

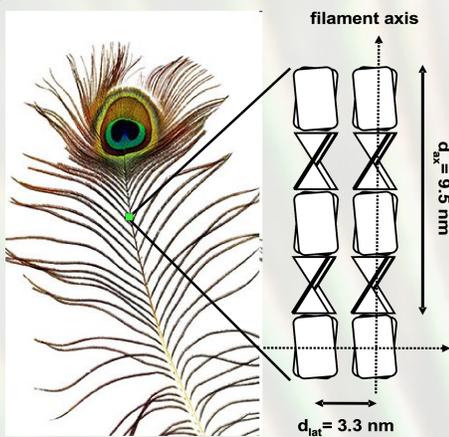


The nanomechanics of feather keratin studied by small-angle X-ray scattering

Silvia Pabisch⁽¹⁾, Stephan Puchegger⁽¹⁾, Helmut O. Kirchner⁽²⁾, Ingrid M. Weiss⁽²⁾, Herwig Peterlik⁽¹⁾
⁽¹⁾University of Vienna, Faculty of Physics, ⁽²⁾Saarland University, INM – Leibniz Institute for New Materials

Introduction

Feather keratin is a highly conserved protein of 98 amino acids synthesized intracellularly in aves. [1] Recent observations that electrostatic rather than H-bonds stabilize F-keratin structures make it necessary to revisit the usual filament-matrix models. [2,3] Therefore, in-situ X-ray diffraction experiments in tension and compression are presented. A pronounced asymmetry in tension and compression of peacock feathers was observed on the nanoscale. F-keratin forms a structure highly ordered crystalline in the axial direction and less ordered in lateral direction. Furthermore, no difference between macro- and nanostrain in axial direction is observed, which makes a hierarchical level between molecular scale and macroscale improbable. In lateral direction, filaments are weakly connected and there is no need to postulate the existence of a matrix. A bamboo roll model for the arrangement of the filaments is proposed.



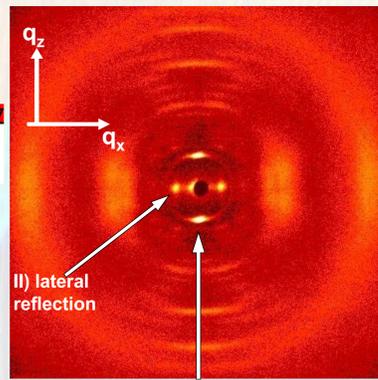
Characterization

Sequence of 98 amino acids:

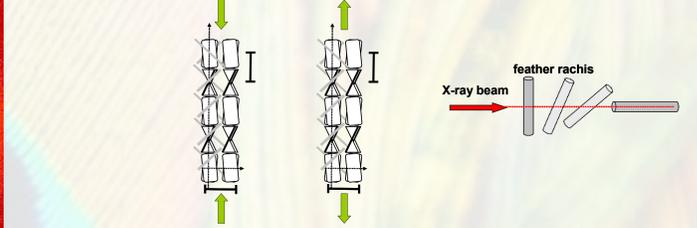
ACNDLCCPCGCTELANSCNEPCVROCEASRV
VIQPSIVVVVILGPTLISSEFP
QSTAVGGCASSSVGNELLASQGV
LYEGGGGLGLGLGCSGRRCVPC*

- crystalline β -core (31)
- N-Terminus (20)
- C-Terminus (47)

Helical arrangement of repeating unit, 9.5 nm per pitch



Analysis of 2 reflections in compression, tension and rotation:

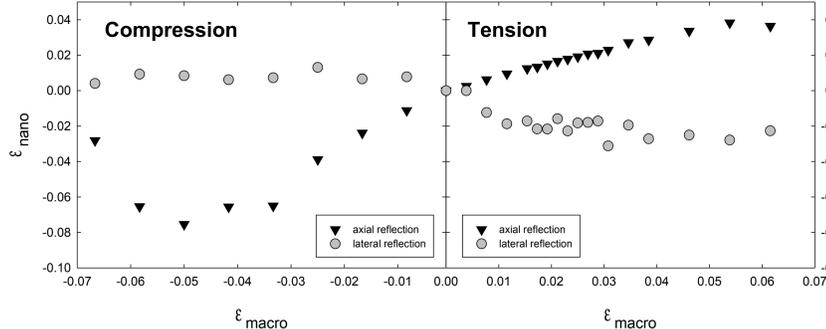


- I) Axial reflection (4th layer line) \rightarrow length of repeating unit d_{ax}
- II) Lateral reflection \rightarrow distance between strands d_{lat}

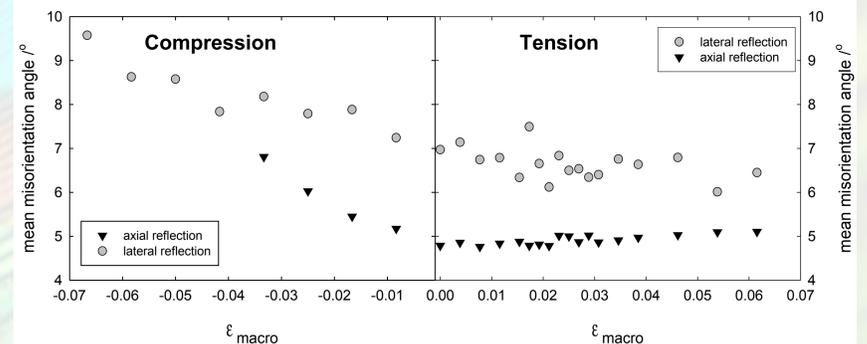
$$d_{ax,lat} = \frac{2\pi}{q_{max}}$$

Results

Axial



Slight asymmetry in compression and tension \rightarrow Poisson's ratio:
 $v_{comp} = 0.01 \pm 0.09$ $v_{tens} = 0.77 \pm 0.10$



Tension: decreasing mean misorientation angle \rightarrow small tendency towards higher alignment

Compression: Increasing mean misorientation angle \rightarrow nanobuckling

In tension: $\epsilon_{nano} \sim \epsilon_{macro}$ \rightarrow indicates no hierarchical levels in axial direction – high cross-linking within strands due to N- and C-termini
In compression: nanobuckling and low Poisson's ratio indicate weak cross-linking between strands

Lateral



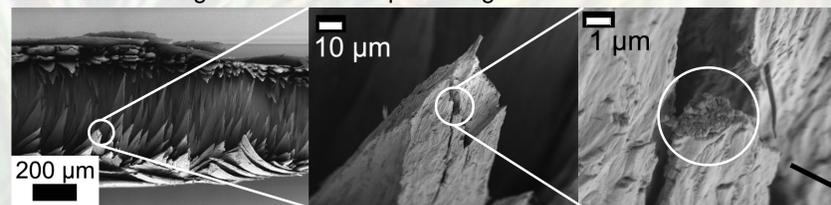
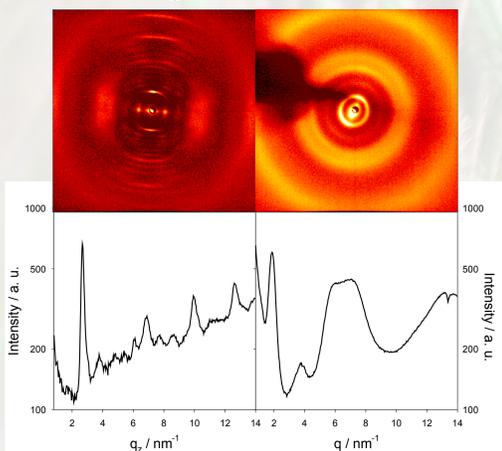
Left SAXS pattern: \rightarrow Pronounced crystalline order in axial direction

Right SAXS pattern: \rightarrow weak higher orders of lateral reflection indicate chain-like or lamellar order with typical distance of 3.4 nm

1D chain is rolled up to form a "bamboo" roll

"Bamboo" roll model is supported by:

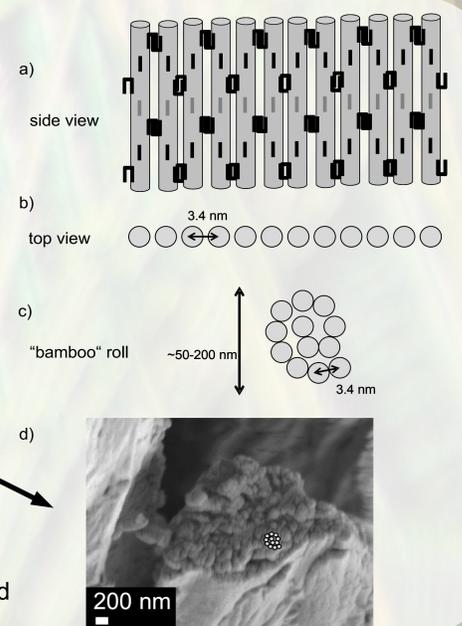
SEM fracture images – broken in liquid nitrogen



Left SEM image: no straight crack could be achieved – very stable structure [4]

Middle SEM image: triangle-shaped fracture, which reveals a bundle structure of about 1 micron

Right SEM images: small bundles with a diameter of 50-200 nm can be observed



Conclusion

Axial direction: Macrostrain and nanostrain are nearly identical in tension \rightarrow no hierarchical levels

Lateral direction: Compression instability suggests multiple hierarchical levels \rightarrow 1D chain forms a bamboo roll

Aim: Model for the structural arrangement of all 98 amino acids