Bioinspired Fabrication and Characterization of a Synthetic Fish Skin for the Protection of Soft Materials

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materials that mimic the structural and mechanical aspects of natural fi

A macroscopic specimen consisting of 690 scales (see Figure 2c) and spanning an overall area of 153.39 ± 0.01 mm in the lateral direction by 167.87 ± 0.01 mm in the longitudinal direction was fabricated, and its mechanics was characterized using standard deformation tests. As compared in panels a and b of Figure 2 (left panels), the synthetic fish skin material has an imbricate layout similar to that of the striped red mullet. Upon bending (right panels in panels a and b of Figure 2), the scales of the natural fish skin and the man-made material begin to rotate and eventually interact, thus inducing bending of individual scales. The following sections compare the observed mechanics of the synthetic fish skin material to theoretical deformation models, thereby elucidating the critical mechathe transverse direction, $\varepsilon_{\text{trans,lat}}$. It was found that the observed Poisson effect was the result of the realignment of fibers in the direction of stretch, which induce a lateral contraction of the mesh. This phenomenon is therefore mostly governed by the geometry of the mesh and the direction of stretch with respect to the principal directions of the mesh. Furthermore, because of the nonlinearity of the material's response exhibited in Figure 4, these values are expected the change with deformation while the trends will remain the same. Interestingly, to the best of our knowledge, this phenomenon has not been reported in the literature, and it would be worthwhile to investigate whether this behavior is also observed in natural fish skins. Third, the response of the skin is clearly anisotropic. In the longitudinal direction, the scales provide very little resistance to strain, because the geometry and structure of the skin allows for the scales to slide across each other freely. In contrast, the scales are restricted from sliding in the lateral direction. Ultimately, these mechanisms allow the mesh to dictate the general response of the skin during stretch.

The final notable observation is that the in-plane strain-stiffening behavior is fully controlled by the geometry of the mesh, which dictates when fiber deformation undergoes the transition from a soft bending mode to a stiffer tensile mode. Figure 4e demonstrates the use of the model for designing a mesh or dermis layer with the desired tensile response for the synthetic fish skin material. Three distinct mesh geometries

bending response in the longitudinal direction: (1) tuning pocket stiffness and (2) controlling substrate thickness. The effect of pocket stiffness is considered by removing the foam substrate from the model (specifically achieved by setting t_{foam} to 0). These results are shown as solid curves in Figure 5e, where it is noted that an increase in normalized pocket stiffness, $\overline{K}$, leads to an increase in skin stiffness and a reduction of the stiffening response at higher curvatures. The blue curve [$\overline{K}$ = 0.05 (far right)] demonstrates the effect of low pocket stiffness, which causes the overall skin to be much more flexible initially than a similar specimen with high pocket stiffness. The discrete points in Figure 5e represent the scaled substrate as modeled in Figure 5a, only with varying values of substrate thickness as specified within the plot. It is noteworthy that adding the foam substrate increases the sti

to the foam, the internal moment of the specimen is calculated as the sum of the moments generated by the scales and the foam:

$$= \boldsymbol{E} \quad \kappa + \boldsymbol{E} \quad \kappa \tag{A9}$$

where $E_t I_f$ is the flexural stiffness of the foam as calculated above, E_s is the modulus of elasticity of the CAB sheet (800 MPa), and I_s