

Effects of Carbon Nanotube Dispersion on the Material Properties of Polymer Matrix Composites



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Abstract

Carbon nanotubes (CNTs) constitute a prominent example of structural nanomaterials, with many potential applications due to their unique mechanical properties. Substantial improvements in mechanical properties of polymers have been attained through the addition of small amounts of carbon nanotubes. The way in which CNTs are distributed inside the matrix can be divided into two main categories namely: aligned and randomly distributed. Modeling of carbon nanotube dispersion in the polymer matrix is an important step for understanding the characteristics of composites. For modeling CNTs dispersion in the polymer, a numerical homogenization technique based on the finite element method (FEM) is used.

Introduction

The combination of extraordinary mechanical and physical properties makes CNTs prospective candidates for reinforcement of polymer matrix composite systems. Besides their extraordinary small size, CNTs are half as dense as aluminum, with a density of 1.33-1.4 g/cm³. CNTs have Young's modulus of about 1TPa and tensile strength 20 times that of steel alloys. Tensile strength of single-walled carbon nanotubes (SWCNTs) is as high as 2GPa, which is much higher than that of high strength steels [1,2]. Models were developed based on the method presented in [3,4] to determine nanocomposite effective mechanical properties. The results of nanocomposite reinforced with randomly distributed nanotubes in the FEM model presented in Figure 1 and Table 1 & 2.

Table 1: Computed Young's moduli of randomly distributed CNT-reinforced nanocomposite.

E_z/E_m	E_y/E_m	E_x/E_m	E_m
1.03	1.027	1.021	100
1.041	1.038	1.037	90
1.055	1.049	1.045	70
1.093	1.07	1.05	50
1.121	1.133	1.108	30
1.185	1.146	1.132	20
1.231	1.178	1.168	10
1.31	1.293	1.289	3.2

Table 2: Poisson's ratios of randomly distributed CNT-reinforced nanocomposite.

E_m	ν_{xy}	ν_{xz}	ν_{yx}	ν_{yz}	ν_{zx}	ν_{zy}
100	0.2981	0.2981	0.2978	0.2937	0.2927	0.2982
90	0.2925	0.2978	0.2928	0.2989	0.2975	0.2942
70	0.2926	0.2926	0.2981	0.2908	0.2912	0.2998
50	0.2847	0.2858	0.2898	0.2871	0.2849	0.2851
30	0.2953	0.2883	0.2988	0.2892	0.2941	0.2953
20	0.2903	0.2844	0.2985	0.2906	0.2945	0.2991
10	0.2983	0.2933	0.2974	0.2992	0.2905	0.293
3.2	0.2888	0.2858	0.2905	0.2933	0.2912	0.295

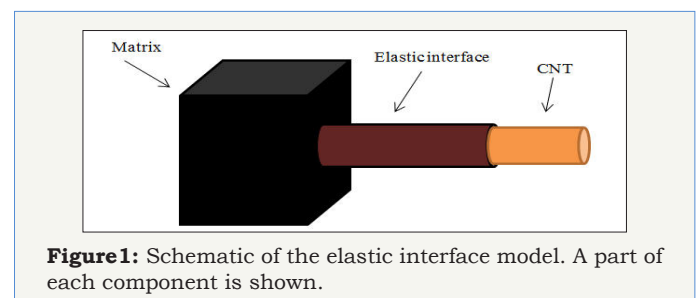


Figure 1: Schematic of the elastic interface model. A part of each component is shown.

The ratio of nanocomposite modulus to matrix modulus in the longitudinal direction, E_z/E_m , is equal to 1.310 in this case for the matrix with modulus of 3.2GPa. This is about 20% lower than the uniformly distributed CNT reinforced nanocomposite

longitudinal modulus [3-5]. A comparison of the results with those obtained for the uniform distribution of straight CNTs indicates that strengthening is much more homogeneous in the randomly distributed CNT case. That is, the ratios of nanocomposite longitudinal and transverse moduli to matrix modulus are close

in this case (at equal E_m values). These results suggest that the random distribution of the CNTs reinforces the matrix in all three directions. In fact, in case of transverse moduli, the portions of CNTs that are oriented along the x- and y-directions contribute to the nanocomposite moduli in those directions.

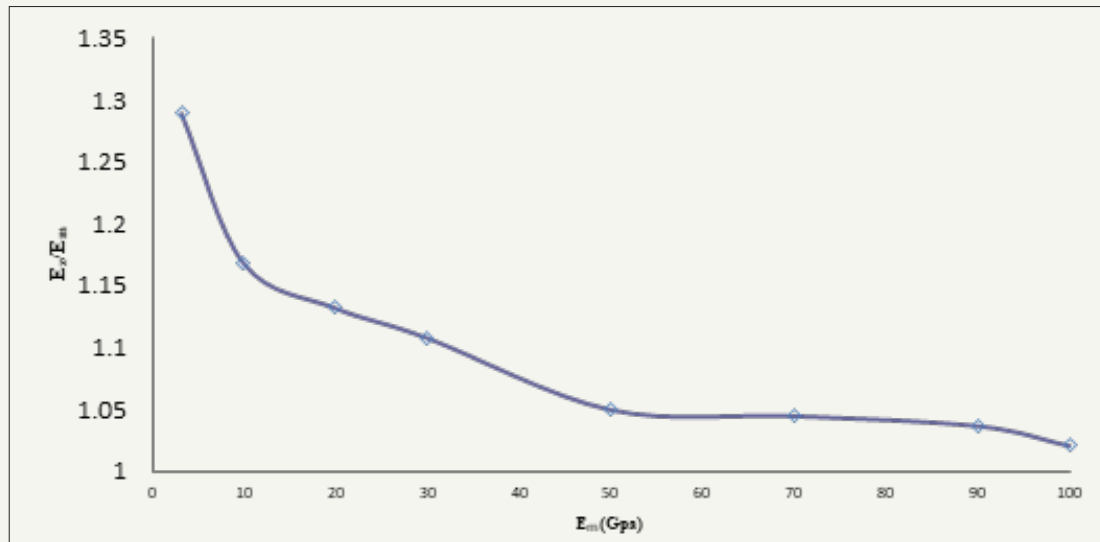


Figure 2: Variation of E_z/E_m with matrix modulus for randomly oriented CNT-reinforced nanocomposite.

Nanocomposite longitudinal modulus decreases with increasing CNT inclination angle, thus limiting the overall effective modulus of the nanocomposite. The variation of nanocomposite longitudinal modulus to matrix modulus, E_z/E_m , with matrix modulus is shown in Figure 2. Note that the ratio of nanocomposite longitudinal modulus to matrix modulus decreases as the matrix modulus increases in this case as well.

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