

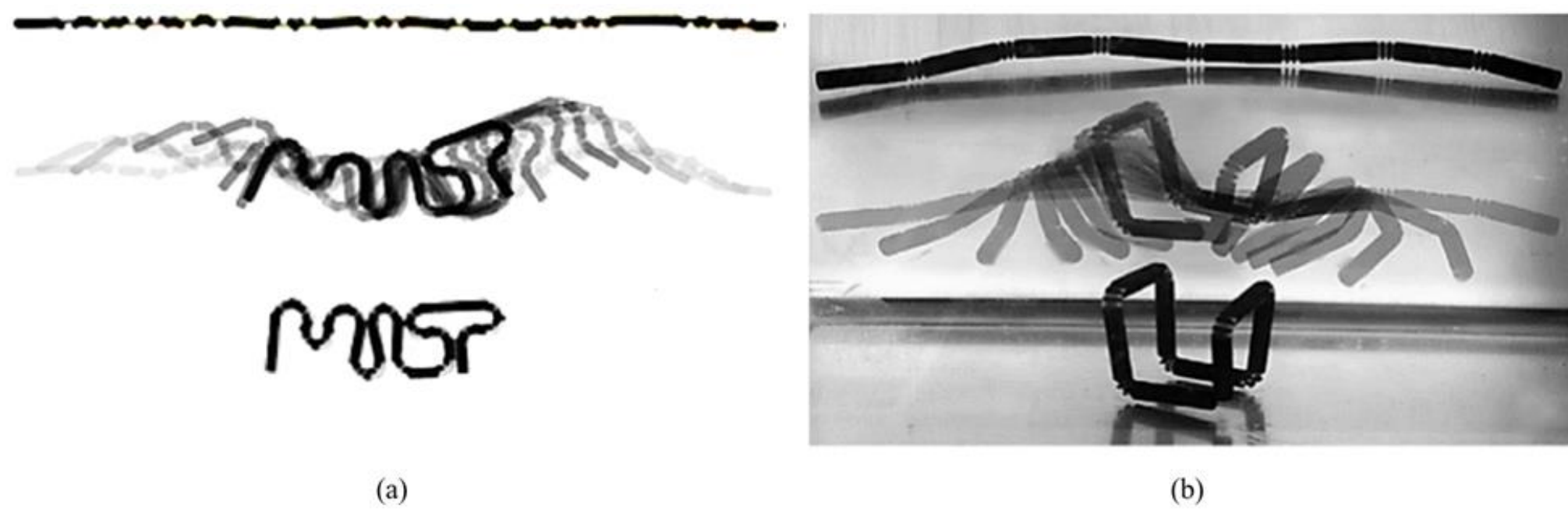
PARAMETERS AFFECTING THE BIFURCATION POINT OF UNSYMMETRIC LAMINATES

Summary

- Un-symmetric laminates (e.g., carbon/epoxy with [0/90] lay-up) exhibit three shapes when cooled: saddle, x-cylindrical, and y-cylindrical, due to bending competition during stiffening.
- Bifurcation occurs when one side becomes stronger or weaker, leading to a shift in bending towards that side.
- The laminate's shape at room temperature depends on the bifurcation temperature (T_b) relative to room temperature.
- T_b is influenced by material properties, lay-up sequence, a/b ratio, and t/a ratio.

Introduction

- 4D printing, introduced in 2013, is a 3D-printed object that is subjected to a stimulus.
- Heat, light, water, solution with different PH are some stimulus.

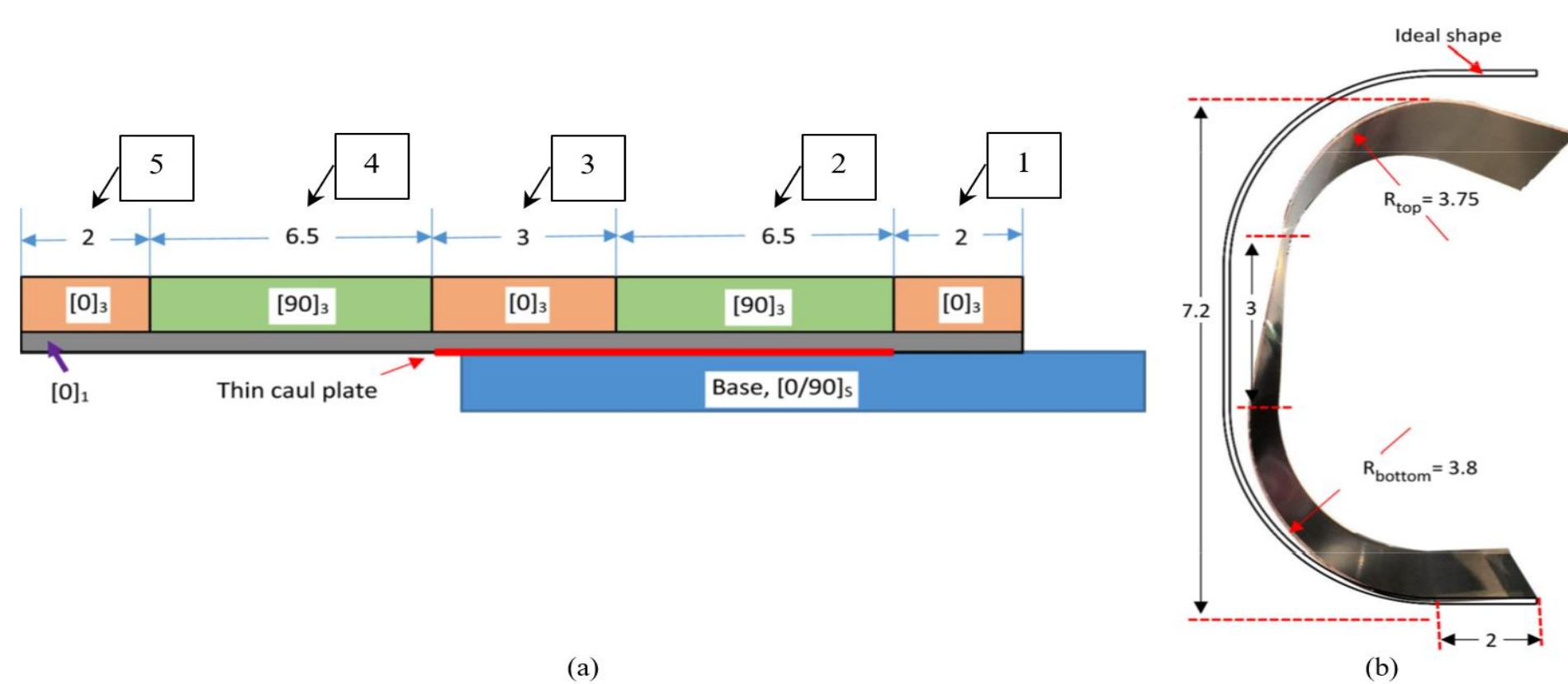


Self-folding process: a: 1D-to-2D and b: 1D-to-3D

- 4D Printing of Composites (4DPC) method was introduced by Hoa in 2017.
- It involves using unsymmetric lay-up laminates made from carbon-reinforced composites.
- The shape of the flat piece changes as it cools from curing temperature to room temperature due to variations in mechanical properties.

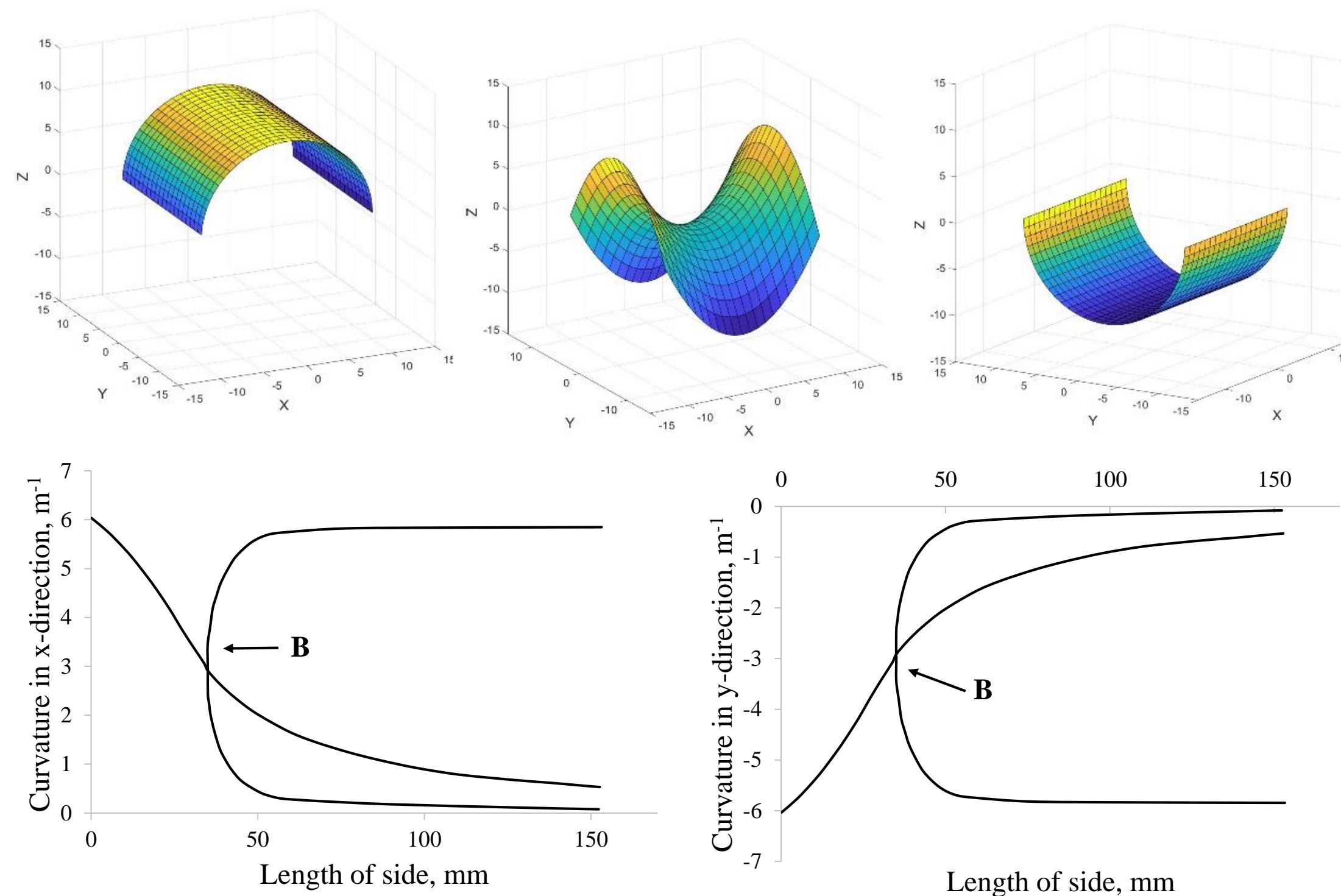


Final configuration of the word "Concordia" made with 4DPC



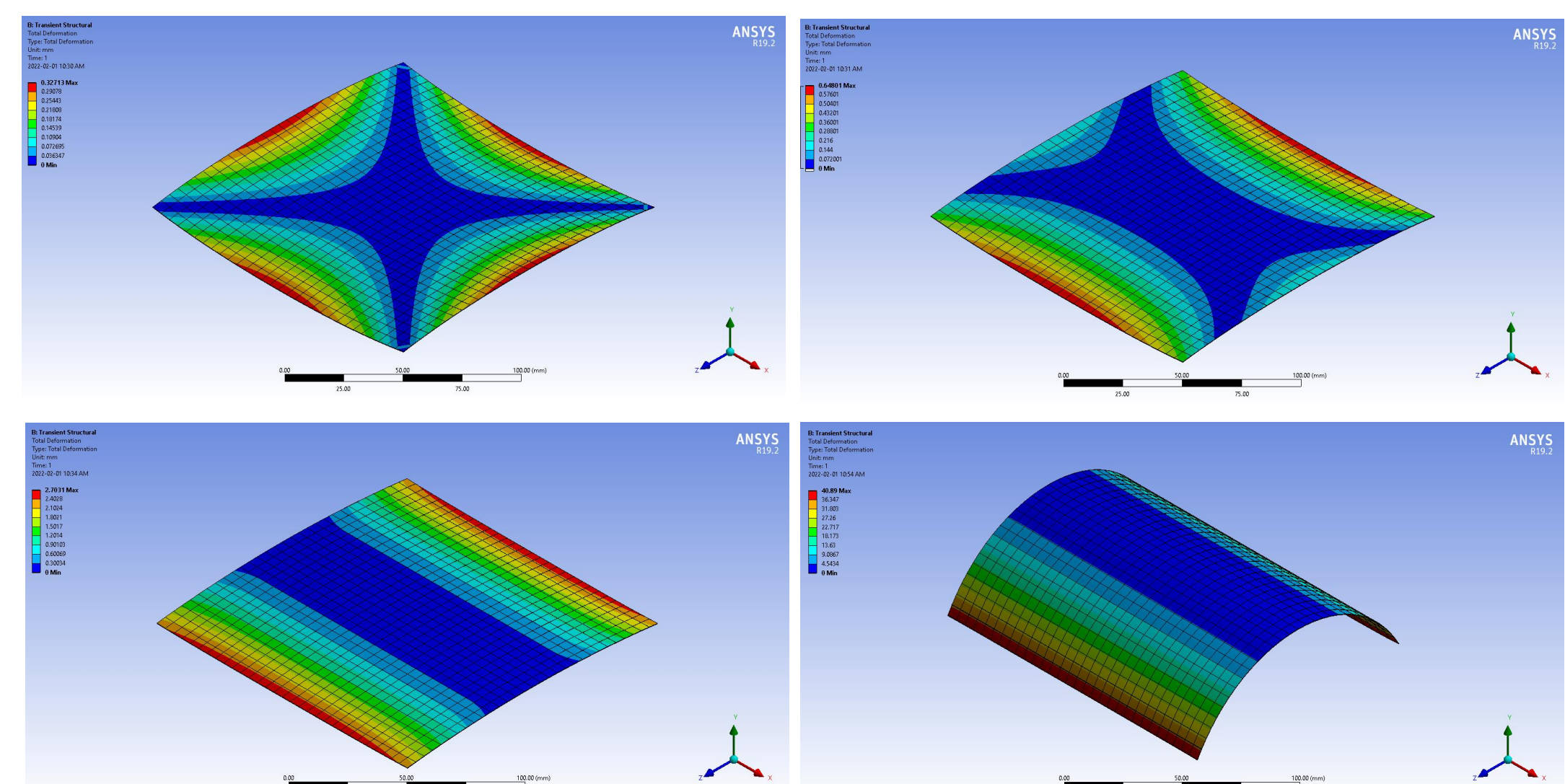
Extended laminate theory by Hyer et al.

Three possible configurations of an unsymmetric laminate at room temperature based on the extended CLT



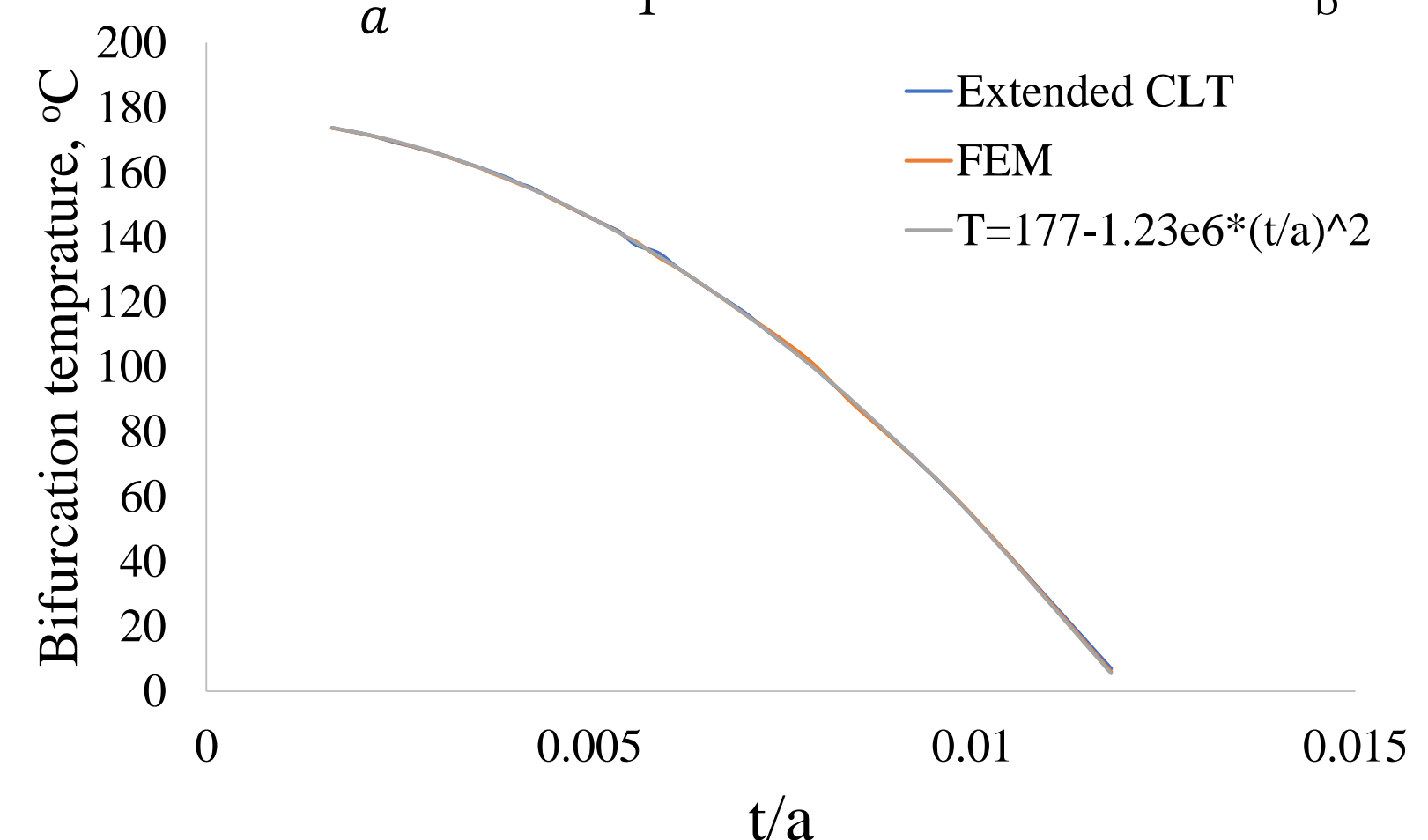
Finite element method

- Applying the incremental finite element analysis on unsymmetric a laminate



Result

- Effect of " $\frac{t}{a}$ " in a square laminate on the T_b



- Effect of " $\frac{a}{b}$ " in a square laminate on the T_b

