Bioinspired Platelet Reinforced Polymer Films

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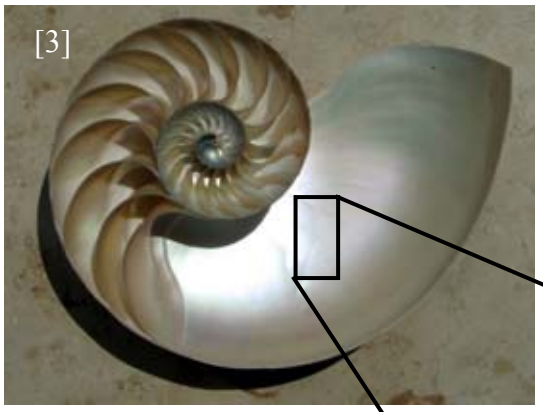
Natural Composite


[3]

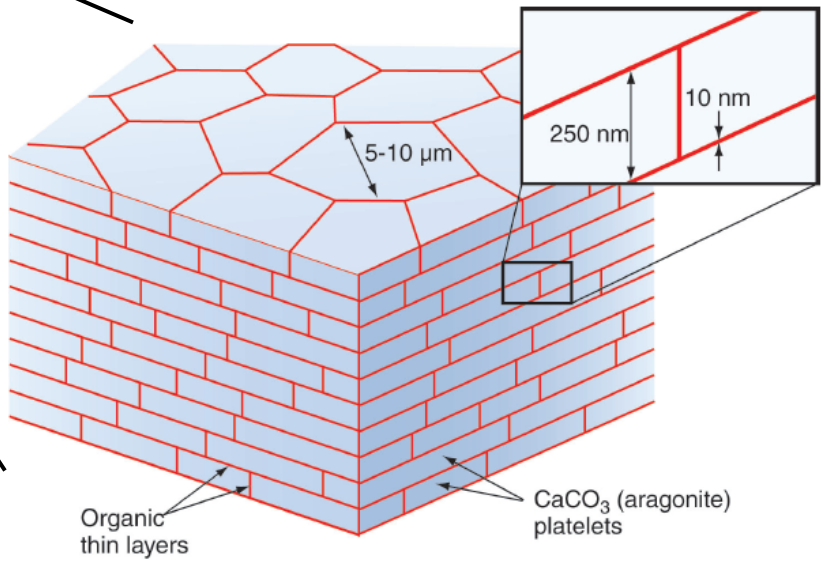
Inner shiny layer of mollusk shells [1,2]

Platelets

200-1000 nm thick aragonite platelets with 5-10 μm diameter

Organic Matrix

10 – 20 nm thick layer of different bio-polymers



[4]

[1] S. Blank, et al. *Journal of Microscopy*, 2003
[2] K. Wada, *Bull Natl Pearl Res Lab 7*, 703 (1961)
[3] http://en.wikipedia.org/wiki/Mother_of_pearl
[4] G. Mayer, *Science* 310, 1144 (2005).

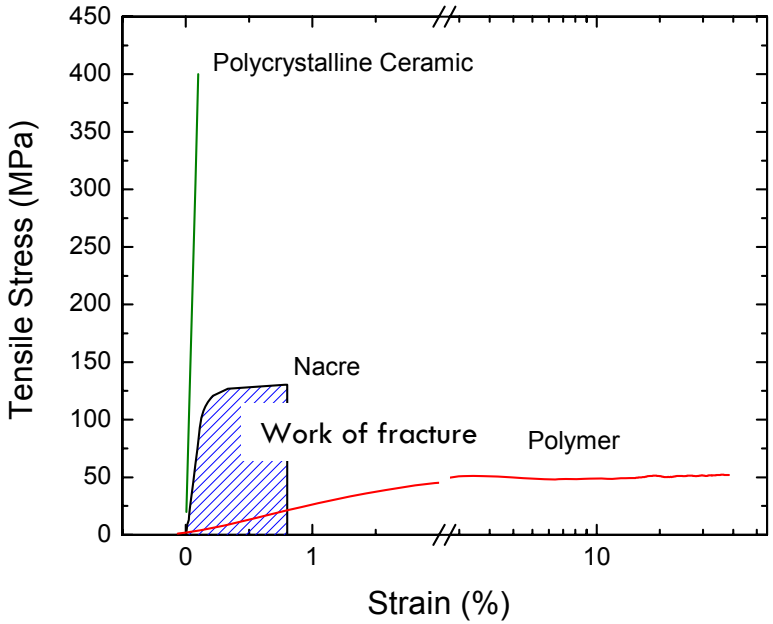
Microstructure Determines Properties

Optical properties

Iridescent

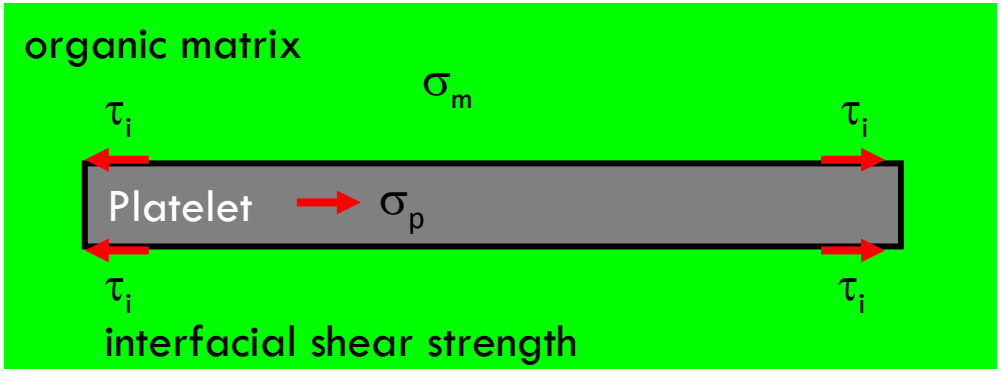
Mechanical properties

- 95 vol% aragonite, but work of fracture is 3000 times higher [2]
- 5–10 fold increase in fracture toughness [3]
- Nacre behaves like ceramic with plastic deformation [4]

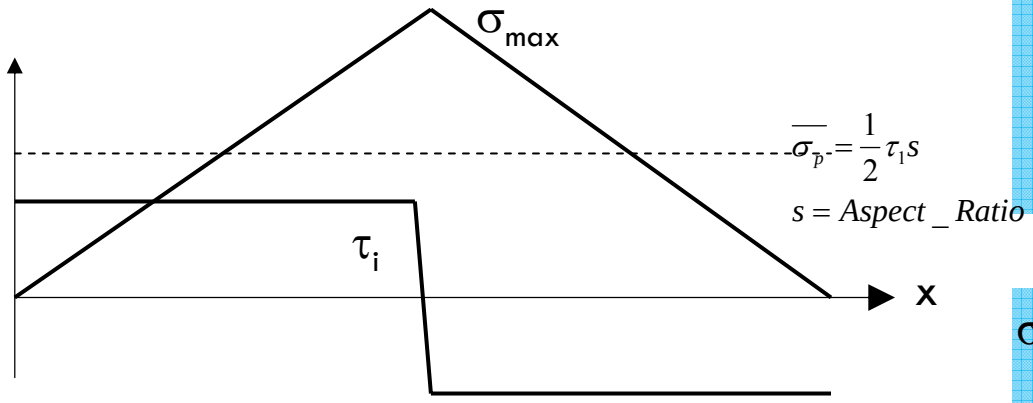


[1] http://www.rambaud.fr/images/nacre%20sur%20sable%20noir_big.JPG
[2] Jackson, *Proc. Of The Royal Soc. Of London Series B*, 1988
[3] Sarikaya, *in Biomimetics design and processing of materials*, 1995
[4] Wang, *Journal Of Materials Research*, 2001

Mechanical Model [1]



$$\sigma_c = \Phi_p \overline{\sigma_p} + \Phi_m \sigma_m$$



$\sigma_{max} < \sigma_{platelets} \rightarrow$ pull out mode

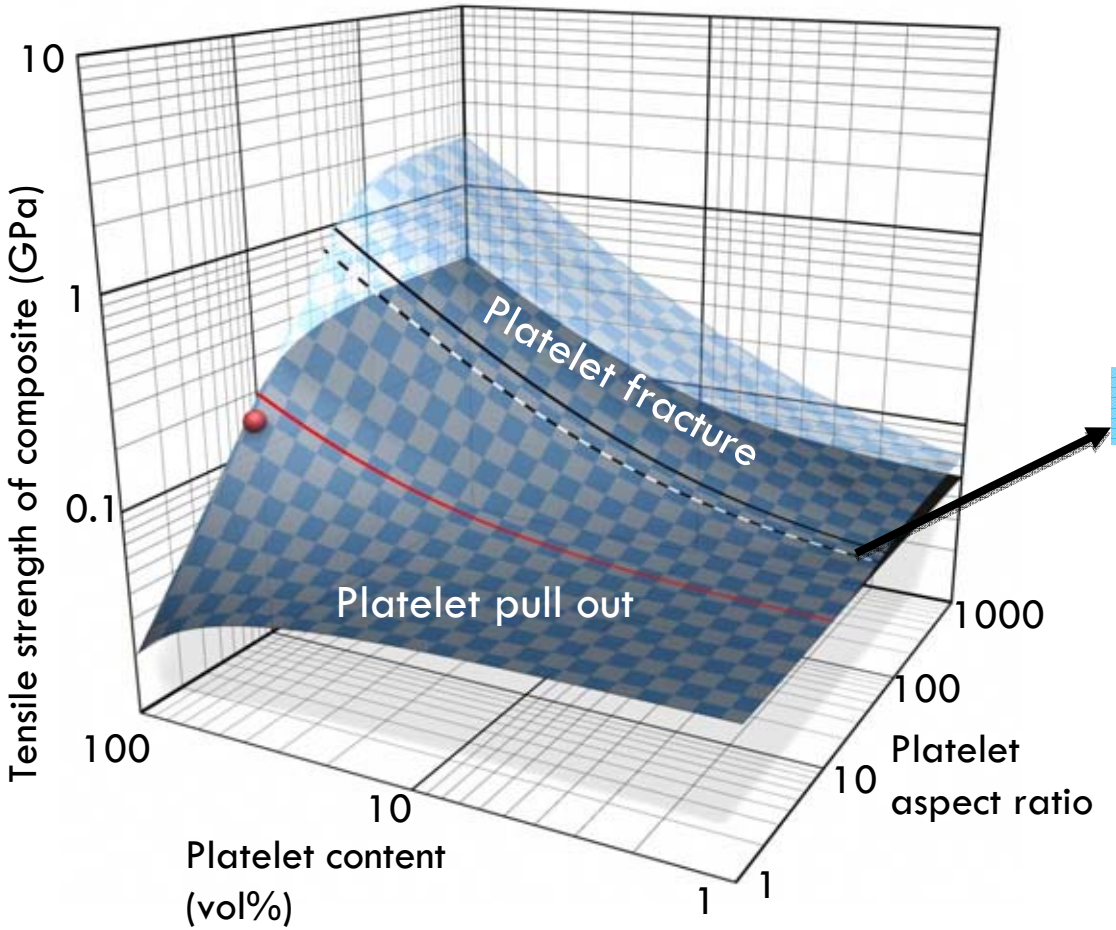
$$\sigma_c = \frac{1}{2}\Phi_p \tau_i s + \Phi_m \sigma_m$$

$\sigma_{max} > \sigma_{platelets} \rightarrow$ platelet fracture

$$\sigma_c = \Phi_p \sigma_{pu}\left(1 - \frac{s_c}{2s}\right) + \left(1 - \Phi_p\right)\sigma_m$$

[1] Glavinchevski, *Journal of Materials Science 8*, 1973

Predicted Tensile Strength of Platelet Reinforced Composites



τ_i=40 MPa

Aragonite platelets

Like in nacre $\sigma_{platelets}$ = 400 MPa

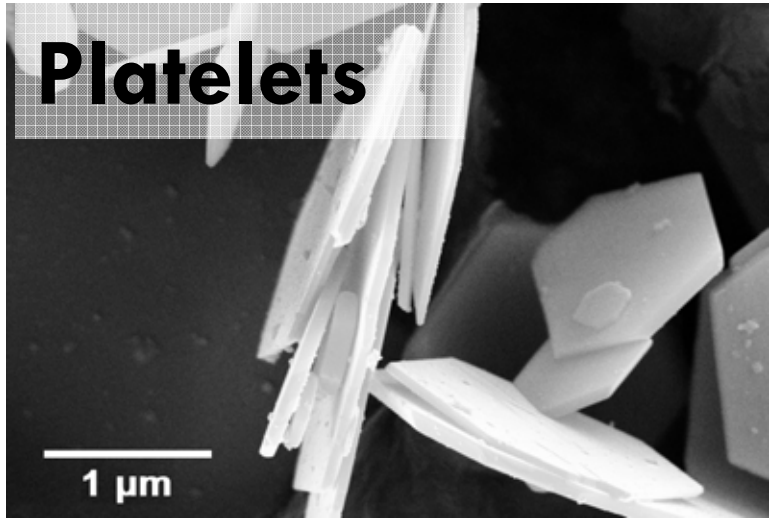
Alumina platelets

Artificial platelets $\sigma_{platelets}$ = 2000 MPa

alumina platelets with s = 40 !!!

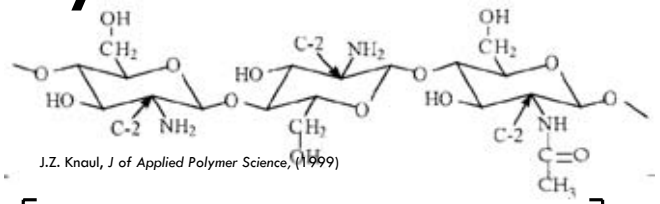
Stronger platelets allow fabricating stronger and still ductile composites

Platelets & Polymers → Artificial Nacre

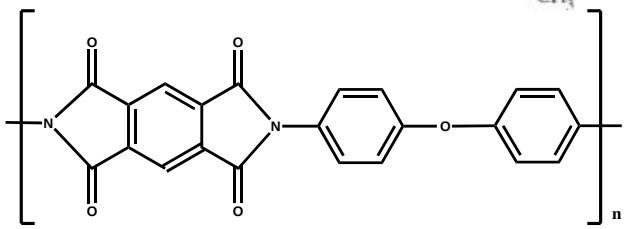


+

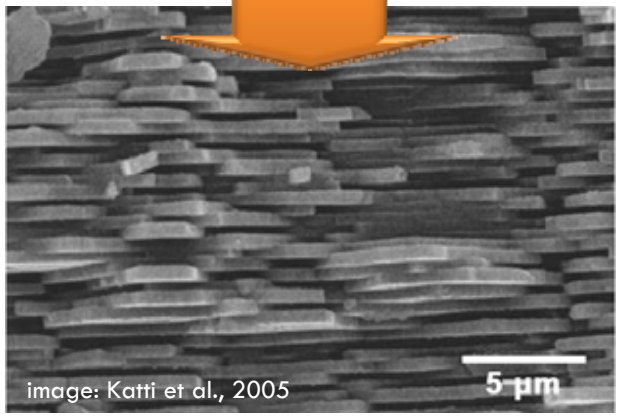
Polymers



J.Z. Knaul, *J of Applied Polymer Science*, (1999)



Is it possible? How to do it?



Outline

Motivation

Fabrication of the Composites

Results

- Mechanical properties
- Structure-properties relation

Conclusion & Outlook

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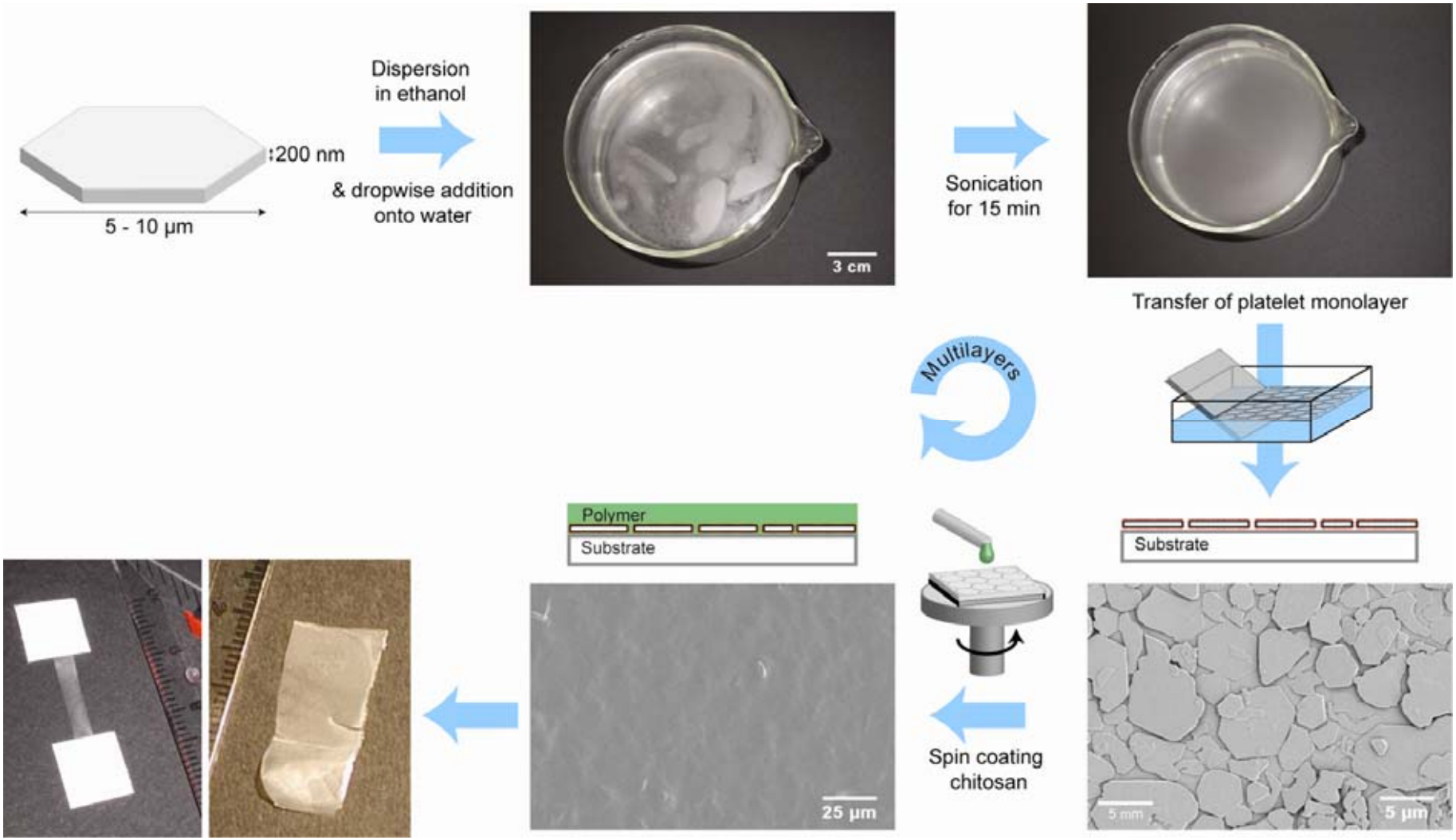
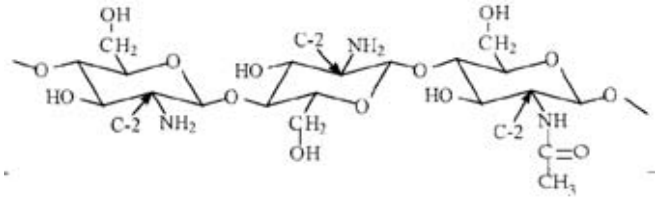
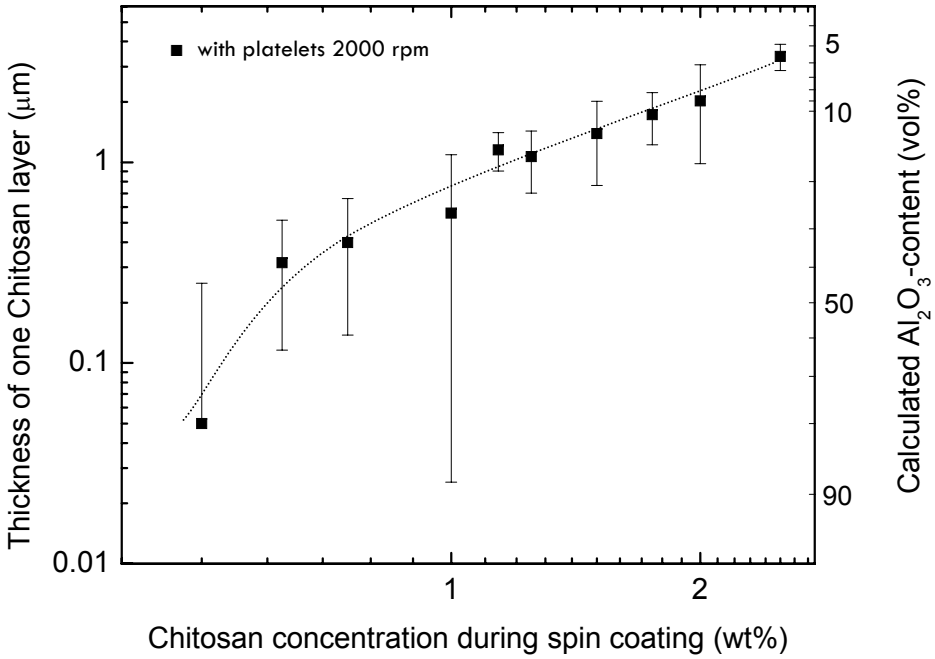
Layer-by-Layer Deposition



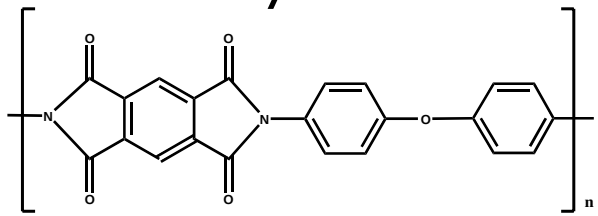
Polymer & Polymer Concentration

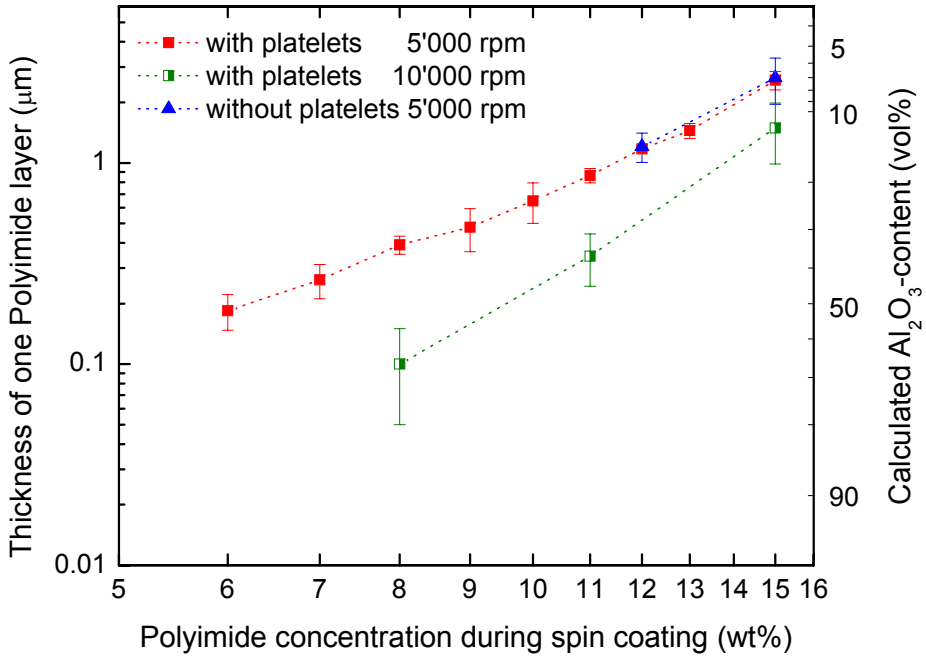
Chitosan





Polyimide





Polymer concentration during spin coating controls alumina content of composite

Polyimide has a much higher reproducibility than chitosan

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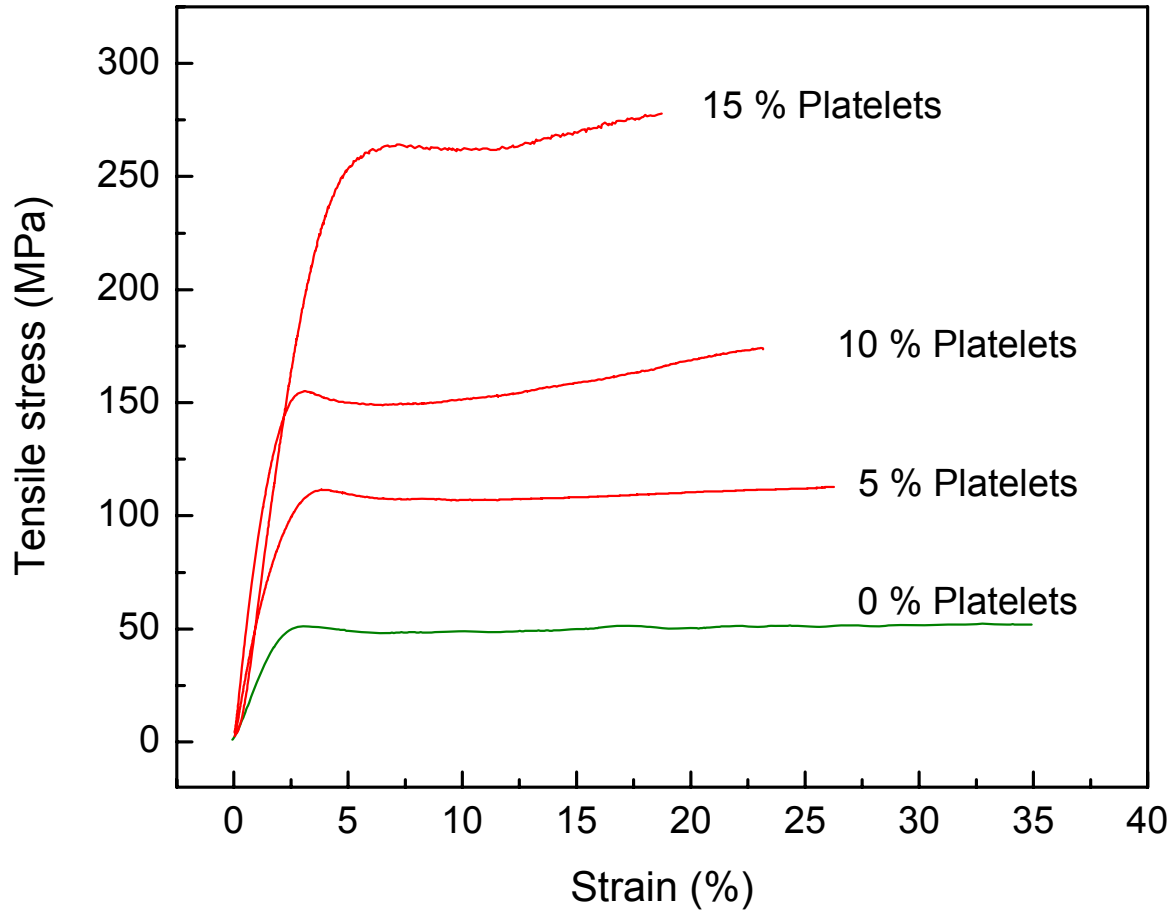
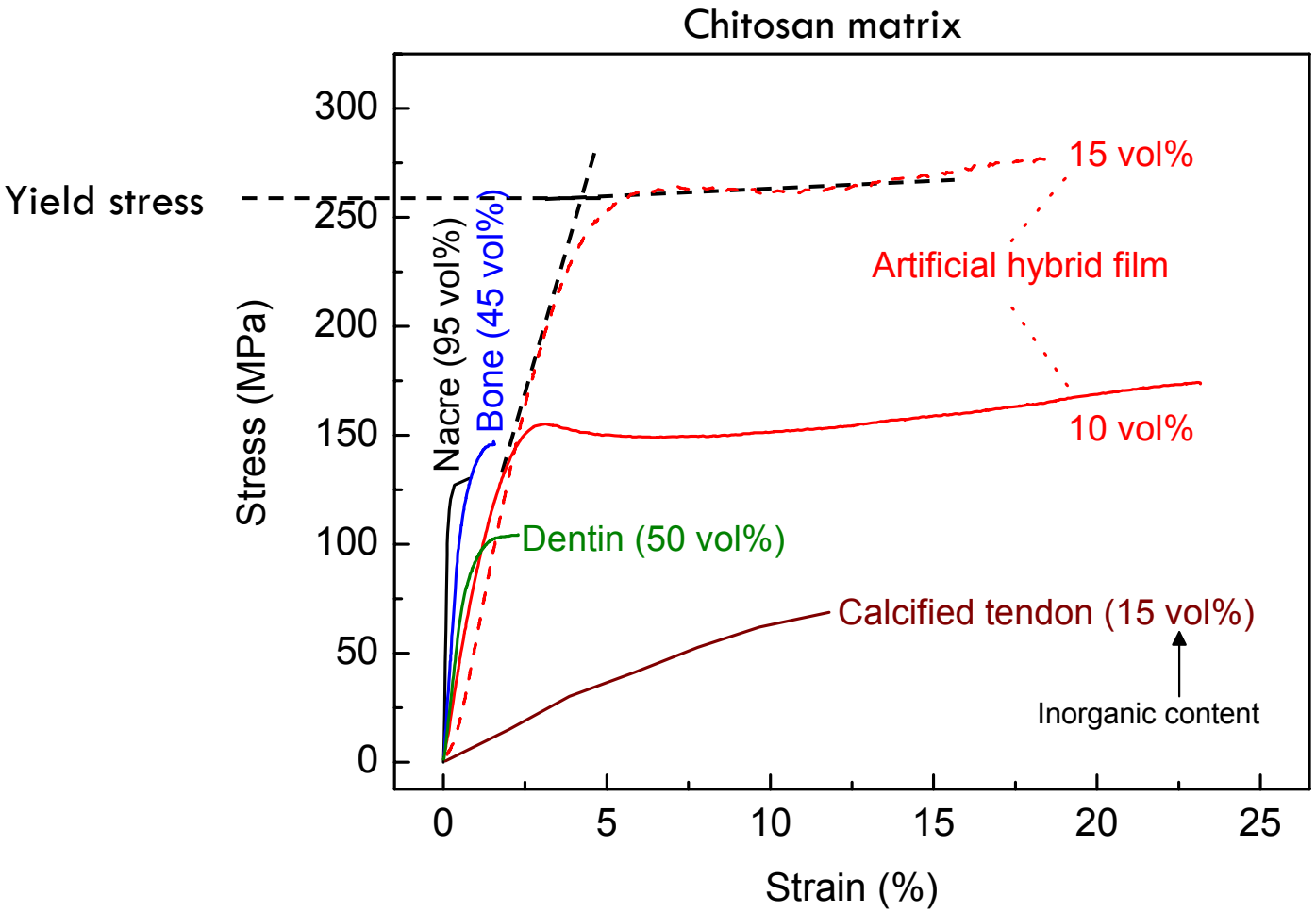
Tensile Test: Chitosan Composites

In all directions in the plane of the platelets!



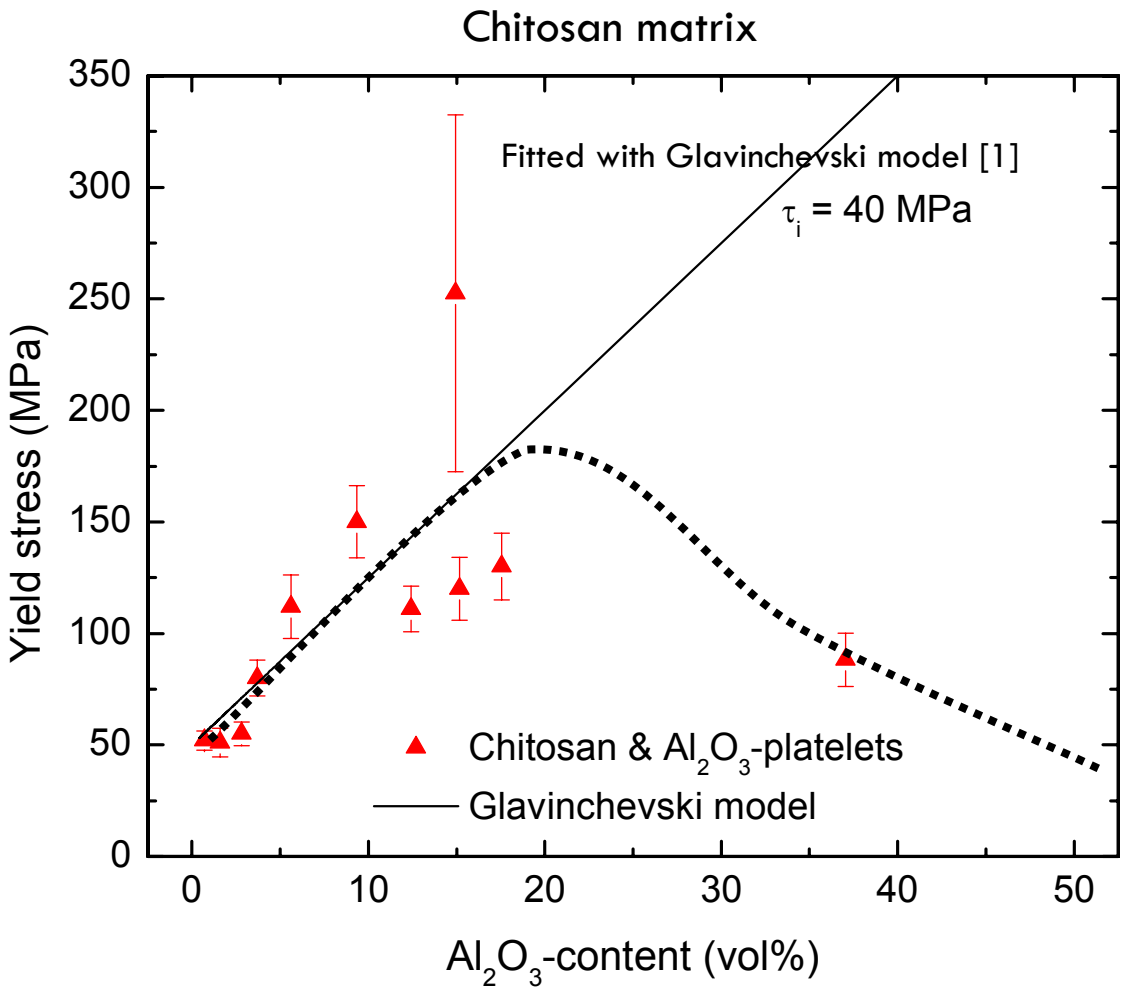
Bonderer, Studart, Gauckler; *Science*; 2008

Comparison to Natural Composites



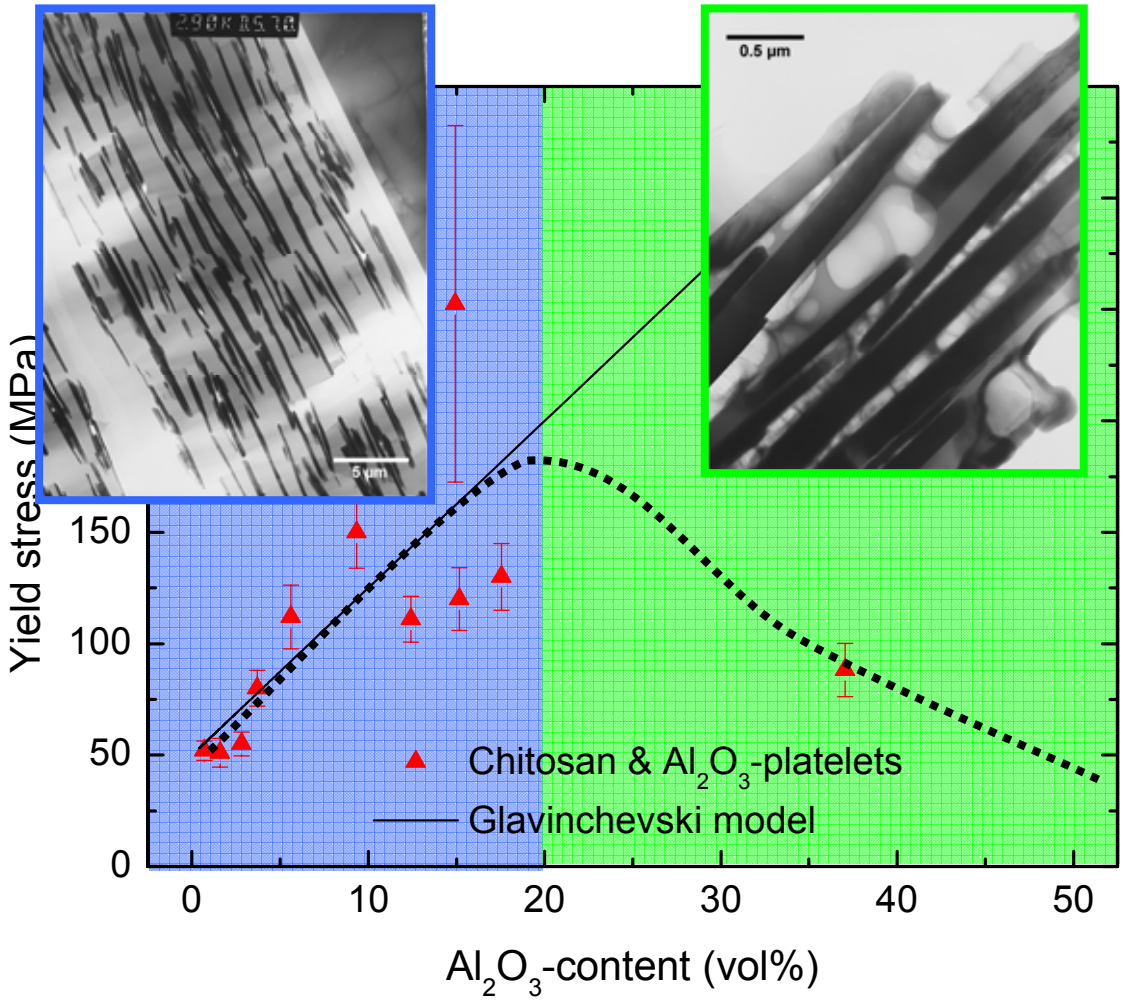
Nacre (red abalone, Haliotis rufescens): R. Z. Wang, *Journal of Materials Research 16*, 2001
Bone & calcified tendon: W. J. Landis, *Journal of Bone and Mineral Research 10*, 1995
Dentin: H. Sano, *Journal of Dental Research 73*, 1994

Yield Stress



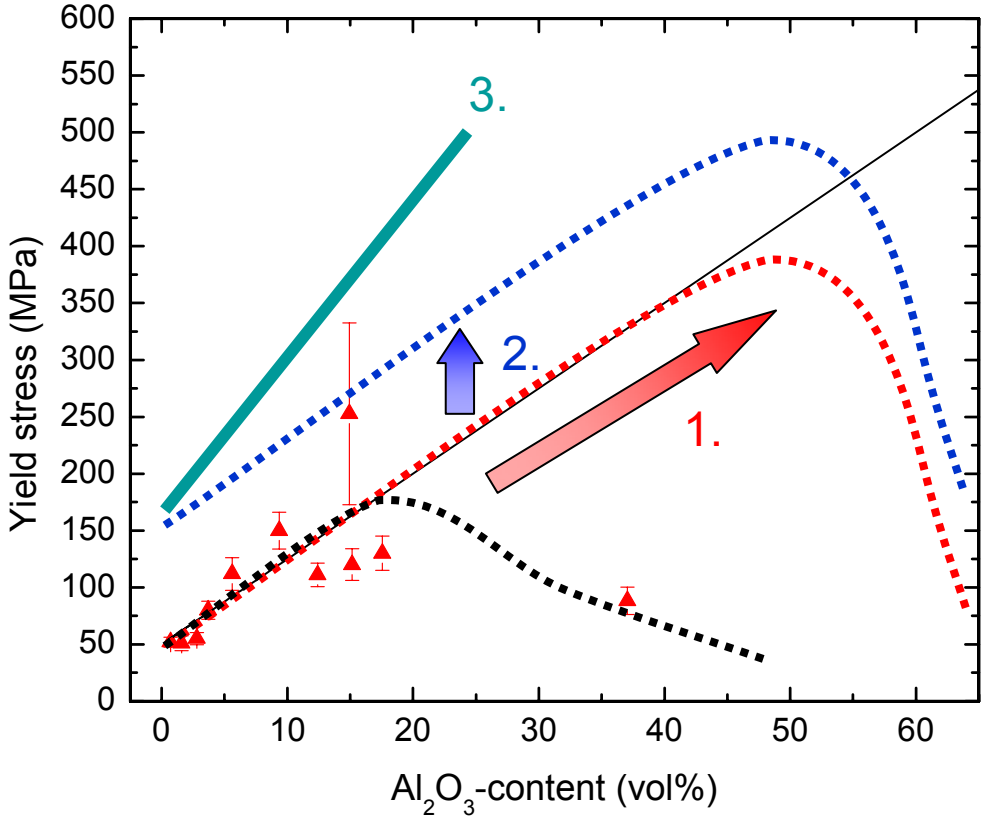
[1] Glavinchevski, *Journal of Materials Science 8*, 1973

Yield Stress & Microstructure



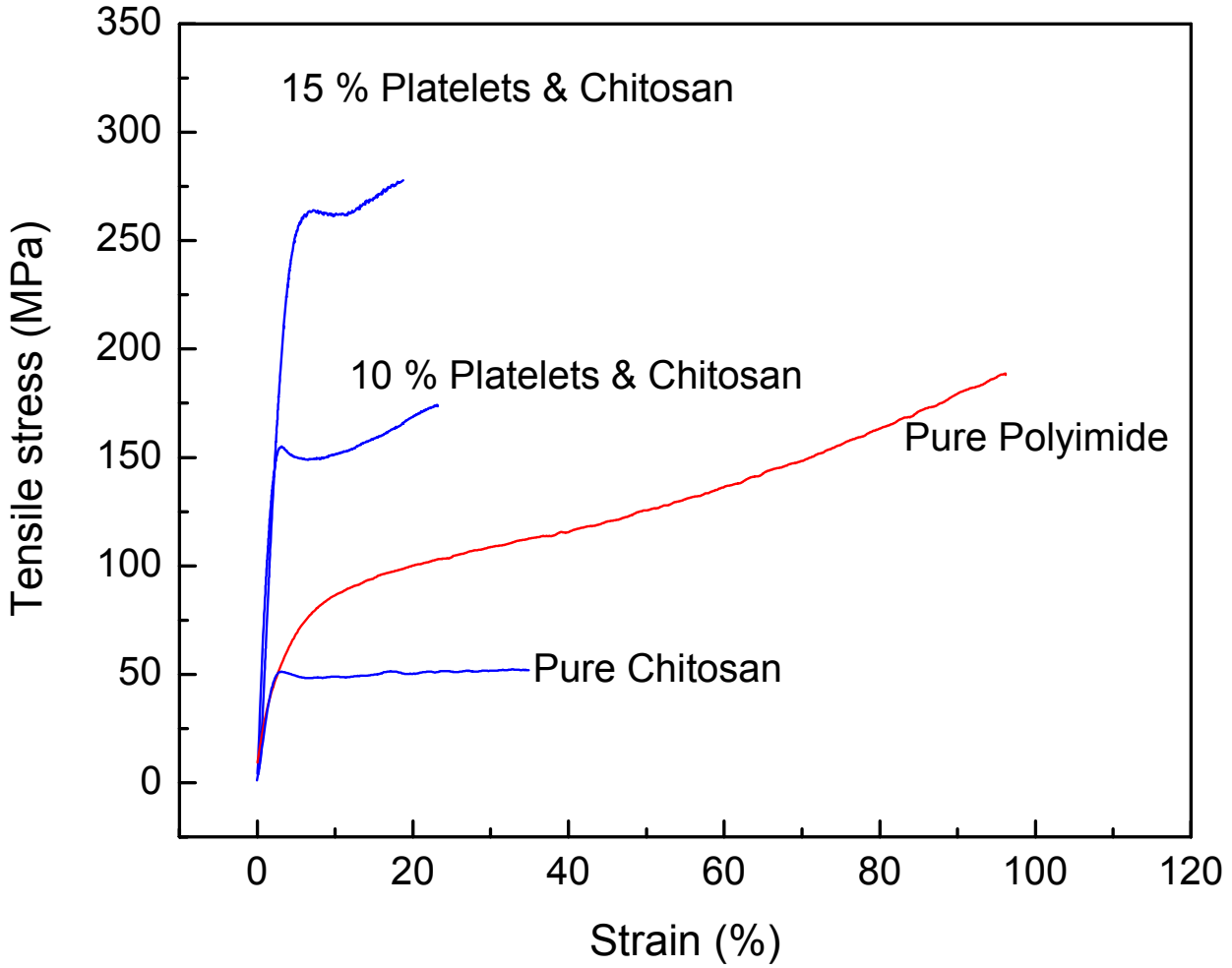
TEM: Prof. J. Woltersdorf, MPI-Halle

What Can We Optimize?



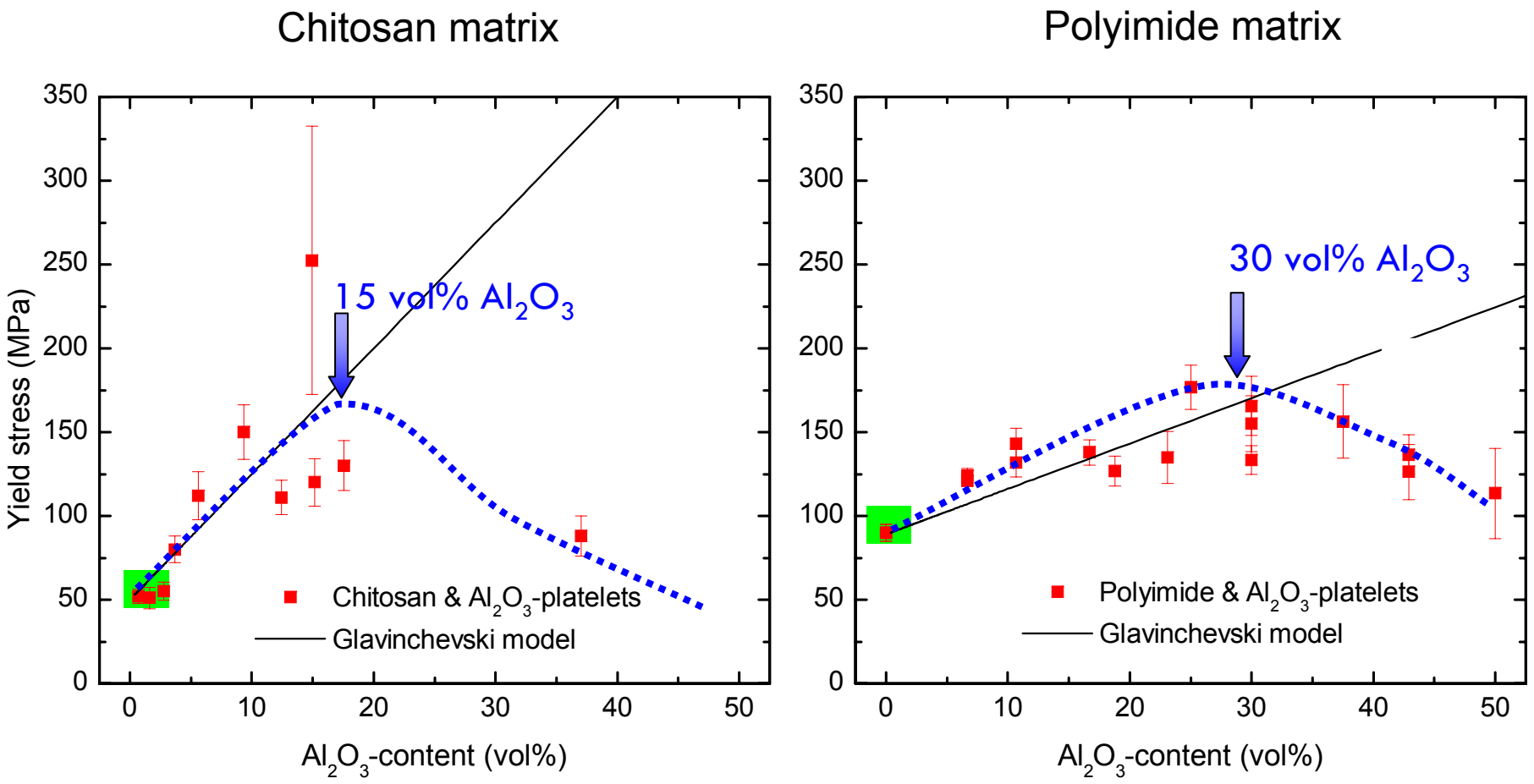
1. Improve processing
2. Change polymer
3. Increase slope

Polyimide vs. Chitosan



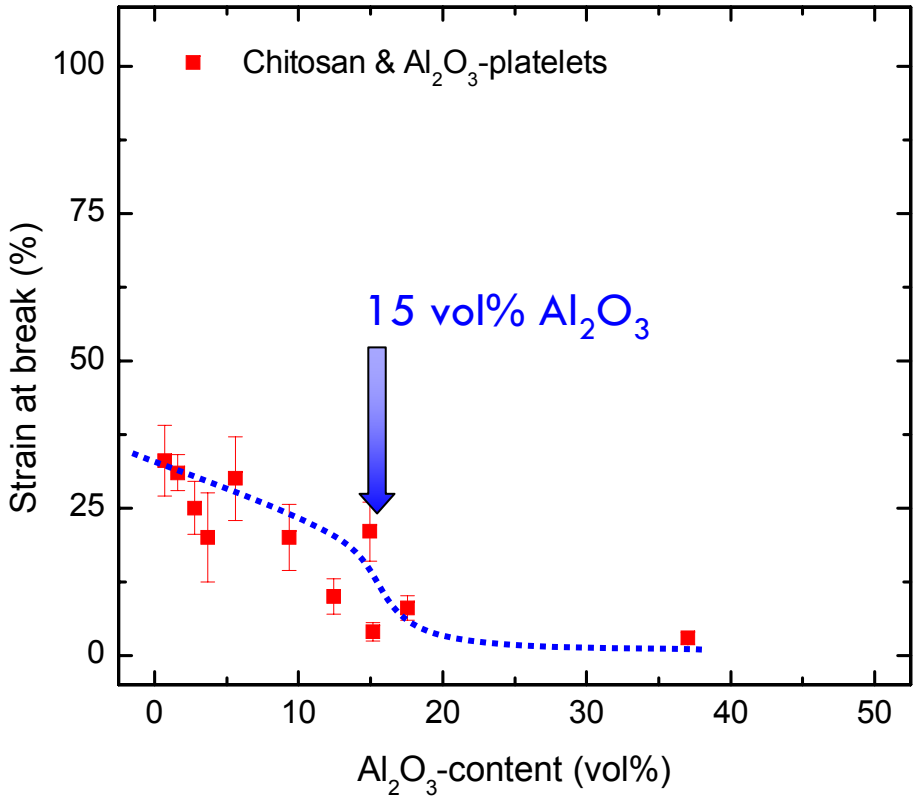
Polyimide is stronger, more ductile and better reproducible then Chitosan

Yield Stress

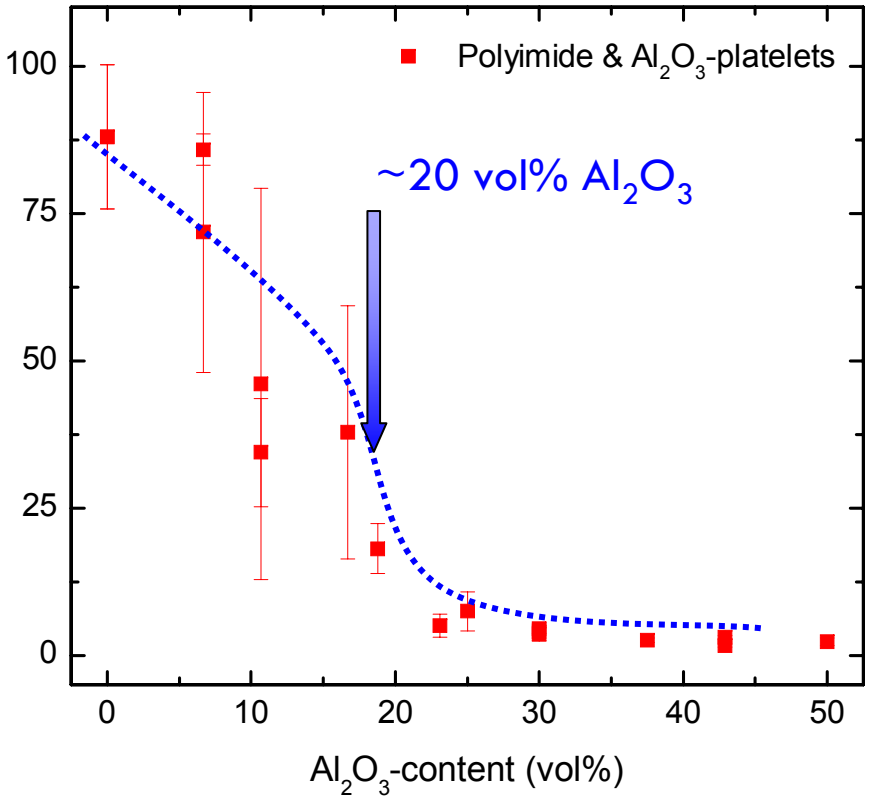


Strain at Break

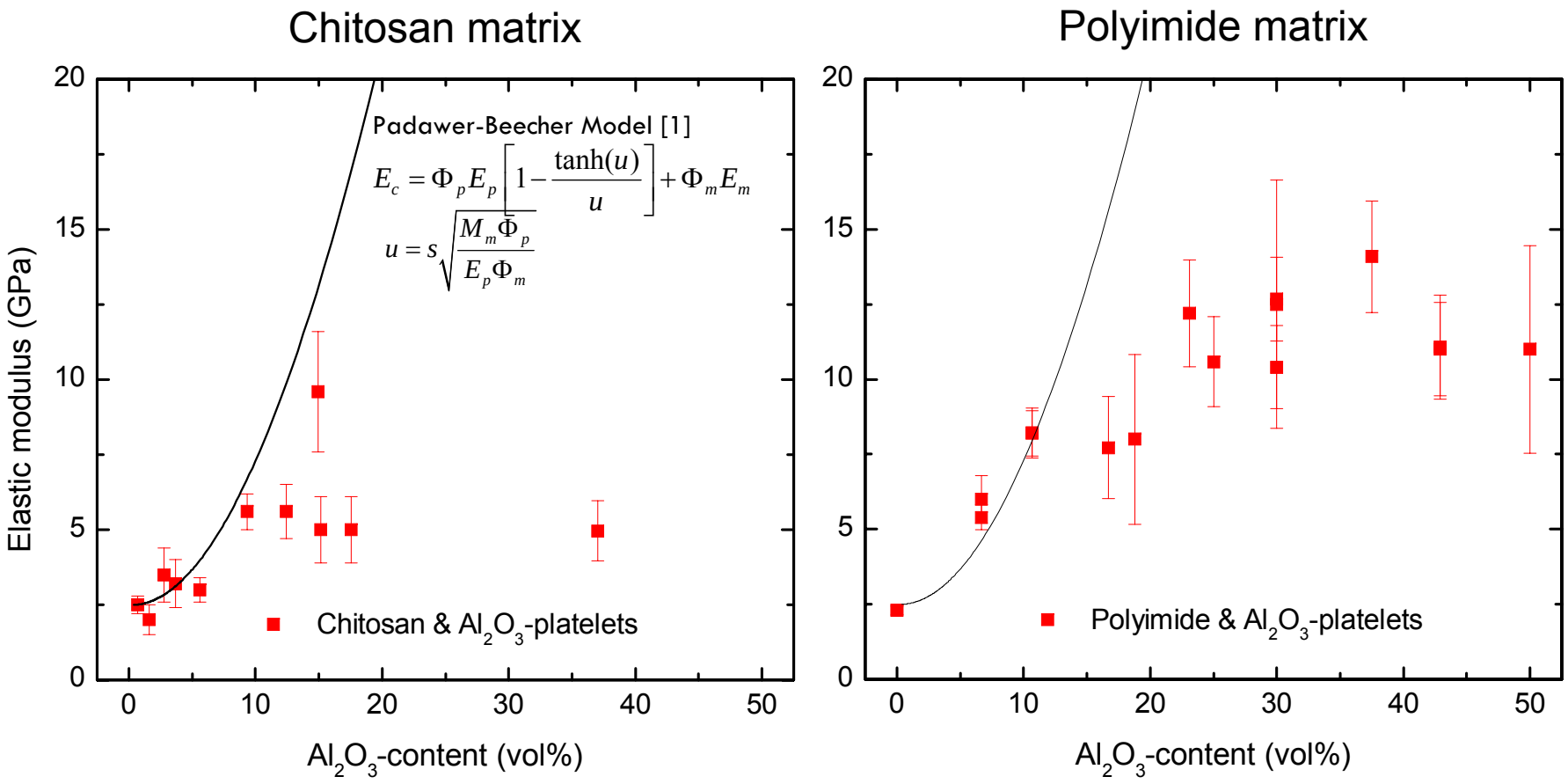
Chitosan matrix



Polyimide matrix

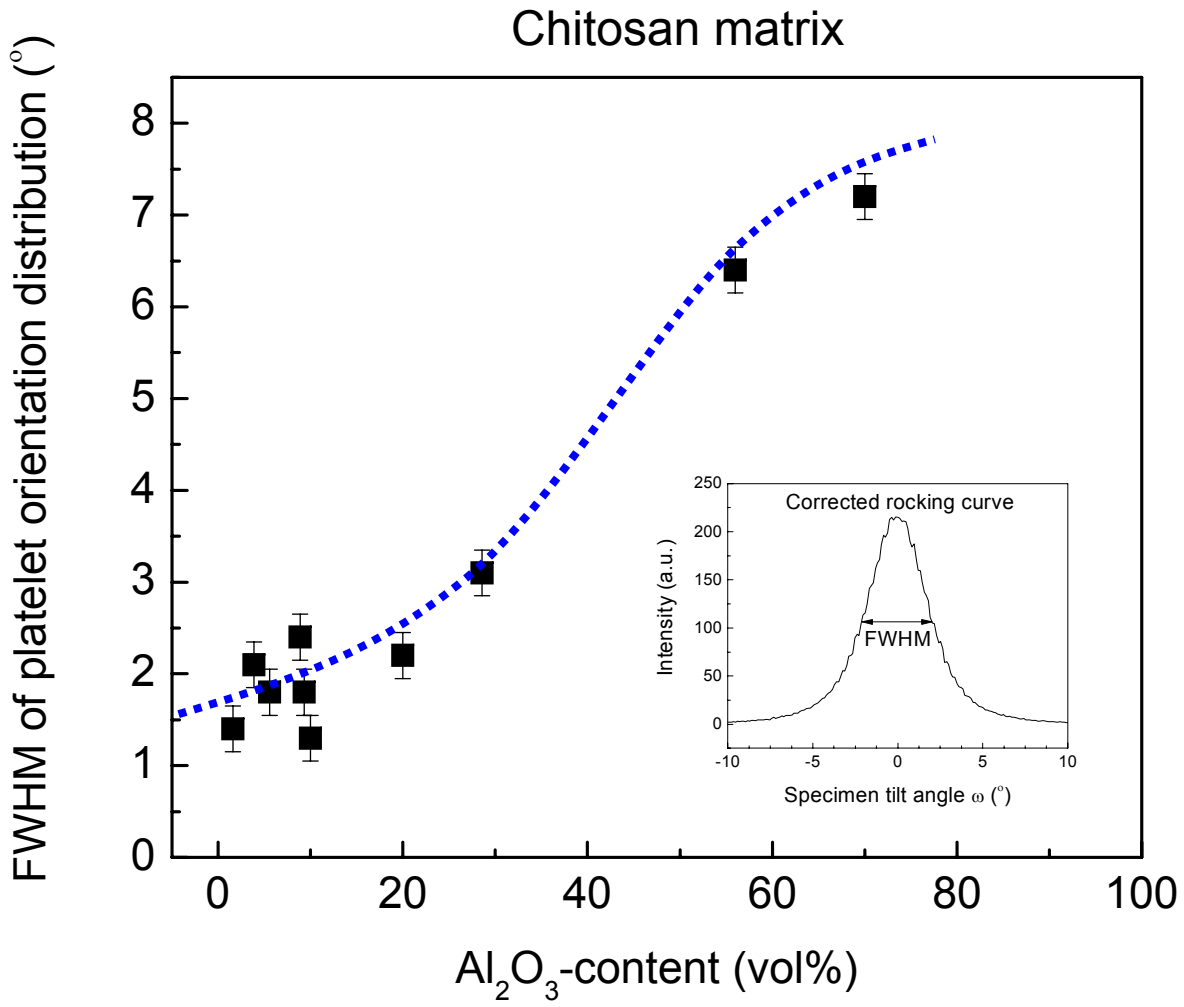


Elastic Modulus



[1] Padawer, *Polymer Engineering & Science*, 1970

Platelet Orientation: XRD



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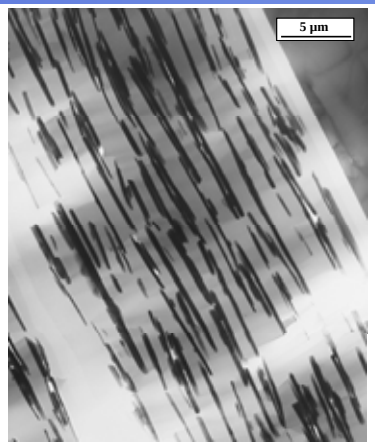
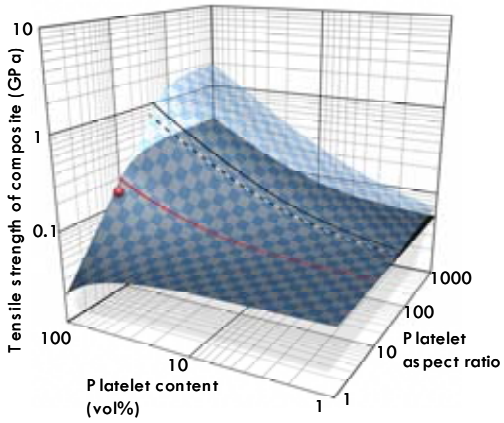
Conclusions

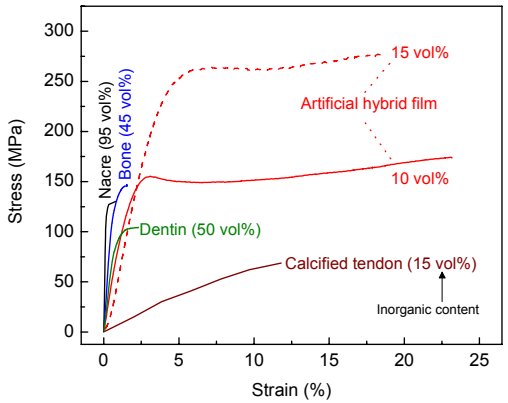
Layer-by-layer assembly of nacre-like composites



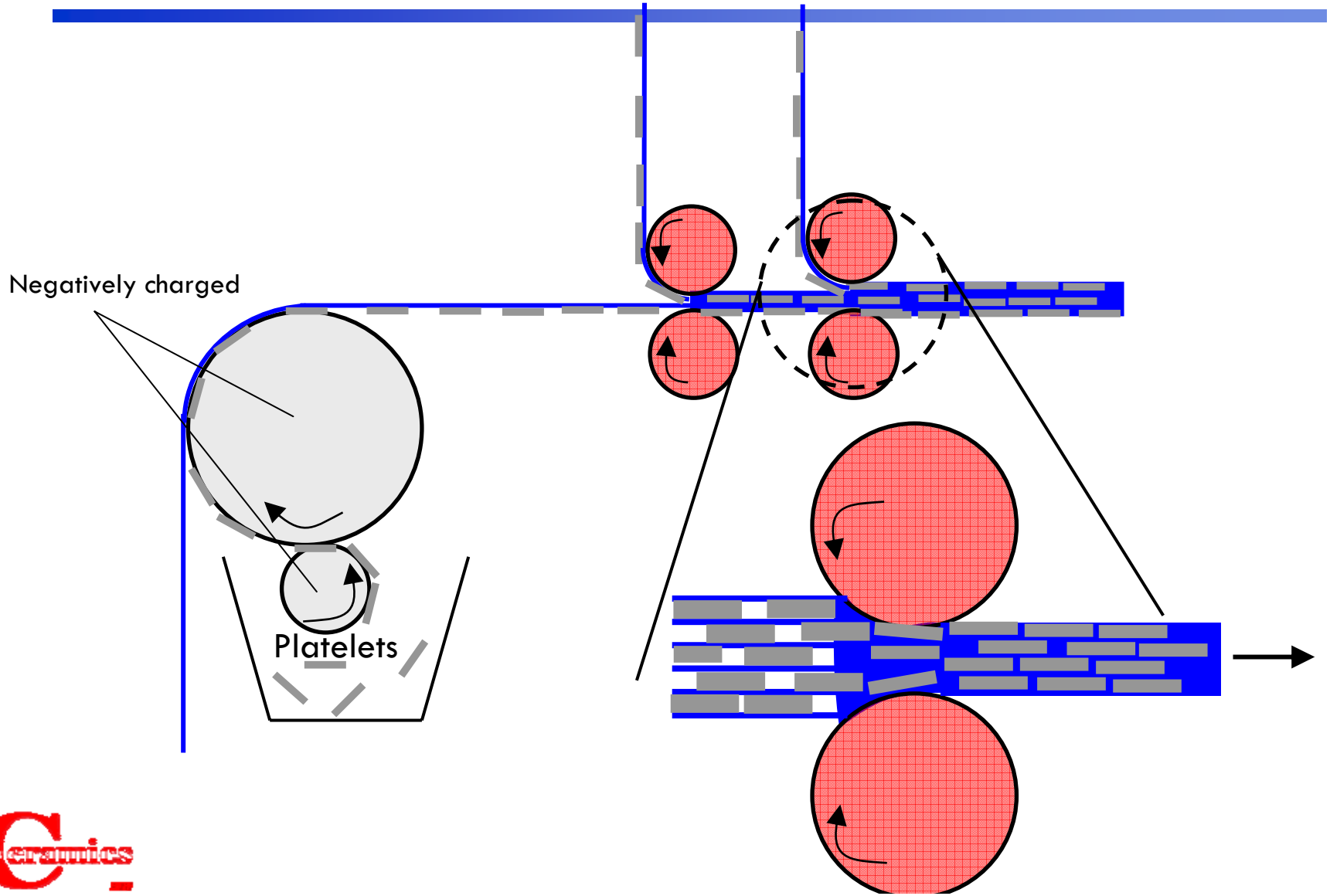


Stronger platelets → stronger but still ductile composites

Composites with 10-15 vol% alumina-platelets exceed the strength and ductility of most natural composites



Possible Alternative Processing



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Thank You for Your Attention

Any Questions?