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Fishnet Statistics for Probabilistic Strength and Scaling of Nacreous Imbricated Lamellar Materials

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Abstract: Similar to nacre (or brick masonry), imbricated (or staggered) lamellar structures are widely found in nature and man-made materials, and are of interest for biomimetics. They can achieve high defect insensitivity and fracture toughness, as demonstrated in previous studies. But the probability distribution with a realistic far-left tail is apparently unkonwn. Here, strictly for statistical purposes, the microstructure of nacre is approximated by a diagonally pulled fishnet with quasibrittle links representing the shear bonds between parallel lamellae (or platelets). The probability distribution of fishnet strength is calculated as a sum of a rapidly convergent series of the failure probabilities after the rupture of one, two, three, etc., links. Each of them represents a combination of joint probabilities and of additive probabilities of disjoint events, modified near the zone of failed links by the stress redistributions caused by previously failed links. Based on previous nano- and multi-scale studies at Northwestern, the strength distribution of each link, characterizing the interlamellar shear bond, is assumed to be a Gauss-Weibull graft, but with a deeper Weibull tail than in Type 1 failure of non-imbricated quasibrittle materials. The autocorrelation length is considered equal to the link length. The size of the zone of failed links at maximum load increases with the coefficient of variation (CoV) of link strength, and also with fishnet size. With an increasing width-to-length aspect ratio, a rectangular fishnet gradually transits from the weakest-link chain to the fiber bundle, as the limit cases. The fishnet strength at failure probability 10^{-6} grows with the link strength scatter as well as with the width-to-length ratio. For a square fishnet boundary, it is typically almost two orders of magnitude higher than it is for the non-imbricated case. This is a major safety advantage of the fishnet architecture over particulate or fiber reinforced materials. There is also a strong size effect, partly similar to that of Type 1. The predicted behavior is verified by about a million Monte Carlo simulations for each of many fishnet geometries, sizes and CoVs of link strength. In addition to the weakest-link or fiber bundle, the fishnet becomes the third analytically tractable statistical model of structural strength, and has the former two as limit cases.

Key Words: Structural safety, probabilistic mechanics, nacre, biomimetic materials, random strength, probability distribution tail, imbricated lamellar structures, staggered platelet structures, Monte Carlo simulations.

Contents

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