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Structure and Mechanics Patterns in the Assembly of Type V Intermediate-Filament Protein-Based Fibers

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Abstract : Intermediate filament (IF) proteins-based fibers are among the toughest fibers in nature, as was shown by native hagfish slime threads and by synthetic fibers that are based on type V IF-proteins, the nuclear lamins. It is assumed that their mechanical performance stems from two major factors: (1) the transition from elastic □-helices to stiff□□-sheets during tensile load; and (2) the specific organization of the coiled-coil proteins into a hierarchical network of nano-filaments. Here, we investigated the interrelationship between these two factors by using wet-spun fibers based on C. elegans (Ce) lamin. We found that Ce-lamin fibers, whether assembled in aqueous or alcoholic solutions, had the same nonlinear mechanical behavior, with the elastic region ending at ~5%. The pattern of the □□□□transition was, however, different: the ratio between □-helices and □-sheets/random coils was relatively constant until a 20% strain for fibers assembled in an aqueous solution, whereas for fibers assembled in 70% ethanol, the transition ended at a 6% strain. This structural phenomenon in alcoholic solution probably occurred through the transition between compacted and extended conformation of the random coil, and not between □-helix and □-sheets, as cycle analyses had suggested. The different transition pattern can also be explained by the different higher order organization of Ce-lamins in aqueous or alcoholic solutions, as demonstrated by introducing a point mutation in conserved residue in Ce-lamin gene that alter the structure of the Ce-lamins' nano-fibrils. In addition, biomimicking the layered structure of silk and hair fibers by coating the Ce-lamin fiber with a hydrophobic layer enhanced fiber toughness and lead to a reversible transition between □-helix and the extended conformation. This work suggests that different hierarchical structures, which are formed by specific assembly conditions, lead to diverse secondary structure transitions patterns, which in turn affect the fibers' mechanical properties.

Keywords : protein-based fibers, intermediate filaments (IF) assembly, toughness, structure-property relationships
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