“Tape-Based Structural Metamaterials”

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Abstract

Cylindrical fibers are one of the most abundant structural reinforcements in high-performance composites. Composite performance is dependent on load being shared between the reinforcing fibers and the matrix through adhesive interactions. However, the matrix has worse mechanical properties than the fibers; too much matrix will decrease composite performance. Moving to a flattened ribbon or tape-like fiber morphology significantly reduces the amount of matrix needed while maintaining strong inter-fiber adhesion. In a tape-based composite, the micromechanical, and thus, overall structural performance is determined by individual tape–tape junctions. The adhesive and mechanical behavior of tapes must be well understood.

Recluse spiders’ 50 nm-thin tape-like silk demonstrates the structural capabilities of tapes. The spider uses its tape silk to make a looped one-dimensional metastructure that significantly increases the web’s toughness. This enhancement is possible because individual tape–tape adhesive junctions of this microscopic sticky tape can withstand the material’s tensile failure stress of ≈1 GPa. We modeled these natural tape–tape junctions and revealed a bi-modal failure behavior, critically dependent on the two tapes’ intersection angle. One mode leads to low strength peeling failure, while the other causes the junction to self-strengthen. This eliminates the inherent weakness in peeling. The self-strengthening mechanism locks the two tapes together, increasing the junction strength by 550%. This impressive behavior is achieved despite there being no dedicated adhesive acting between the two tapes. Tapes do not need a dedicated adhesive to be mechanically robust.

We used our understanding of tape–tape junctions to make tape-based composites. We systematically studied the effect of inter-tape adhesion within the composites by using tapes with different adhesive strengths. One tape we used had separate backing and adhesive materials. The backing is the structural reinforcement while the adhesive is the matrix. We also used recluse silk inspired tapes that have strong inter-tape adhesion without a dedicated adhesive. Without a matrix, these tape-based materials are not composites, they are metamaterials or quasi-composites. Traditional composite theory predicts a composite without a matrix to have

mechanical properties equal to those of the structural reinforcement. However, our tape-based quasi-composites are 34% stronger and 291% tougher than the tapes used within the quasi-composites. This work proves that tapes are undervalued materials that can be implemented in structural metamaterials to outperform modern fiber-reinforced composites.