A Scaling Law for Fractal Contact and Interlocking

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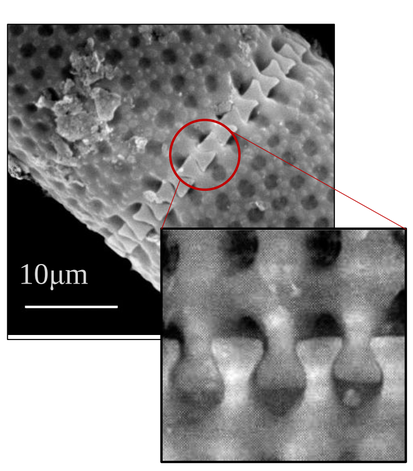
ABSTRACT

Inspired by topological interlocking in nature, Koch fractal interlocks were designed and fabricated via 3D-printing. Integrated theoretical-numerical-experimental models were developed to evaluate the role of the order of hierarchy *N* and geometric imperfections.

Motivation and Objective

- **Topological interlocking in nature**

Ammonite: *Craspedites nodiger*



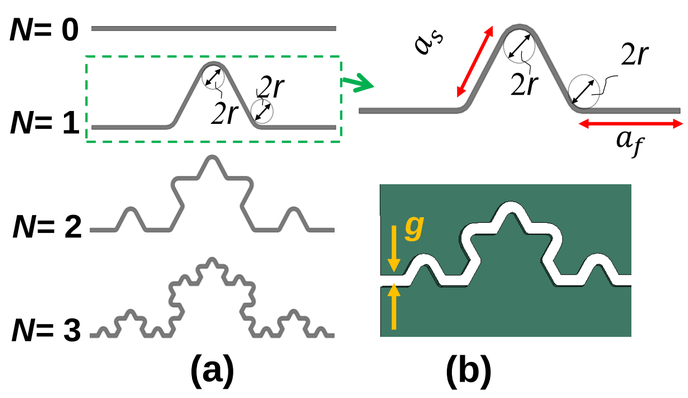
Diatom: *Aulacoseira ambigua*

Deer skull

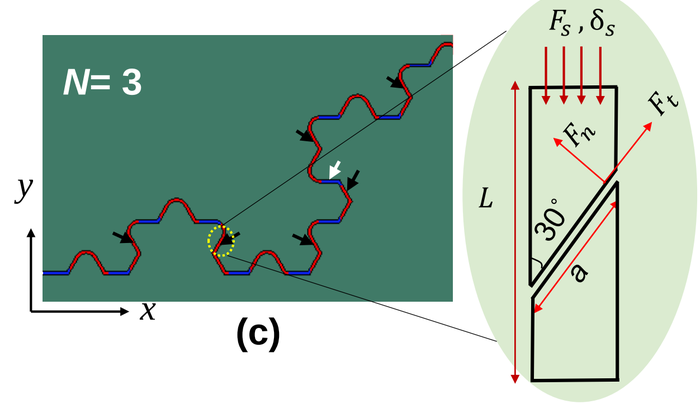
- **The goal of this research** is to evaluate the mechanical performance of an innovative design of **fractal contact and interlocking**.

Design and Theoretical Model

- **Self-similar Koch fractal interlocking**
- **Geometry of the models is defines by *g*, *r*, *N* and a_N**



- **Non-Hertzian, Conformal Contact of Flat and Slant segments**

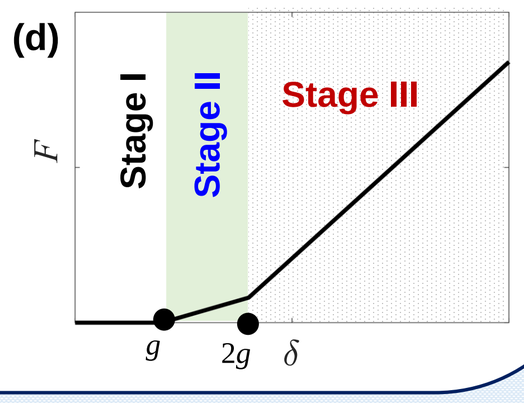


- **Deformation mechanism**

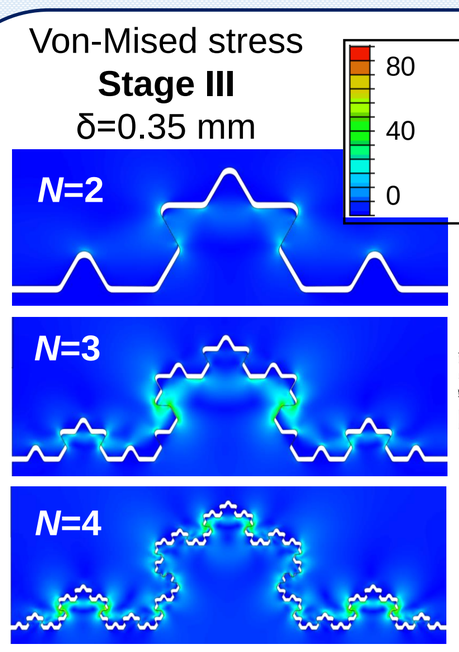
Stage I: $F(N) = 0$; $\delta < g$

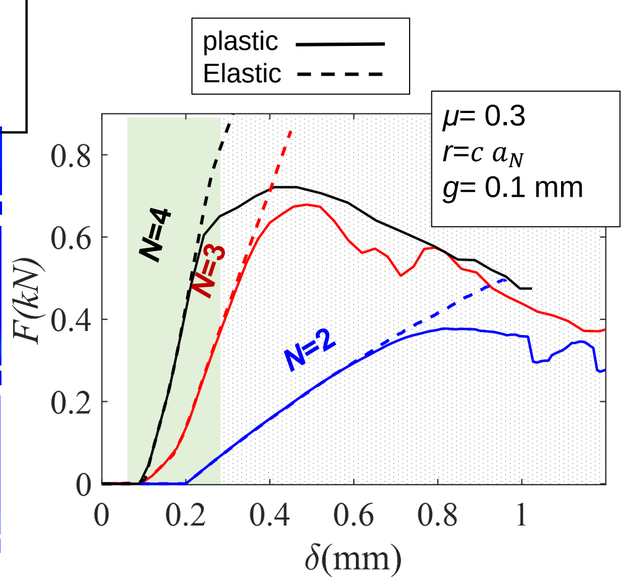
Stage II: $F(N) = f_n a_n \, n_f^{c\,[N]}$; $g < \delta < 2g$

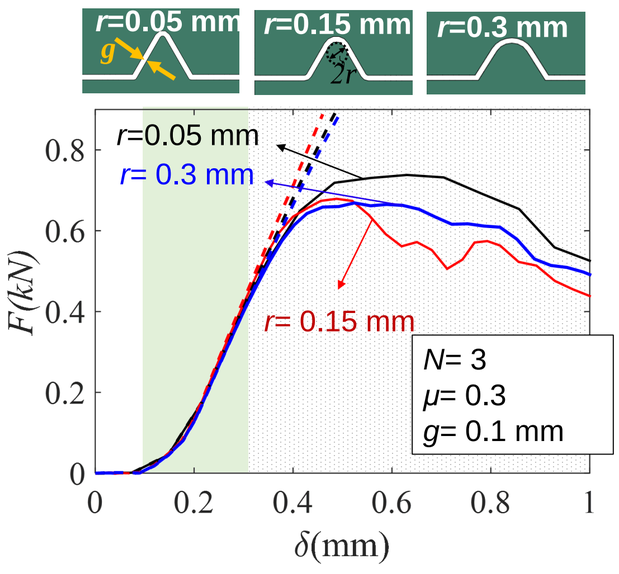
Stage III: $F(N) = f_s a_s \, n_s^{c\,[N]} + f_n a_n n_f^{c\,[N]}$; $\delta > 2g$

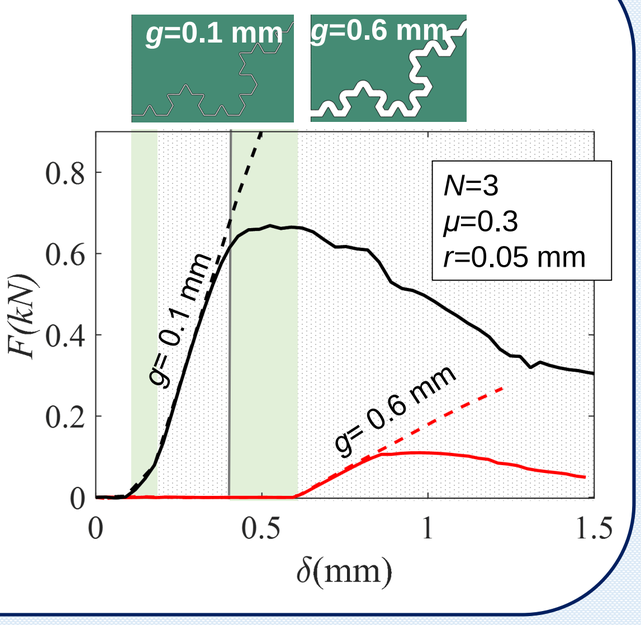


Finite Element Results









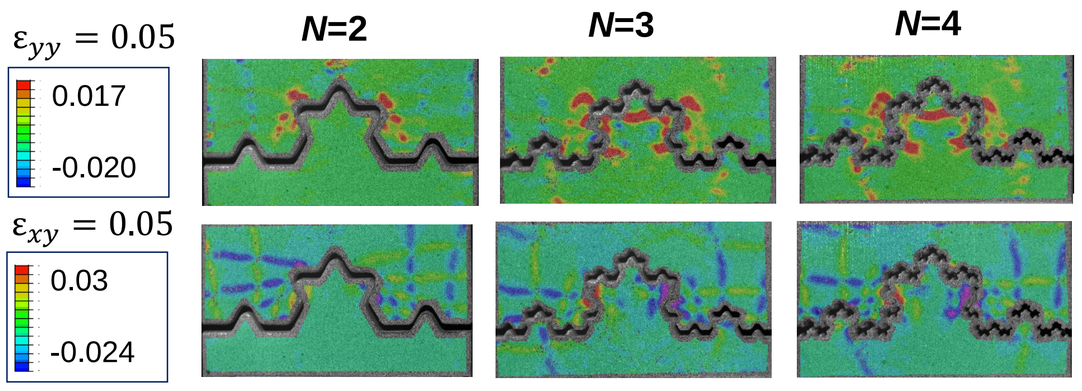
Experimental Results

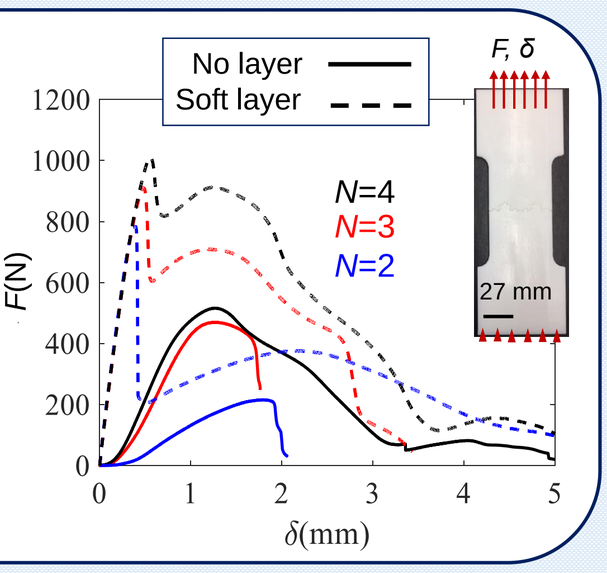
Experimental method:

- Uniaxial tension on Zwick machine
- Displacement rate of 0.024 mm/min
- Digital Image Correlation (DIC)

Observations :

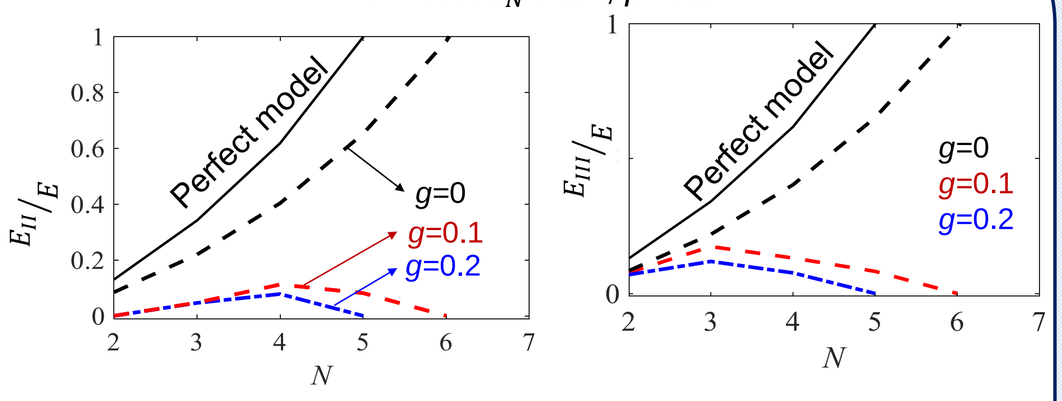
- When N increases, stiffness, strength and toughness increases.
- Adding a soft layer can significantly increases stiffness, strength and toughness for all *N*s.





A Scaling Law

$r = 0.15a_N$ mm , μ=0.1



- The ideal model with no imperfection (i.e. ***g*=0 and *r*=0**) provides the upper bond of the stiffness of the fractal contact and interlocking
- Due to geometric imperfection *g* and *r*, an optimal *N* exists for maximum stiffness.

Conclusion

- Koch fractal geometry can significantly improve energy dissipation, stiffness and strength of topological interlocking.
- The mechanical properties of Koch fractal contact and interlocking are sensitive to geometric imperfections.

References

- Potapova, M., and English, J. (2010). *Aulacoseira ambigua*. In Diatoms of the United States. Retrieved July 14, 2017.
- Fratzl, Peter, et al. "The mechanics of tessellations–bioinspired strategies for fracture resistance(2016)
- Li, Y., Oritz, C., and Boyce., 2012, “Bioinspired, mechanical, deterministic fractal model for hierarchical suture joints”, Physical Review E 85, 031901 (2012).
- Mandelbrot., B. B., 1977, “The fractal geometry of nature” International Tiusiness Machines Thomas J. Watson Research Center.

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