

## PASSIVE AND ACTIVE MECHANICS OF BANKSIA SEED PODS

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Biological materials consist of only a few basic building blocks, namely sugars, proteins and a few minerals which are assembled into structurally complex materials to ensure (multi)functionality for the particular organism. Prominent examples are bone or nacre, composites of mineral and protein possessing high stiffness and strength. Apart from mineralized materials, protein- and sugar-based materials such as spider dragline silk or plant fibres achieve similarly high values. On the other end of the scale are soft materials with 3 to 4 magnitude lower stiffness and strength values (eg. parenchymatic tissue or artery). Common concept for all biological materials is that a wide range of material properties is achieved by structuring rather than changing their chemical components and frequently materials combine high strength and toughness when needed.

A comprehensive understanding of the structure function relationships of biological materials requires measurements of mechanical properties at a range of different length scales, often in combination with other techniques (eg. X-rays, microscopy, spectroscopy). This approach will be illustrated on the example of plants and especially dead but multifunctional tissues such as the seed pods of *Banksia attenuata*, a native Australian species. The seed storing pods can remain on the plant for up to 15 years without metabolism before they open upon elevated temperatures (eg. caused by bush fires). During the storage period the seed pod material must passively resist weathering, microbial degradation and attacks by bird beaks. Interestingly, the seed pods do not open at uniform temperatures. Instead, opening temperatures change gradually along a climatic South-North gradient increasing towards North. We were able to identify the "temperature sensor" of the seed pods: the inner curvature of the layered follicles gradually increases providing Northern seed pods with a higher flexural rigidity. Opening is activated by a temperature-dependent decrease of the elastic modulus of the inner resistance layer, allowing pre-stresses to be released. However, the initial opening is not sufficient to release the seeds, further opening is fueled by moisture changes which lead to directional swelling and at the same time to changing mechanical properties in different layers of the seed pod.

The findings on Banksia seed pods provide inspiration for self-sensing, moving and actuating materials and systems. We expect a comparably easy transfer into technical application because metabolism and biological signaling is not required for functionality. Since the material consists only of a few basic building blocks, namely cellulose, hemicelluloses, lignin, tannins and waxes, recycling and sustainable material use seem to be much easier compared to multi-component composites.