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Mechanical and electrical properties of carbon nanotube reinforced epoxide resin composites

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Abstract: Carbon nanotubes (CNTs)/epoxide resin composites were prepared, the mechanical and electrical properties of the composites were investigated. The effects of concentration and dispersion state of CNTs on the tensile strength, tensile modulus and electrical resistance of the composites were studied. The results indicate that the CNTs can be dispersed well in the epoxide resin matrix by ultrasonic method, and the mechanical and electrical properties of epoxide resin matrix can be improved significantly. The tensile tests show that the tensile strength and tensile modulus are higher than those of epoxide resin if the content of CNTs is less than 1.75% (mass fraction). When the content of CNTs is 0.75%, the conditional best results are obtained, the tensile strength of the composite is the highest, increased by 18.3% and the tensile modulus is increased by 20.5% compared with the matrix. With the increase of CNTs, the electrical resistance of the composites decreases greatly, while the conductivity of the composite increases. The percolation threshold values of electrical characteristic transformation for this composite material were determined for the first time.

Key words: carbon nanotubes; composites; epoxide resin; mechanical properties; electrical properties

1 Introduction

Carbon nanotubes (CNTs) have unique mechanical properties, excellent electrical conductivity and very high aspect ratio[1]. This makes CNTs be extremely useful. According to the CNTs different properties, their advantages could be used in the electronic device making, electrode materials preparation and reinforcement of various composites[2−4], etc. It is well known that CNTs are one of the most promising nanomaterials in the 21st century.

CNTs/epoxide resin composites have resin as matrix and CBTs as reinforcers. Epoxy resin has excellent mechanical and physical properties, which can be used in coatings, adhesives, and resin matrix composite. But the cured resin is usually friable, their fatigue durability, the thermal stability, and resistance to impact are poor, and the electrical properties are not good enough. Theoretically, the carbon nanotubes addition can improve the mechanical properties and the electrical properties of the epoxy resin greatly, and expand the application of epoxy resin to a larger extent. ALLAOUI et al[5], SCHADLER et al[6], BRETON et al[7] have prepared carbon nanotubes/epoxide resin composites by melt mixing method. They have found that carbon nanotubes can improve the mechanical properties of epoxide resin matrix. LI et al[8] have fabricated carbon nanotubes/epoxy composite fibers. In their studies, the tensile strength and tensile modulus are improved 25% and 75%, respectively. The maximum tensile strength and elastic modulus are as high as 1.5 GPa and 28 GPa due to the uniformity of stress-loading optimized by epoxy matrix.

In this work, the carbon nanotubes (CNTs)/ epoxide resin composites were prepared by ultrasonic dispersion and vacuum casting. The effects of carbon nanotubes on tensile strength and electrical resistance of composites were studied. The fracture surface appearances of the composites material were observed, and the enhancement mechanisms of carbon nanotubes were discussed.

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2 Experimental

The carbon nanotubes were bought from Chengdu Institute of Organic Chemicals, Chinese Academy of Sciences. Their diameter was about 8−15 nm, length was about 50 μm, the purity was over 95%. The epoxide number of epoxide resin (E-44) was 0.41−0.47. The amine number of the low molecule polyamide was 380−420 mg/g.

The experimental instruments included ultrasonic equipment (Ultrasonic Instrument Company of Kunshan), electric hot water tank (Laboratory Instrument Factory of Hangzhou Sky), scanning electron microscope (Sirion models −200, Japanese), transmission electron microscope, electrochemical station (Solartorn companies), the electronic testing machine, and vacuum drying chamber.

To prepare carbon nanotubes/epoxide resin composites, carbon nanotubes were added and stirred into proper quantity of solvent, and then treated by ultrasonic method for 1 h to form a homogeneous suspension. According to the designed proportion, epoxide resin was added to the suspension and dispersed by ultrasonic treatment for specific time. After removing the excess solvent of the mixture by vacuuming, then a curing agent was stirred into the CNTs/epoxide resin suspension for a moment. After that, the mixture was placed in a vacuum chamber to degas the bubbles induced by stirring. Finally, the mixture was cured through several stages to form densified samples for property measurements and structural observations.

3 Results and discussions

3.1 Effect of ultrasonic dispersion

To test the effect of ultrasonic dispersion method, the transmission electron microscope (TEM) was used to observe the as-received and dispersed CNTs. Fig.1 shows the TEM image of as-received carbon nanotubes, it can be found that the carbon nanotubes are bended and twisted together, aggregating to a bulk structure in micro-scale. In order to break the aggregated CNTs, the CNTs are put into alcohol and mixed by ultrasonic treatment for specific time. The TEM image of dispersed CNTs is shown in Fig.2, it can be seen that the CNTs are in a very good dispersion state, and the degree of aggregation between CNTs decreases greatly. It is easy to distinguish the single nanotube. Therefore, the ultrasonic dispersion of carbon nanotubes can decrease the degree of aggregation, helping to make full use of the outstanding characteristics of the CNTs.

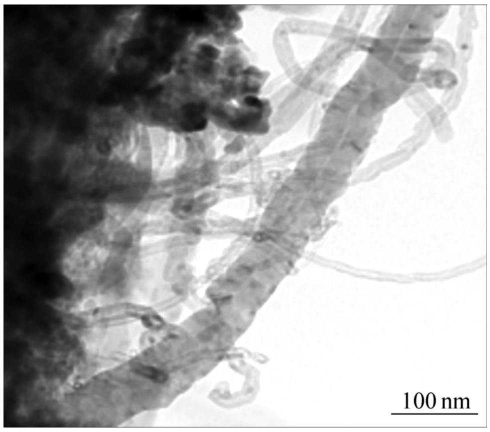

Fig.1 TEM image of original CNTs

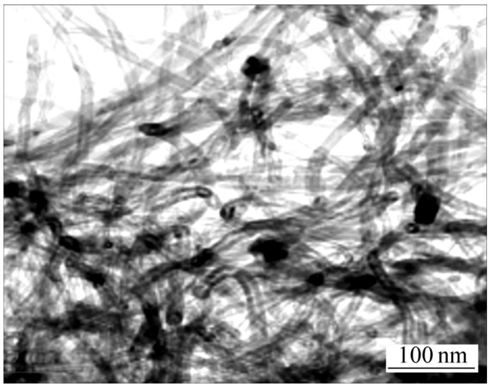

Fig.2 TEM image of dispersed CNTs

3.2 Mechanical properties of composites

To measure the mechanical effect of CNTs on the matrix, the samples with specific size of composites were prepared according to the requirements of tensile test. The results of the tensile strength and tensile modulus are shown in Figs.3 and 4. It can be found that the carbon nanotubes can improve the tensile strength and tensile modulus of resin matrix obviously. With the increase of carbon nanotubes, both the tensile strength and tensile modulus of composites increase. However, when the addition of CNTs is over 1.75%, the extra CNTs addition will cause a decrease of the mechanical properties. In this study, 0.75% carbon nanotube addition has the best effect on the mechanical properties of the matrix. The tensile strength increases by 18.3% and the tensile modulus increases by 20.5% compared with the matrix. The mainly probable reason is that a carbon nanotubes network structure is formed, which can take more mechanical loading from the matrix when the matrix is under stress. This means that when the applied loading is over the elastic deformation stress, the carbon nanotubes have a stress transfer effect[9−11], which can enhance the strength and plasticity of the resin matrix.

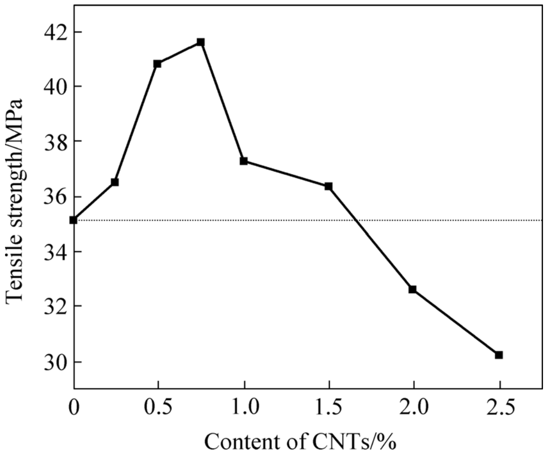

Fig.3 Influence of CNTs on tensile strength

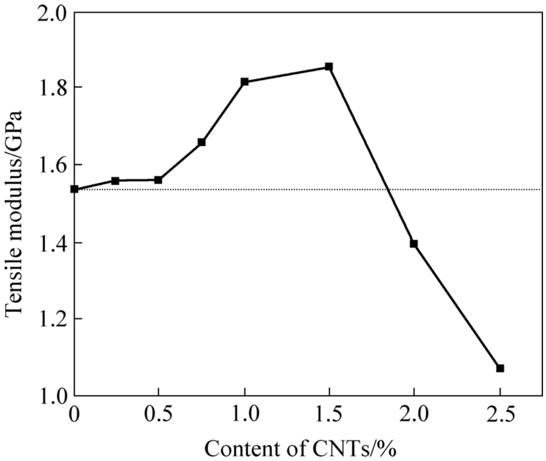

Fig.4 Influence of CNTs on tensile modulus

When the content of carbon nanotubes is less than 1.75%, the carbon nanotubes are dispersed uniformly in the matrix, without obvious agglomerating. However, too much CNTs (more than 1.75%) will do harm to the matrix, and the strength of composites will be lower than that of the matrix. This may be resulted from the bad dispersion of too much more CNTs. The extra CNTs will aggregate more seriously due to their high aspect ratio, and to produce a lot of defects in the matrix. Too much more CNTs can also increase the viscosity of the resin matrix and impede the removal of bubbles, thus a lot of cavity would be remained in the matrix and degrade the mechanical properties to a great extent.

The SEM images of tensile fracture surfaces with different contents of CNTs are shown in Fig.5. The fracture surface of pure epoxide resin in Fig. 5(a) is very smooth, which is a typical brittle fracture. This indicates that the epoxide resin is very brittle.

The appearance of tensile fracture surface has changed greatly after adding carbon nanotubes, see Figs.5(b)−(d). When the content of carbon nanotubes is 0.25%, the appearance of tensile fracture surface of composites becomes rougher and ragged like clouds. With further increase of carbon nanotubes, the tensile fracture surface is much rougher and their crack becomes more random. This is probably because the crack expansion is blocked by the CNTs network and when the loading increases, the crack will form in the weak area of

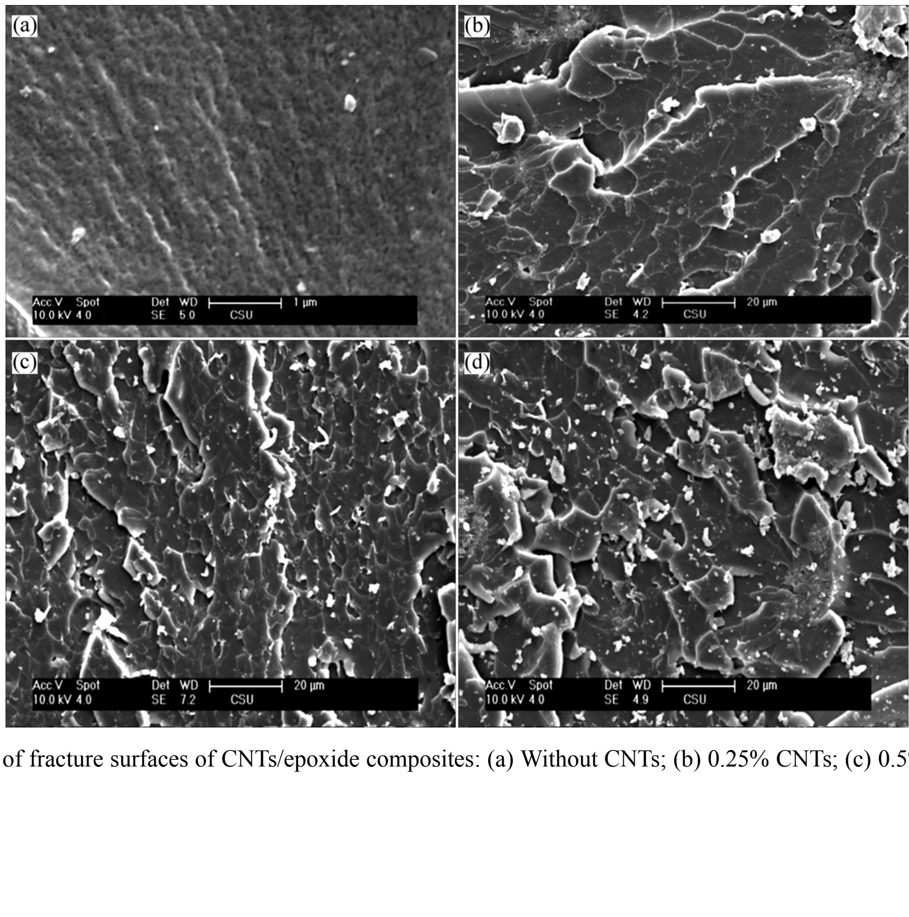

Fig.5 SEM images of fracture surfaces of CNTs/epoxide composites: (a) Without CNTs; (b) 0.25% CNTs; (c) 0.5% CNTs; (d) 0.75% CNTs

the CNTs network[12]. The carbon nanotubes play an important role for pinning crack, and carry more external force. Furthermore, the carbon nanotubes are nano-scale units with high specific surface area. They have a firm connection and strong interaction with matrix. So, the loads are transferred through the resin matrix to the carbon nanotubes effectively, prevent the expansion of micro-cracks resulted from the stress concentration [13−16], and improve the strength of composites greatly. On the other hand, when the content of CNTs is over a certain content, the extra carbon nanotubes aggregate more seriously, and the CNTs dispersion becomes inhomogeneous in the matrix. The network structure of CNTs disappears, the CNTs intertwine together to form a cluster in micron size, which will produce negative effects on the stress transfer from the matrix to the CNTs. As a result, too much CNTs addition will make the mechanical properties of the composite less than that of the resin matrix.

3.3 Electrical properties of composites

The resistivity of the carbon nanotubes/epoxy composites with different contents of carbon nanotubes was measured by solartron SI 1287 electrochemical station. Fig.6 shows the logarithm relationship between the volume resistance and the content of carbon nanotubes. It can be found that with increasing addition of carbon nanotubes, the resistivity of the composite decreases dramatically. This means the conductivity of the composite increase greatly. According to the percolation theory, when the content of carbon nanotubes is low, the carbon nanotubes distribute randomly in the matrix, and do not form a conductive network. At this stage, the conductivity of composites mainly depends on the conductivity of the matrix which is insulator. With

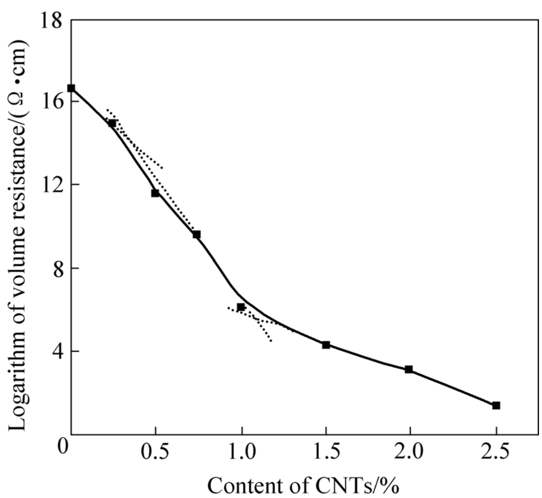

Fig.6 Effects of CNTs on volume resistance

increasing content of carbon nanotubes, they begin to connect and interact with each other to form a network. The above percolation threshold values, the continuous conductive channel is developed in the frame of the network, the resistivity will decrease greatly. The matrix will change from insulator to semiconductor. In the end, it will become a conductor. The effects of CNTs on the volume resistance are shown in Fig.6. From Fig.6, the percolation threshold values can be determined. They are 0.3% for the transformation from insulator to semiconductor, and 1.1% for the transformation from semiconductor to conductor.

4 Conclusions

1) In the CNTs/epoxide resin composite, the CNTs stress transfer effect is of great importance. By properly controlling the CNTs addition and their disposing state, the strength and electrical conductivity of epoxy resin can be improved effectively.

2) The conditional optimum content of carbon nanotubes for the CNTs/epoxide resin composite system is 0.75%. The tensile strength and tensile modulus are increased by 18.3% and 20.5%, respectively, compared with the epoxide resin matrix.

3) The electrical resistance of the composites decreases to a great extent. The percolation threshold values for electrical characteristic transformation are 0.3% and 1.1%, respectively.

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