Investigating the Use of Friction to Achieve Ductility in Composites

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High performance lightweight composites are known for their high stiffness, high tensile strength and good fatigue properties. However, they usually show a brittle behaviour and fail abruptly without hardly any deformation as a warning. As a result, complex maintenance procedures and significantly greater safety margins than for conventional materials are currently required when designing composite parts. Thus, the introduction of pseudo-ductile behaviour into the otherwise brittle composites is highly desirable. [1]

The underlying idea of this project was inspired by natural nacre. Although nacre consists of approximately 95 % brittle mineral aragonite ($CaCO_3$) and of only 5 % weak but ductile proteins and polysaccharides, it outperforms its constituents in terms of toughness by a factor of 1000 without sacrificing much of the strength (cf. Fig. 1, right). The increase in toughness is achieved by a brick and mortar arrangement of mineral platelets and organic interfaces (cf. Fig. 1, left). One of the key mechanisms of this structure was found to be the interlocking wedge shape of the aragonite platelets in combination with internal constraints provided by the organic interfaces. Under tensile loading (cf. large black arrows in Fig. 1, middle), the platelets slide relatively to each other. The transverse opening caused by the wedges is constrained by the bonding nature of the organic interfaces (cf. small grey arrows in Fig. 1, middle). The friction, which is induced at the wedges' common interfaces (cf. normal forces marked as small black arrows in Fig. 1, middle), leads to strain hardening, delocalisation of failure and consequently to an increased failure strain. [2]

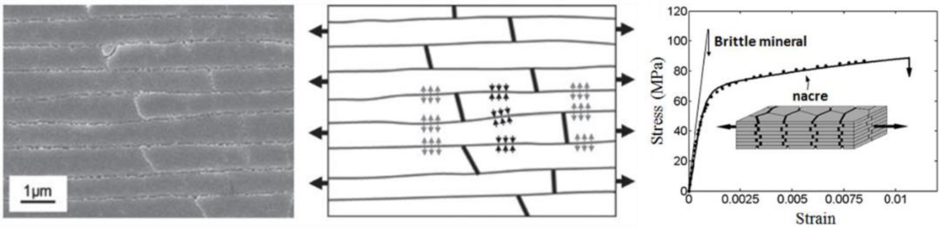

Fig. 1: Electron microscopy image of aragonite platelets of nacre (left); resulting stresses due to longitudinal tensile loading (middle); stress-strain diagram of aragonite and nacre (right); all images taken from [2]

The overarching goal of this work, which was comprised of **5 major steps**, was to find out if it is possible to create a strong but ductile engineering material by transferring the depicted nature-inspired friction mechanism to carbon fibre reinforced materials. Based on a **literature review** on natural and manmade materials which exploit friction or interlocking mechanisms, **analytical models** which describe the stress-strain relation of structures that harness the said friction mechanism could be derived. The models were then used to **design and dimension specimens** which were 3D printed from a polymer as well as specimens from carbon composite material with well-balanced combinations of material and geometrical properties for tensile testing. A major difficulty of this work was to find a reliable **manufacturing** technique for the composite wedge-shaped platelets. A suitable way of manufacturing the specimens implies curing skins of prepreg material in 0°-direction together with several scarfed layers of prepreg material in 90°-direction as filler between two wavy mould halves in an autoclave. Subsequently, the specimens underwent **tension tests** until they ultimately failed. The experiments revealed that after an initial region with high stiffness (static friction), the sliding mechanism (dynamic friction) took over. The experiments showed that it is possible to reach between 15 and 20 % strain in composites by making use of the friction mechanism. However, due to the weak external constraints which were made out of acrylic glass in order to be able to observe the sliding of the platelets, the specimens only reached strengths between 20 and 30 MPa. The measurements from the video extensometer revealed the desired uniform distribution of the elongation along the specimens. This is because every time two platelets happen to slide on each other a bit further than the other platelets, the specimen locally hardens and consequently other areas for the sliding mechanism are activated.

The principle of the friction mechanism of natural nacre accompanied by the desirable delocalisation of failure is now proven to work with composites in a laboratory environment. To pave the way for real material applications and to significantly strengthen the structure, internal constraints in the composite specimen can be realised. This could be achieved by bonding the CFRP platelets together with an adhesive or by machining connected wedge shaped platelets out of a composite laminate.

References

[1] Bacarreza O, Maidl S, Robinson P, Shaffer MSP. Exploring the Use of Friction to Introduce Ductility in Composites. ICCM21 - 21st International Conference on Composite Materials 2017.

[2] Barthelat F. Nacre from mollusk shells: a model for high-performance structural materials. Bioinspiration & Biomimetics 2010;5(3):35001.