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Numerical prediction and experimental analysis of the buckling loads of SMPC cylindrical shells

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SMPC cylindrical shell

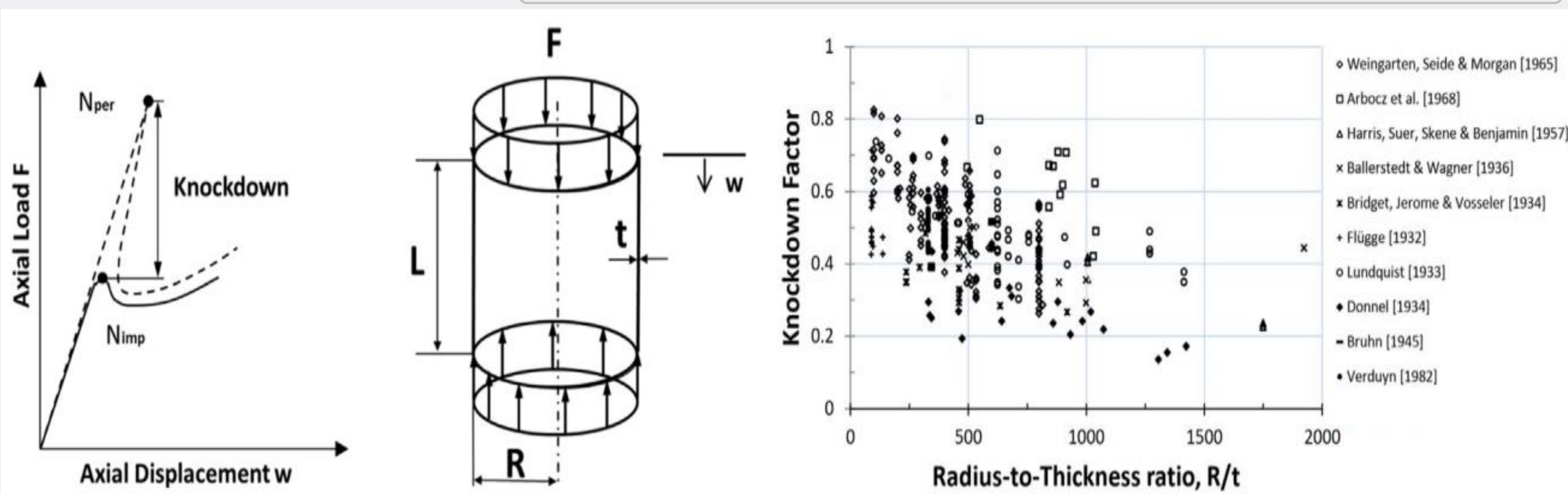
- Shape Memory Polymer Composite (SMPC) is a kind of smart material with shape memory effect and excellent mechanical properties, which make it increasingly irreplaceable in functional integrated components of aerospace structures

Imperfections

- Geometric
- loading
- material

KDF: the ratio of the maximum axial load-bearing capacity of a cylindrical shell in practical applications to its theoretical critical buckling load

NASA (cylindrical shell): $\mathrm{KDF} = 1 - 0.901 \times \left(1 - e^{-\sqrt{R/t}/16}\right)$

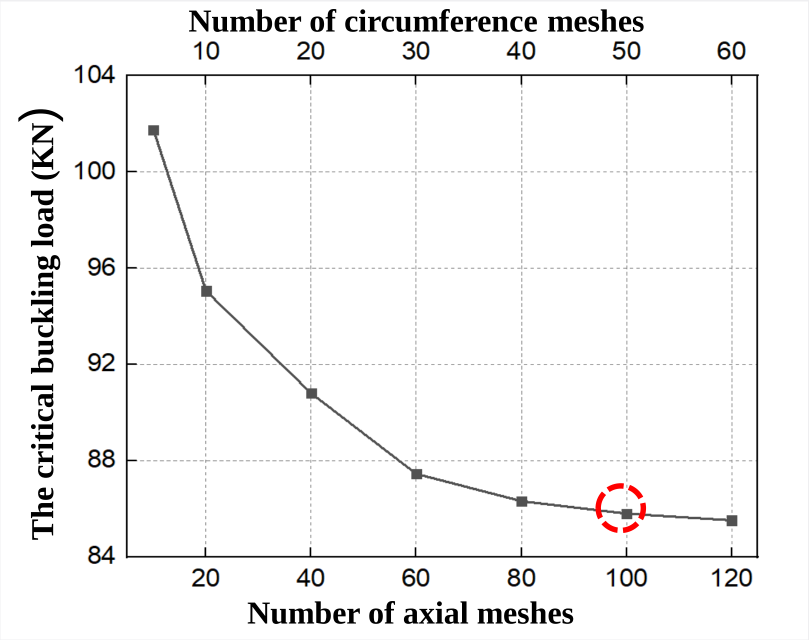


Load-displacement curve and KDF of cylindrical shell

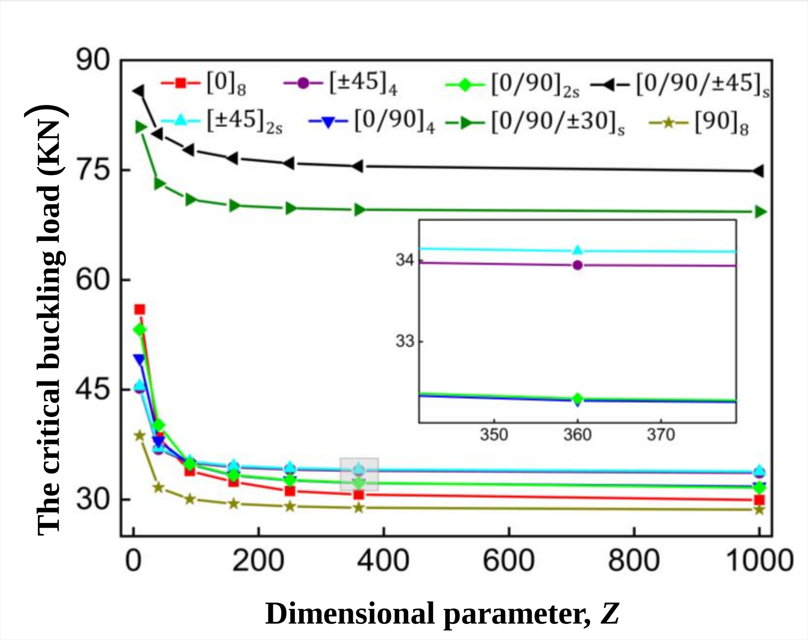
H Wagner, C Huhne, et al. Thin-Walled Structure, 2018, 127: 629-45.

Parameter study of the finite element model

- **Key parameters, such as the overall size, fiber stacking configurations and mesh size should be first determined before the subsequent nonlinear finite element analyses and experiments**
- **Dimensional parameter** $Z = 0.6L^2/Rh$



The mesh convergence study

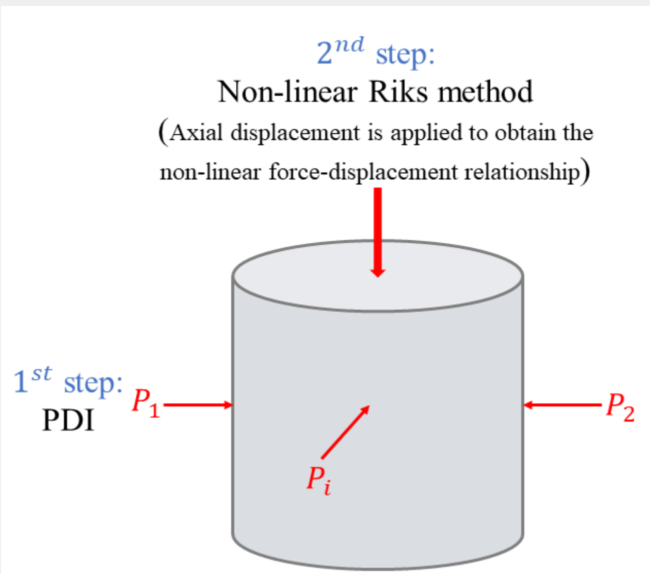


The critical buckling loads as a function of Z

- Z =90
- Fiber stacking configuration $[0/90/\pm 45]_2$

Numerical simulations

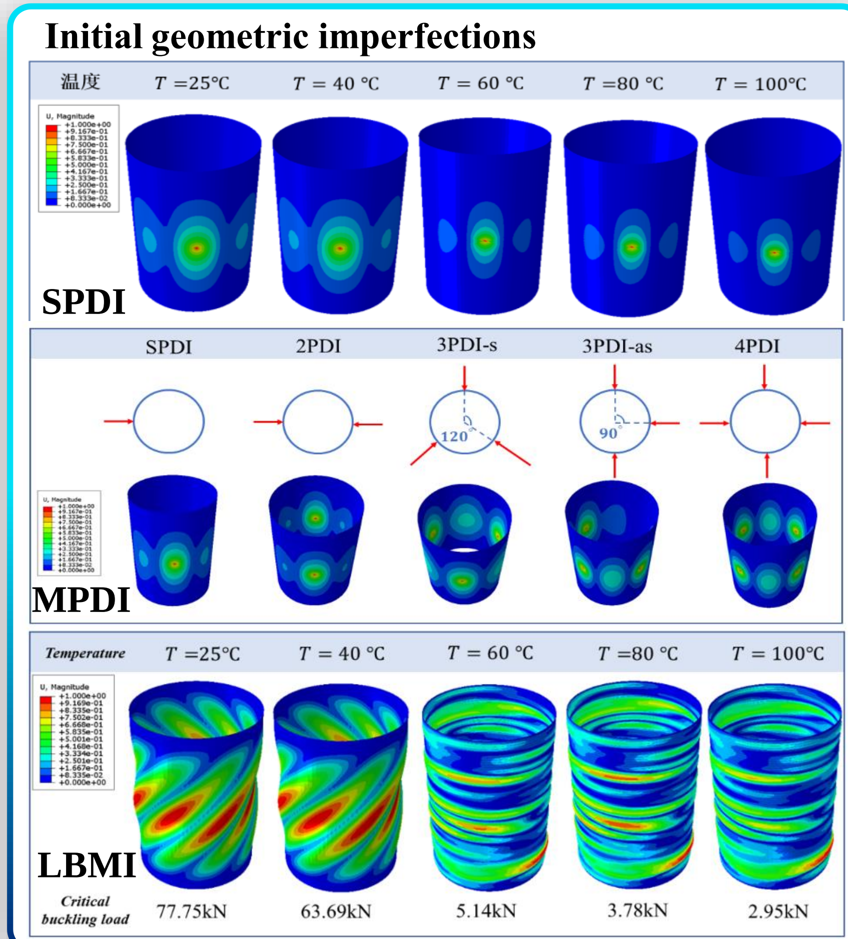
- **The single perturbation displacement imperfection (SPDI), multiple perturbation displacement imperfection (MPDI) and linear buckling mode imperfection (LBMI) techniques are introduced to verify the geometric imperfection sensitivities of SMPC cylindrical shells**



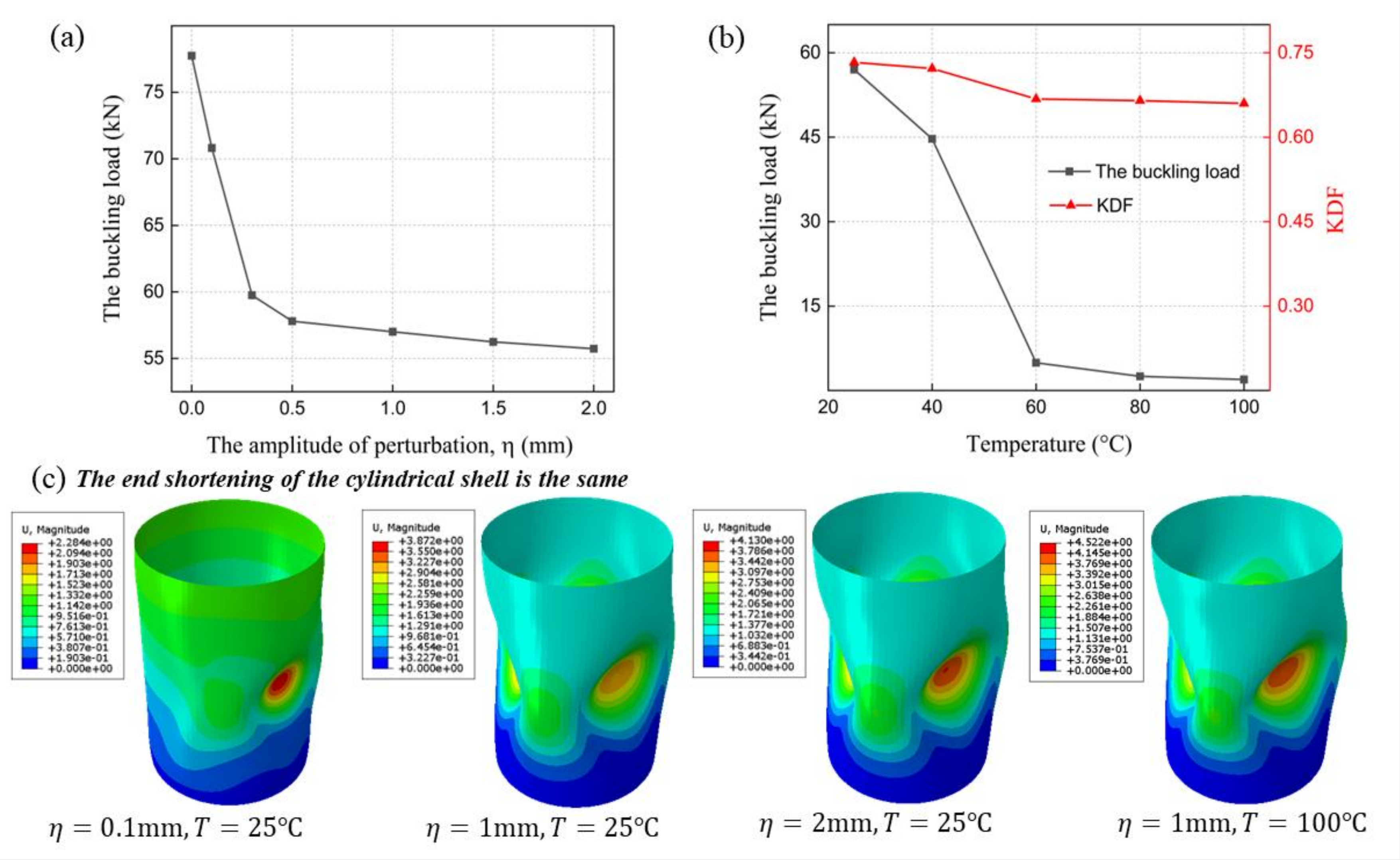
The basic ideas of SPDI and MPDI techniques

- The geometrical imperfections are not localized in the axial direction, and the shapes of initial geometric imperfections are independent of temperature.

PDI → **Linear buckling mode** → **LBMI**



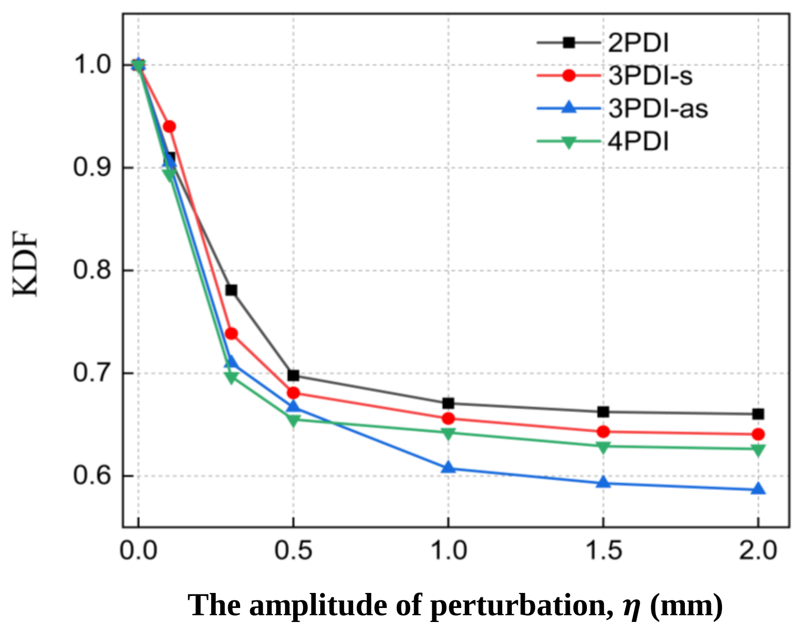
SPDI technique

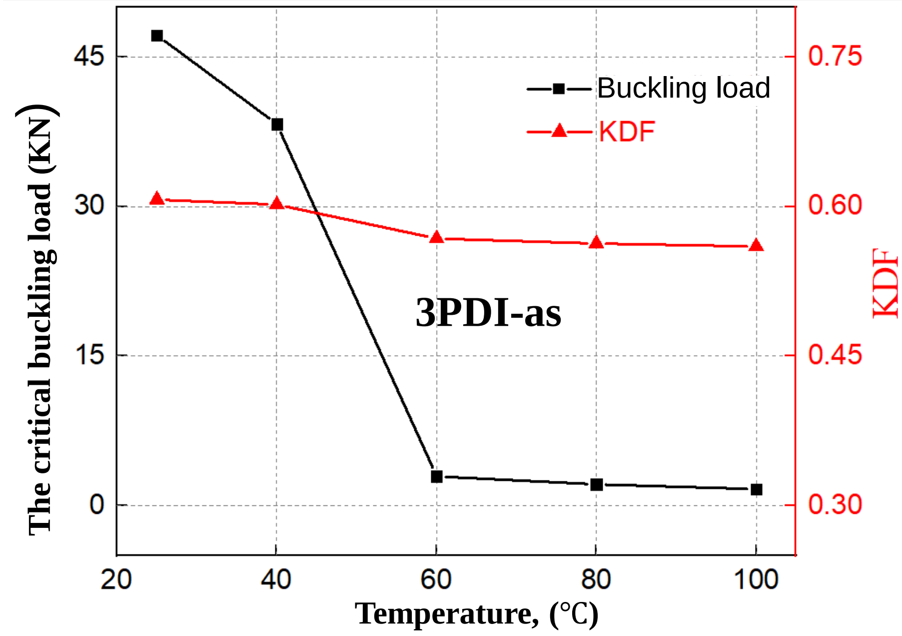


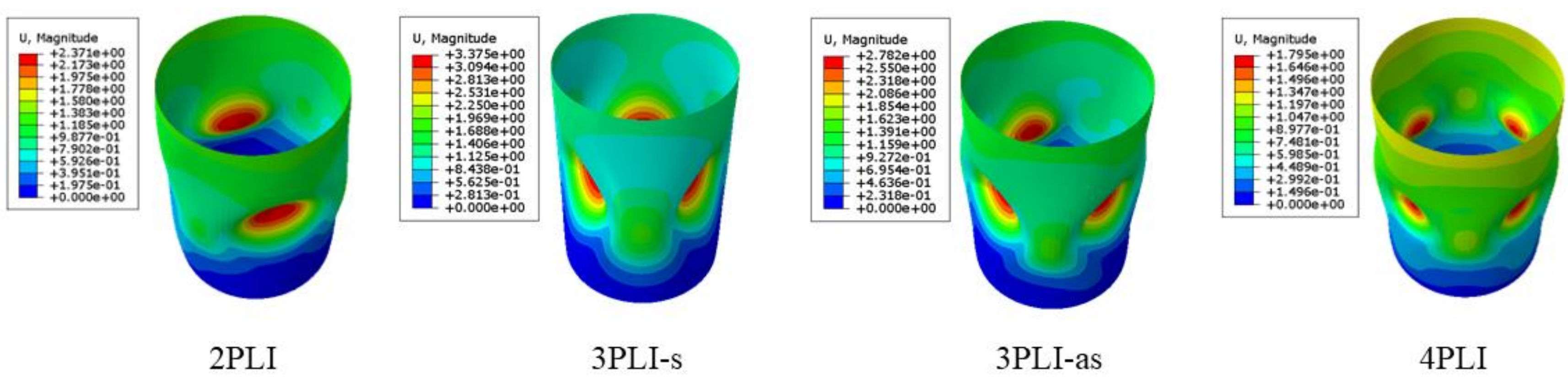
The results of the SPDI method

- ➢ $\eta = 1$ mm
- ➢ The buckling loads are sensitive to temperature
- ➢ The post-buckling patterns and KDFs are insensitive to temperature

MPDI technique



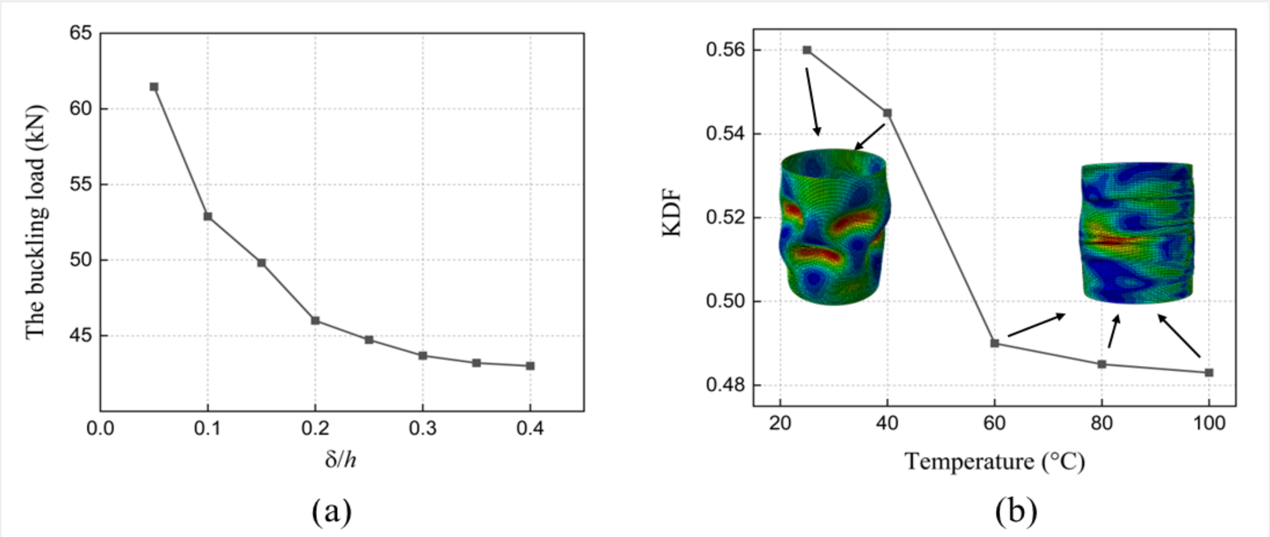




The results of the SPDI method

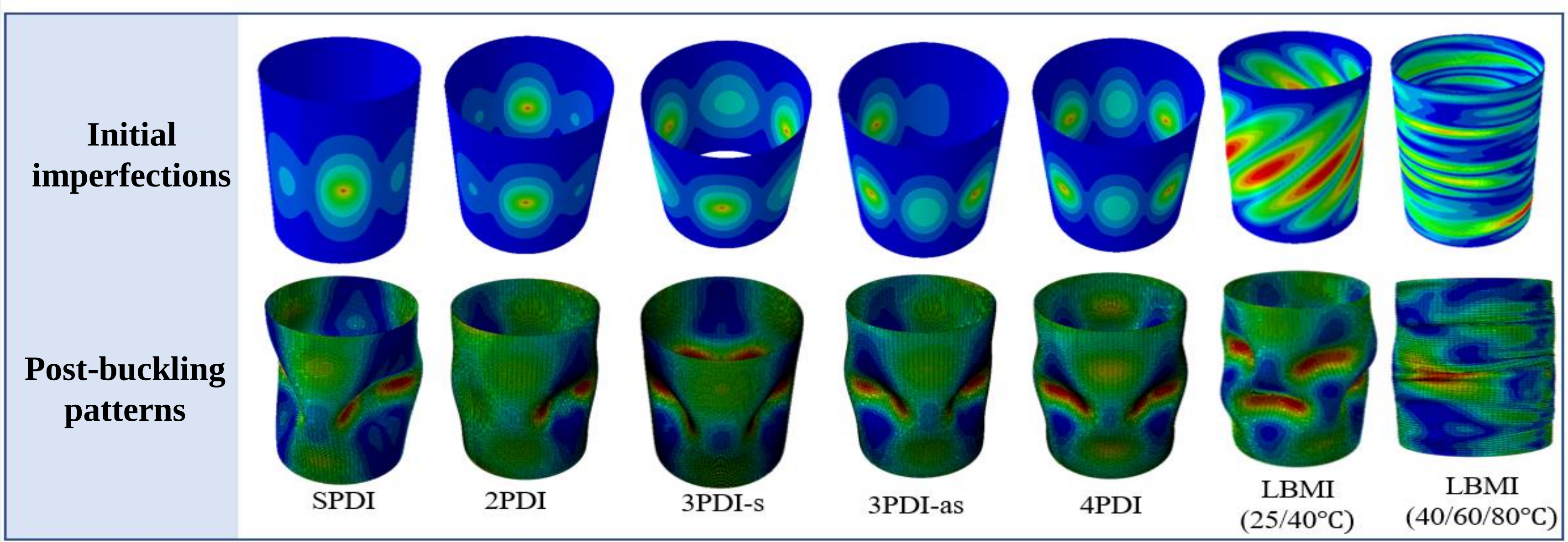
- $\eta = 1$ mm
- MPDI will be represented by 3PDI-as

LBMI technique



The results of the LBMI method

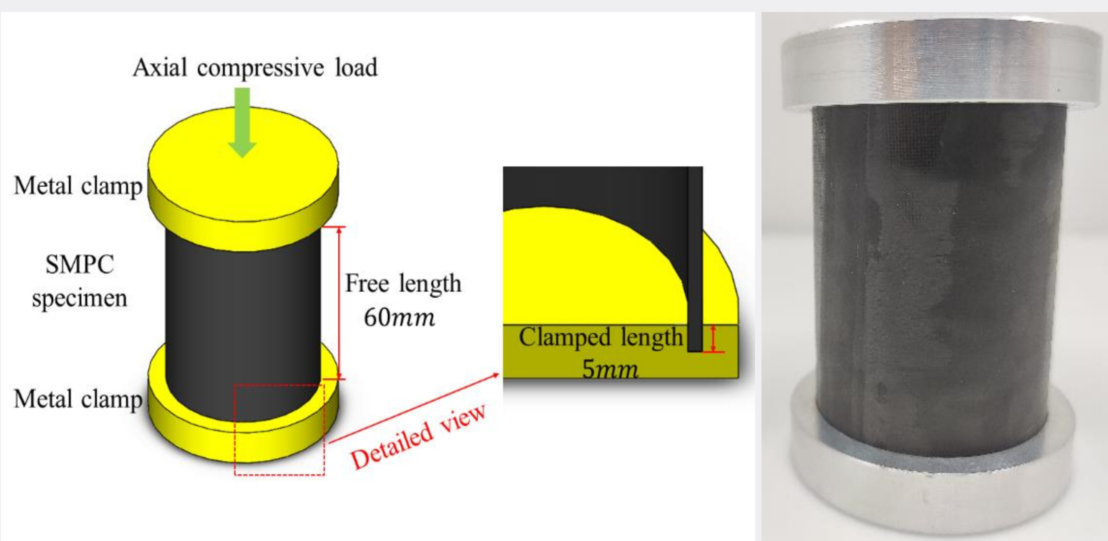
- Scaling factor is 0.3
- The geometrical imperfections are localized in the axial direction



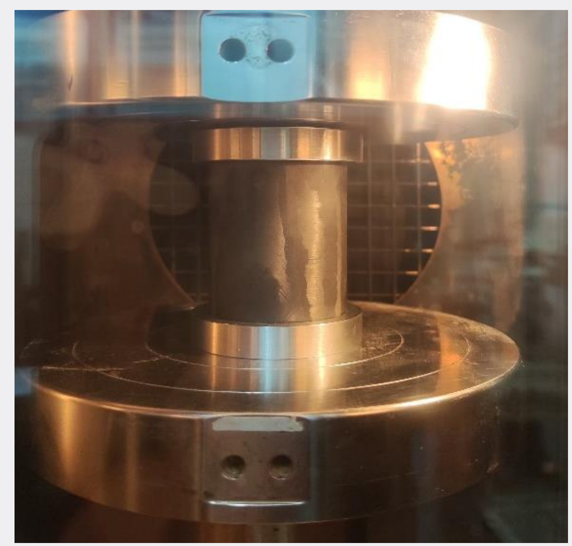
Buckling tests under axial compression

- Autoclave molding
- $[0/90/\pm45]_2$
- Diameter is 40 mm, free length is 60 mm
- Isothermal buckling tests of SMPC cylindrical shells under axial compression

The fabrication of SMPC cylindrical shells



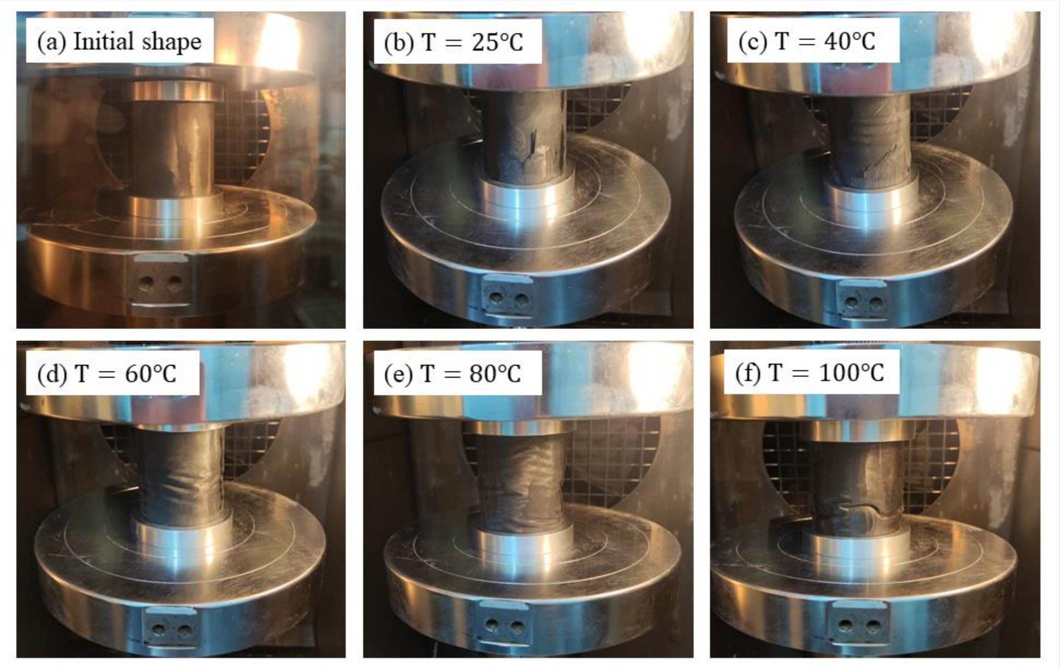
Specimen of SMPC cylindrical shell



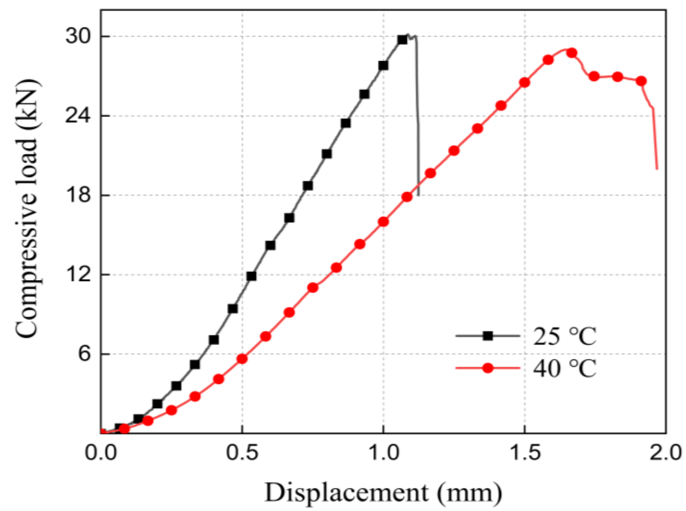
Axial compressive test

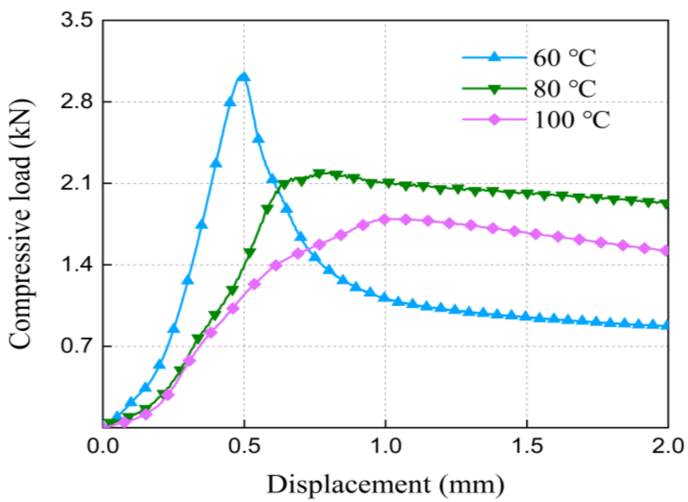
Results of experimental and numerical analyses

- At low temperatures (25 ℃ and 40 ℃), the SMPC cylindrical shell is more prone to brittle fracture than buckling deformation
- At high temperatures (60 ℃, 80 ℃ and 100 ℃), the SMPC cylindrical shell buckles before being destroyed



The initial shape and deformation morphologies

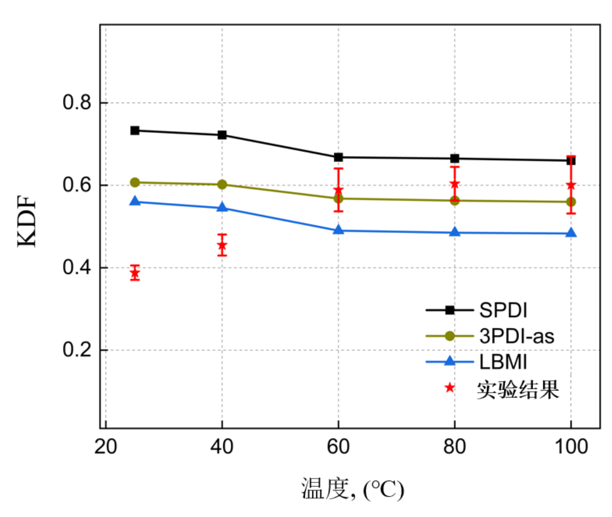




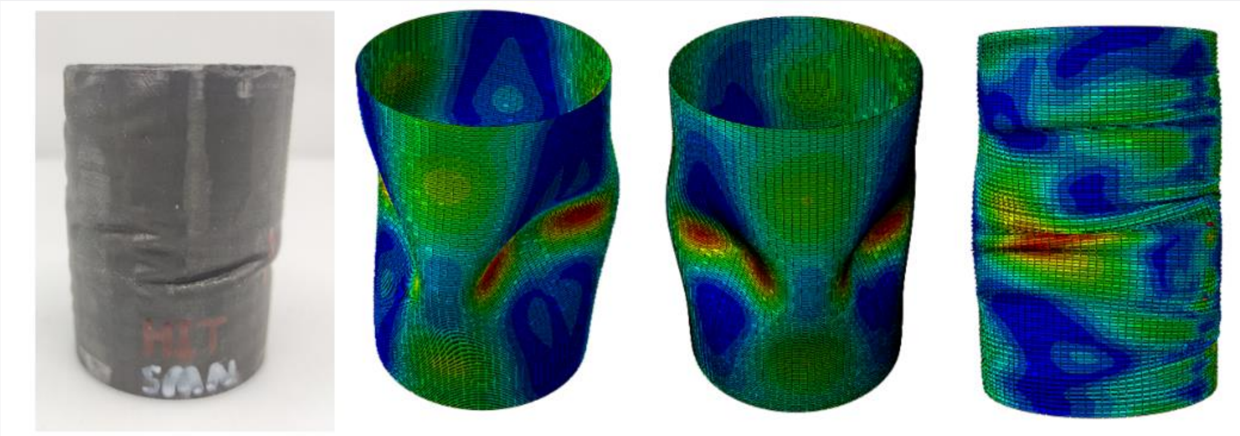
The axial compressive load–displacement curves

Conclusions

- In the low-temperature region, all three imperfection methods overestimate the load-bearing capacity and KDF
- In the high-temperature region, the SPDI method overestimates the KDFs; the KDFs calculated by the MPDI and LBMI techniques are in good agreement with the experimental results
- Only the LBMI method can distinguish the influence of temperature on the post-buckling patterns, and the corresponding post-buckling pattern is more consistent with the experiment



KDF from numerical simulations and experimental results



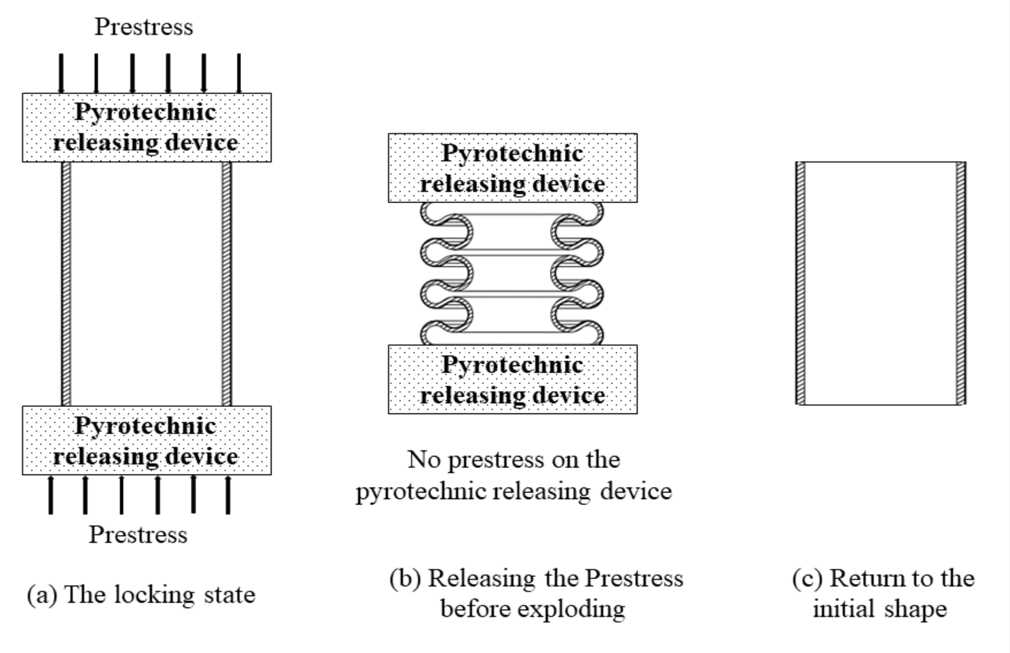
Experiment SPDI MPDI LBMI

The post-buckling patterns of $[0/90/\pm45]_s$ SMPC cylindrical shells in the high-temperature region

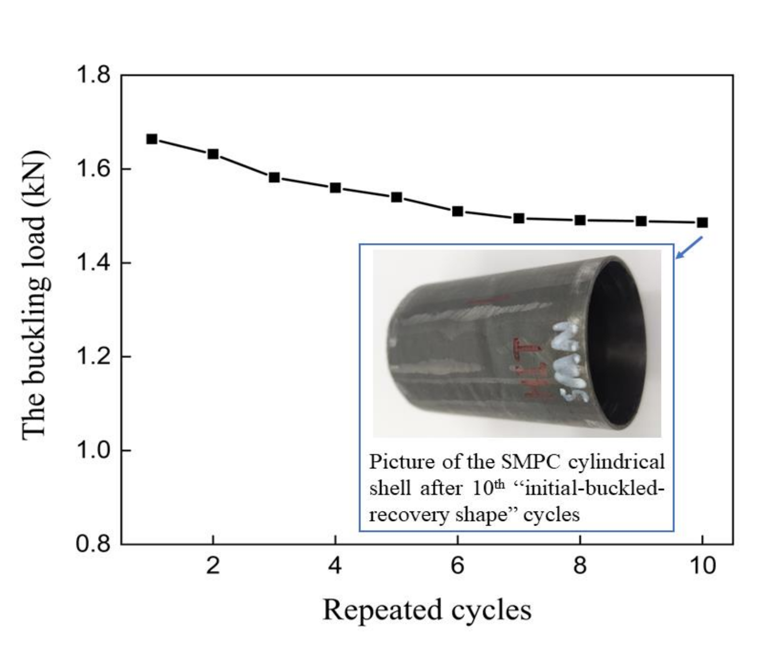
The assumption of application

- **Locking state**: effectively bear the prestress due to its characteristics of large load carrying capacity and small axial deformation before failure
- **Releasing prestress**: the SMPC cylindrical shell buckle and shorten under the action of pre-stress so that the prestress can be smoothly unloaded, and the instantaneous impact can be significantly reduced.
- **Return to initial shape**: reheated again to its T_g

- The buckling load decreases from 1.67 kN to 1.49 kN after 10 repeated "initial-buckled-recovery shape" cycles, which is a decrease of only 10%
- The SMPC cylindrical shell can return to its initial shape without any damage



The working process of the auxiliary vibration reduction structure of the space pyrotechnic releasing mechanism



The repeated experiment

Thank you