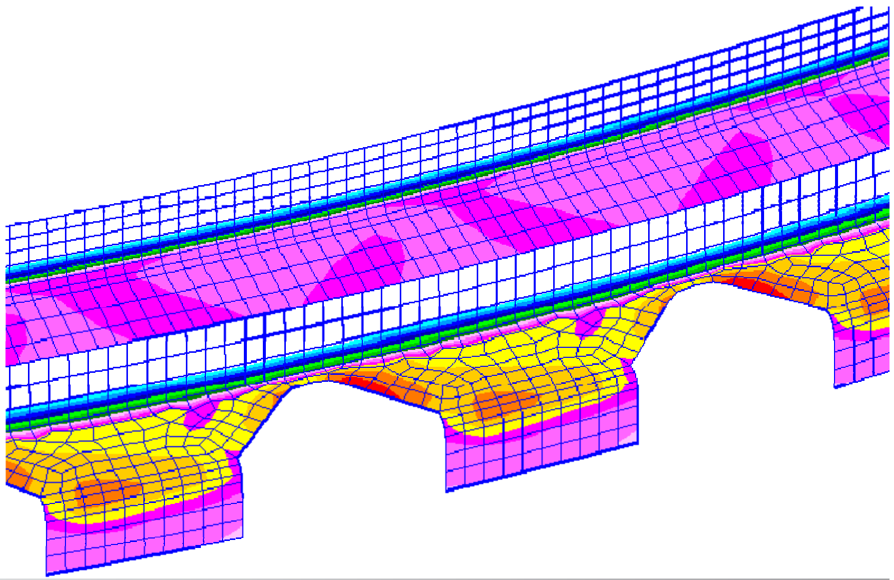
Process	P1	P2	P3	P4
Global Radius	1964.5	1963.0	1967.1	1968.9

→ Good agreement with measured global radius

Stresses:

Process	P1	P2
Fiber Stresses Chords [Mpa]	-63 – 33	-125 – 65
Fiber Stresses Frame [Mpa]	-33 – 53	-65 – 102
Matrix Stresses [MPa]	30 – 34	58 – 70

→ No significant changes of stresses in fitting position



Conclusions

Spring-In deformation is highly dependent on gel-temperature and fibre-volume-fraction

→ **Reproducible process conditions required for cost effective, high precision manufacturing**

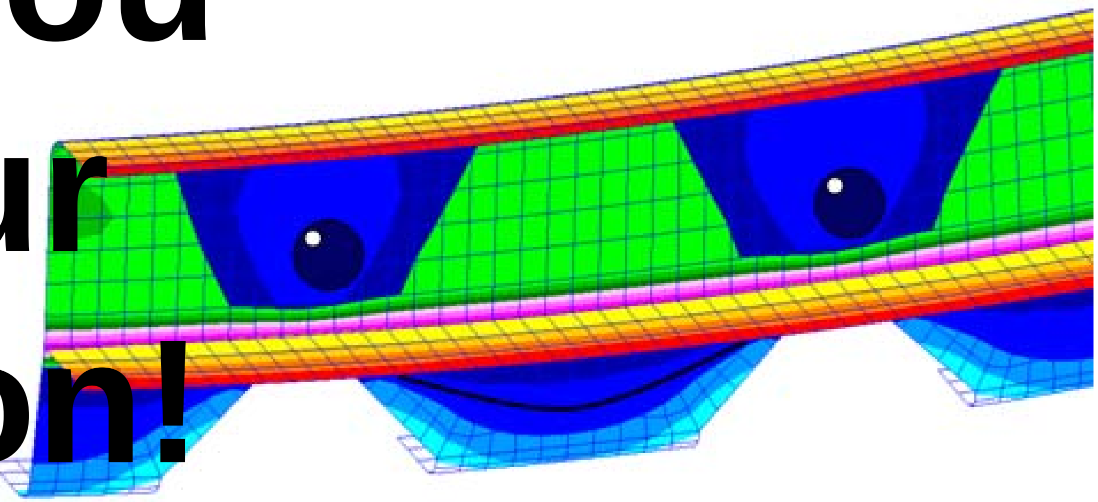
Simple L-shaped coupons can be used to investigate the Spring-In behaviour of complex composite structures

→ **Realisation of Spring-In compensated manufacturing moulds possible**

Lower gel-temperatures lead to reduced Spring-In angles but also increase cycle times significantly

→ **Reduced Spring-In angles indicate a lower stress level in the laminate**

Thank you for your attention!



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