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Mini Review

Buckling Behaviour of Protein Microtubules

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Abstract

Protein microtubules take part in several cellular activities including mitosis, cell movement and migration. During these cellular activities, they can be subject to various types of external loading and pressure. In this study, the bucking of protein microtubules obtained via scale-dependent continuum models are investigated. Several continuum-based formulations, which have been proposed for the buckling of protein microtubules, are reviewed briefly. Finally, the effects of surface elastic properties on the growth rate of buckling in protein microtubules are studied.

Keywords: Protein microtubules; Buckling; Axial loading; Size effects

Introduction

Size effects have a crucial role to play in the statics and dynamics of various ultra-small structures [1-6]. On the other hand, the mechanics of nanostructures [7-14] and microstructures [15-26] is of high importance due to their applications in different nanomechanical and micromechanical systems such as Nano sensors and nanoactuators. Therefore, developing size-dependent mathematical frameworks for analyzing the statics and dynamics of both nanostructures and microstructures would provide a useful tool in nanoengineering and microengineering. Protein microtubules are one of the most important parts of living cells, which participate in many processes inside cells [27,28]. For instance, in the process of mitosis, microtubules help chromosomes to separate and migrate into two opposite positions. In addition, these filaments provide a reliable pathway for protein transportation inside cells. In these processes, microtubules are likely to be subject to various loads such as axial compression. In this study, the buckling instability of protein microtubules under axial compressive loads is investigated. Different size-dependent models of these small-scale structures are also reviewed.

Buckling of Microtubules

Let us consider a single microtubule of length L, inner radius Ri and outer radius Ro. The microtubule has a hollow cylindrical geometry and consists of α and β tubulins, as shown in (Figure 1). It has been proven that size influences have a significant impact on the mechanica0000000l behavior at small-scales [29-36]. Since the inner and outer radii of microtubules are of several nanometers, the nonlocal theory is mostly used to describe size influences. The nonlocal theory is an elasticity-based theoretical tool, which was first utilized by Peddieson et al. [37] for the deformation of nanostructures. According to this theory, we have the following differential equation for the constitutive response of microtubules.

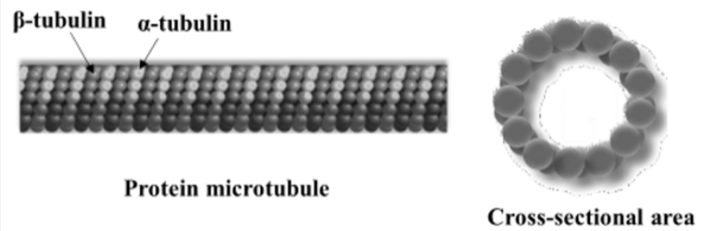

Figure 1: The structure of a protein microtubule.

$$\sigma-\mu_{nl}-\nabla^2\sigma=C:\varepsilon$$

Where

$$\mu_{nl}=(e_0 l_c)^2\ ,$$

In which σ , C and ε are, respectively, the stress, elasticity and strain tensors; moreover, ∇^2 and $e_0 l_c$ stand for the Laplace operator and nonlocal constant, respectively; also, l_c and e_0 are symbols, which are used for calibrating the model and incorporating the effects of the internal configuration of the structure [38,39]. In addition to nonlocal effects, surface influences have a crucial role to play in the mechanics of ultra small structures such as microtubules. At nanoscales, surface influences become important since the ratio of the surface energy to its bulk counterpart substantially increases. For the microtubule, there are two different surface layers (i.e. outer and inner surface layers). To incorporate surface influences, the following equations can be utilized [40,41].

$$\sigma_{sur=}\tau_{sur}+C_{sur}\varepsilon_{sur}\ ,$$

Where

$$\lambda_{sur=}\left[\Lambda+\frac{\partial\Lambda}{\partial\varepsilon_{sur}}\right]_{\varepsilon_{sur}=0}$$

Here "sur" is employed to indicate "surface". λ_{sur} is the residual stress in surface layers [42], and ʌ represents the microtubule surface energy density. Figure 2 depicts the dimensionless growth rate of buckling in protein microtubules [43] subject to axial compression. Calculations are conducted for various surface elastic constants [40]. The horizontal axis of the figure denotes the instability wave number. It is concluded that the growth rate of buckling in microtubules decreases when the elastic constant of surface layers increases. This is because of the fact that the surface elastic constant is associated with an increase in the microtubule stiffness.

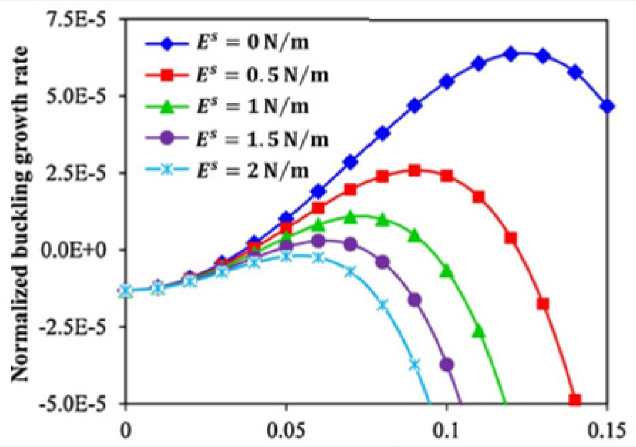

Figure 2: Buckling behaviour of microtubules for different surface elastic constants [40].

Conclusion

The buckling instability of microtubules in human cells has been investigated via scale-dependent theoretical models. Two main scale-dependent theories for the statics and dynamics of microtubules (i.e. surface and nonlocal theories of elasticity) were reviewed briefly. Finally, the influences of buckling wave number and surface elastic constant on the buckling behaviour were studied. It was concluded that higher surface elastic constants substantially reduce the growth rate of buckling in the protein microtubule.

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