Issues about Strength of Nanofiber Reinforced Composites

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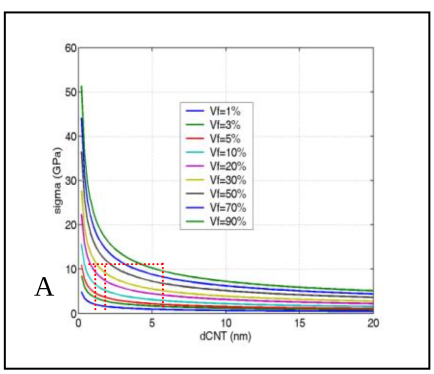
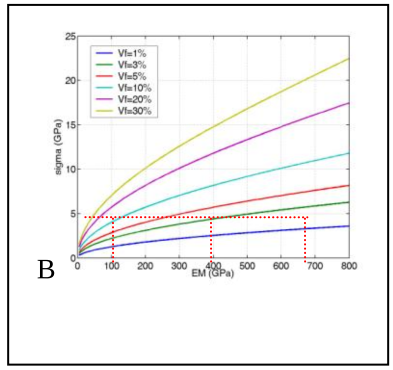
How to effectively increase the mechanical strength of nanofiber/nanotube reinforced nanocomposites has been a challenge to the scientific community. This article investigates main factors affecting strength of nanofiber/nanotube reinforced nanocomposites based on energy consideration. It shows that the strength of nanocomposites is systematically dependent on the volume fraction of nanofibers added, their diameters, the interfacial bonding strength between the nanofiber and the matrix, as well as the Yong's moduli ratios between the nanofiber and the matrix, as following equation indicates:

$$\sigma = 2\sqrt{\frac{E_M s^* V_f}{d_{NF}(1-\frac{E_M}{E_{NF}}V_f)}} + \sigma_M(1-V_f) \quad (1)$$

Where E_M stands for Young's modulus of matrix, s* stands for interfacial bonding strength, V_f is the volume faction of nanofiber (NF), d_{NF} denotes the diameter of nanofiber (NF), E_{NF} is the Young's modulus of NF, and σ_M is the strength of the matrix.





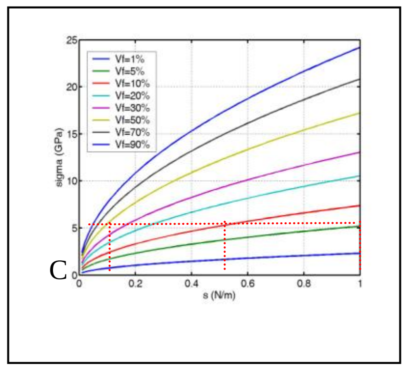
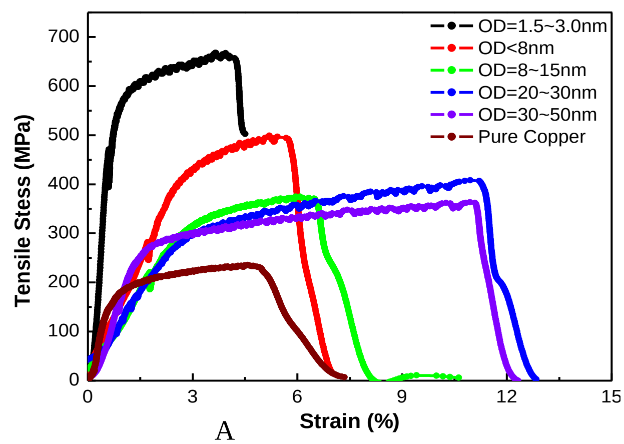


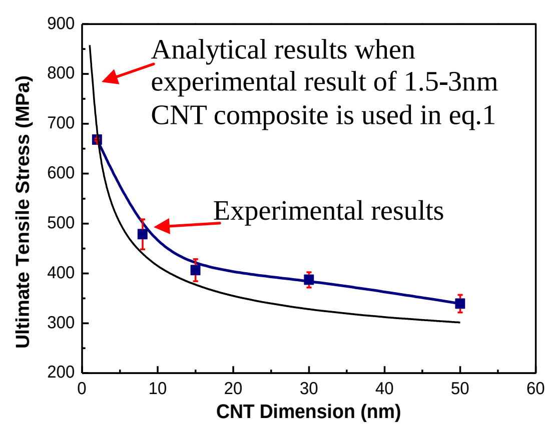
Fig.1 A) Relationships between reinforced strength (first part of eq.1) and diameter of nanofiber/nanotube. The interfacial bonding energy density is fixed at 0.5N/m. B) Reinforced strength versus Young's of a matrix c) reinforced strength versus interfacial bonding strength density. Insets are different volume fractions. Except other mentioned, typical values for comparisons are: Young's modulus of matrix and the nanotube/nanofiber are 200MPa and 1,000MPa, respectively. The typical diameter of nanotube/nanofiber is 1.5nm, and the typical interfacial bonding density is 0.7N/m.

The schematic relationships between reinforced strength and dependent factors are shown in Figure 1. Fig. 1A indicates that the reinforced strength is largely dependent on the diameter of the nanofiber/nanotube. For example, in order to realize a nanocomposite with strength of 10GPa, it will need 90% nanofiber/nanotube if the diameter is 5nm (Fig. 1A). The volume fraction will be reduced to 20% if the diameter is reduced to 2nm. If the diameter is reduced further to 1nm the required volume fraction of nanofibers will be only 5%. Therefore, a much smaller volume fraction is needed if a smaller diameter nanotube/nanofiber is used. On the other hand, for the same amount of nanofiber addition, the smaller the diameter the greater the reinforced strength of the nanocomposite. For example, for a 1% addition of nanofibers, the resultant strength of nanocomposite will be about 4GPa if nanofibers are 1nm in diameter. However, nanofibers with 10nm in diameter will produce only about 0.2GPa in strength. Therefore a much less required addition of diameter nanofibers with smaller diameters to achieve a desired resultant strength. The smaller addition smaller diameter nanofibers makes nanocomposites more efficient and more cost effective in comparison to conventional composites.

Figure 2A shows experimental results of tensile stress-strain responses of Cu/CNT composites fabricated with electrochemical deposition in which similar interfacial boding is achieved, when different CNT diameters were used. The ultimate strength of pure copper is about 230MPa, which is the similar as published data. When CNTs with diameter of 30nm-50nm was added to form Cu/CNT composite, the resultant tensile strength is increased to about 350MPa, or about 52% greater than that of pure copper in tensile strength. Under the same condition, if the same CNTs smaller diameters (20nm~30nm) were used, the resultant tensile strength is increased to about 400MPa, or about 74% greater than that of pure copper. When CNT diameter of <8nm was used the resultant tensile strength is increased to about 500MPa, or about 117% higher than that of pure copper. Similarly, if Cu/CNT nanocomposite was fabricated with diameter of 1.5nm~3nm the resultant tensile strength is increased to about 670MPa (Cu/DWNT, Figure 2A). This value is about 191% greater than that of pure copper, or almost about three times of that of the pure copper fabricated under the same condition. These data show that the smaller the CNT diameters the greater tensile strength will be resulted (Figure 2B). The trend denoted in Figure 2B agree well with eq. 1 and predications as shown in Figure 1A. Future work will investigate the interfacial bonding by the combination of analytical and experimental approaches.



A



B

Fig. 2 Tensile stress-strain curve of pure Cu and Cu/CNT composites with different diameters (A) and averaged tensile strengths versus CNT diameters of Cu/CNT composites (B)