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Toughness anisotropy in feather keratin

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The presence of mechanical anisotropy has been identified in the β-keratin composite from which the feathers and claws of birds are composed. It is known that the degree of molecular "misorientation" of the composite can explain local variations in the longitudinal Young's modulus of material from feather shafts [1]. Transverse and longitudinal moduli have recently been found to differ [2] in ostrich claw keratin. Because of the small size of even the largest feathers, measurements of transverse properties of the feather keratin composite are difficult to make. One property that it is technically feasible to measure on small samples is fracture toughness. Instrumented scissors have been used successfully to measure the fracture toughness of small samples of plant and animal tissues [3, 4]. Briefly, in these studies a pair of scissors has been fitted between the crossheads of a universal test machine and the work done in cutting through the test specimen recorded. Calibrations need to be performed prior to testing to determine the work done during cutting without a test specimen in place. Frictional forces as the blades close are not constant as scissor blades are slightly curved (what is termed their "set"). Also, bearings must be fixed to the handles and frictional losses will occur in these unless well lubricated. To calculate the work of fracture of the specimen, the work done in cutting the specimen is measured from the load-displacement trace and divided by the area of the cut surface to give the work of fracture (J m^{-2}).

Since the samples of keratin we wished to examine were small, we adopted a slightly different approach to cutting. A modified pair of toenail clippers (Boots PLC, Nottingham, UK) were used to cut the specimens. The clippers comprised a pair of sprung beams, joined at one end, the opposing blades at the free ends. Although the blades of the clippers were curved (radius of curvature approximately 18.5 mm) the use of small test pieces (<3 mm) meant that the actual length of the cut surface was only 0.1% greater than the straight-line distance. The clippers normally operate by depressing a lever attached by a spigot close to the blades; this was removed and force applied directly to the end of the clippers by the compression plattens of an Instron 5564 universal test machine (Instron Ltd., High Wycombe, UK). The force versus displacement curve of the clippers was recorded-force increased linearly until the blades made contact. Cutting tests on the samples of keratin were carried out at a test speed of 2 mm min^{-1}. A feather from each of 5 ostriches (*Struthio camelus* L.) was available for study. Small squares of keratin were cut from the proximal end of the dorsal surface of the feathers. Small samples were taken to avoid any possible influence of specimen curvature on the results. Two longitudinal and two transverse test specimens were prepared from each feather and these data pooled to give a single value of transverse and longitudinal cutting energy for each feather. The force-displacement diagram of a typical test is shown in Fig. 1. The work done in cutting the specimen was taken as the difference between the area under the load-displacement curve during a test and the calibration curve.

The mean longitudinal cutting energy was 5.31 kJ m^{-2} (SEM = 0.89, range 3.02–7.89 kJ m^{-2}) and the mean transverse energy 15.14 kJ m^{-2} (SEM = 1.65, range 10.64–18.07 kJ m^{-2}). The difference in toughness was statistically significant (paired t-test comparison, $t_4 = -6.16$, $p = 0.0017$).

The feather keratin composite from the feathers we examined clearly shows significant differences in fracture toughness between longitudinal and transverse directions. The explanation for this is likely to lie in the patterns of microfibrillar orientation present within the material. The presence of multi-directionality in feather keratin has been identified qualitatively [5, 6] and, more recently, quantitatively [1]. Most keratin molecules tend to be orientated predominantly axially, so it would be surprising if we did not observe mechanical anisotropies. The range of values of toughness we found (3.02–18.07 kJ m^{-2}) are similar to those reported in studies of mammalian α-keratin, for example human finger nail has a longitudinal toughness of

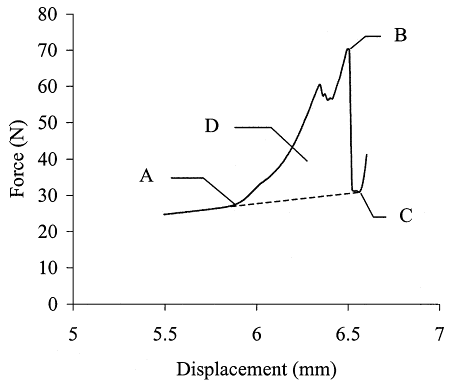

Figure 1 The first phase of the graph shows force increasing linearly with displacement until contact is made with the specimen at A. The force rises rapidly as cutting commences, then suddenly decreases (B) when the specimen has completely cut through. Finally, there is a rapid increase in force as the blades make contact at C. The area, D, above the calibration curve (dashed line) represents the work done cutting the keratin sample.

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6.76 kJ m^{-2} and a transverse toughness of 17.06 kJ m^{-2} [4].

Despite differences in the molecular structure of α- and β-keratin, the toughness of the two types of keratin appears quite similar. Further research is required to explore the implications of these patterns and how modification by biotic and abiotic factors may influence their function in the living organism.

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