EFFECTS OF SIZING ON THE MECHANICAL AND ELECTRICAL PROPERTIES OF CARBON FIBERS

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Abstract
Due to the high specific strength and modulus, carbon fibers (CFs) are widely used as reinforcements in composite materials and CF reinforced polymer matrix composites have become a dominant material in the aerospace, automotive and sporting goods industries. The surface of commercial CFs is usually coated with a nano-scale polymer layer, so-called sizing, for the handling and protection purposes. Effects of sizing on the surface properties of CFs and on the fiber/epoxy interfacial adhesion and strength have been studied extensively. However, effects of sizing exclusively on the properties of CFs have not been reported. In this study, the mechanical and electrical properties of CFs before and after desizing were measured for both TC33 and T700SC CFs. Weibull analyses indicated that the fiber strength decreased after desizing for TC33 CFs, but the strength remained relatively constant for T700SC CFs. On the other hand, measurement of the electrical resistivity showed only a little decrease for both TC33 and T700SC CFs. SEM observations revealed a deepened surface striation after desizing for TC33 CFs as compared with the smooth surface for both sized and unsized T700SC CFs. The effects of sizing on the mechanical and electrical properties of CFs were discussed.

1. Introduction

Due to the high specific strength and modulus, carbon fibers (CFs) are widely used as reinforcements in composite materials and CF reinforced polymer matrix composites have become a dominant material in the aerospace, automotive and sporting goods industries. The surface of commercial CFs is usually coated with a nano-scale polymer layer, so-called sizing, for the handling and protection purposes. Effects of sizing on the surface properties of CFs and on the fiber/epoxy interfacial adhesion and strength have been studied extensively [1-2]. Wang *et al.* [1] compared two different sizings on the fiber/matrix interfacial adhesion. The results showed that Toray-sized T800 CF/epoxy composite has higher interlaminar shear strength than domestic-sized T800 CF/epoxy composite because Toray-sized T800 CFs have more active and rougher surface than the domestic-sized T800 CFs. However, not all kinds of sizing could improve the interfacial bonding at the fiber/matrix interface. Dai *et al.* [2] studied the effect of sizing on surface properties of CF and the fiber/epoxy interfacial adhesion by comparing sized and unsized T300B and T700SC CFs. They found that the presence of sizing agent on T300B and T700SC fiber surface was not positive for the interfacial bonding. Morever, sizing removal can reduce the acid parameter of CF surface promoting bonding strength at the fiber/matrix interface. In spite of the extensive studies about the sizing effect on the interfacial adhesion, effects of sizing exclusively on the properties of CFs have received little attention. Guo *et al.* [3] investigated the effect of epoxy sizing on CF strength during manufacture of CF reinforced resin matrix composites by heat treating the sized CF at different temperatures which correspond to the different stages of curing

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temperatures for different matrices. The effects of the physicochemical interactions between the CFs and epoxy sizing on CF strength were discussed. In this study, the presence of sizing on the mechanical and electrical properties of CFs was investigated for two different CFs with different surface morphology. It was shown that the tensile strength of sized fibers could be quite different from that of desized fibers. Therefore, one needs to be careful about which fiber strength to choose when comparing the strength of fibers with different surface modifications.

2. Experimental

2.1. Materials

Two types of PAN-based CFs were used in this study. They were TAIRYFIL TC33, manufactured by Formosa Plastics Corporation in Taiwan and T700SC by Toray Industries, Inc. in Japan. The SEM micrographs of the cross section and surface morphology of both fibers are presented in Fig. 1. As shown, TC33 CFs have a kidney-shaped or elliptical cross section, and T700SC fibers have a circular one. T700SC CFs have a smooth surface, whereas TC33 fibers show surface striations along the fiber axis. Desizing of CFs was carried out by immersing in acetone (denoted as CF type-desizing) or in NaDDBS(sodium dodecylbenzenesulfonate) solution (denoted as CF type-NaDDBS) at room temperature for one hour, followed by cleaning in deionized water and then drying at 120℃ in the oven overnight.

2.2. Characterizations

For the characterization of CFs with and without sizing, single fiber tensile test was used to measure the fiber strength using a universal testing machine (Shimadzu) with a load cell of 1 N. The surface morphology was observed using SEM and AFM. The electrical resistivity of CFs was measured at room temperature using four point probe method on single fibers [4]. The electrical contacts were made by using silver paint. A Keithley model 580 micro-ohmmeter was used in the measurements.

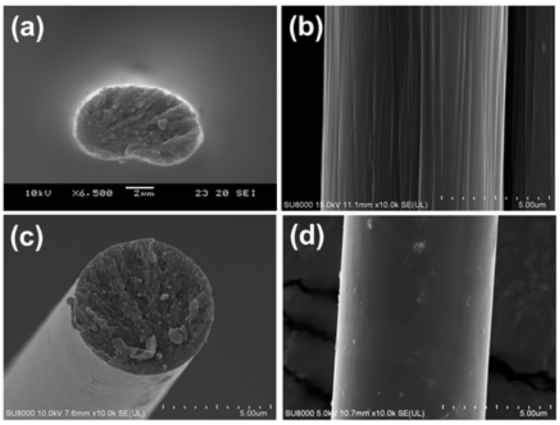

Figure 1. SEM images of CFs: (a)(b) TC33, (c)(d) T700SC.

3. Results and Discussion

3.1. Single fiber tensile test and resistivity measurement

The tensile strength of CFs with sizing and after desizing was measured using single fiber tensile test and the results are presented in Table 1. For the TC33 CFs, a significant decrease (22.7%, from 3.47 to

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2.68 GPa) of tensile strength after desizing was obtained. The decrease of strength was less (13.8%, from 3.47 to 2.99 GPa) when NaDDBS solution was used in the desizing process. Compared with the strength, a slighter decrease (~8%) of tensile modulus was found for both desizing samples using acetone and NaDDBS. On the other hand, both the strength and modulus remained relatively constant after desizing for T700SC CFs.

Table 1. Tensile and electrical properties of carbon fibers.

Specimen Type	Strength (GPa)	Modulus (GPa)	Resistivity (μΩm)
TC33	3.47 ± 0.46	197 ± 7	21.1 ± 1.3
TC33-NaDDBS	2.99 ± 0.69	180 ± 10	21.6 ± 1.6
TC33-desizing	2.68 ± 0.58	181 ± 11	19.5 ± 0.8
T700SC	4.45 ± 1.44	218 ± 16	18.0 ± 1.4
T700SC-NaDDBS	4.54 ± 1.09	231 ± 19	15.6 ± 1.6
T700SC-desizing	4.38 ± 1.48	229 ± 27	16.1 ± 0.9

Since the fiber strength data often show appreciable scatter as presented in Table 1, the statistical distribution of fiber tensile strength is usually adopted by the two-parameter Weibull distribution [5,6]. Fig. 2 shows the Weibull distribution of CFs before and after desizing for TC33 (Fig. 2(a)) and T700SC (Fig. 2(b)) CFs. As shown, for TC33 CFs, the strength distribution shifted towards the lower strength after desizing with a smaller shift for TC33-NaDDBS samples, and three distinct lines were obtained. On the other hand, the three distribution lines mixed together especially in the high strength side, indicating that the fiber strength was not affected by the desizing for T700SC CFs. The reason was attributed to the smooth fiber surface for T700SC CFs as compared with the surface striations for TC33 CFs, as will be shown in the SEM observations and AFM surface morphology scans.

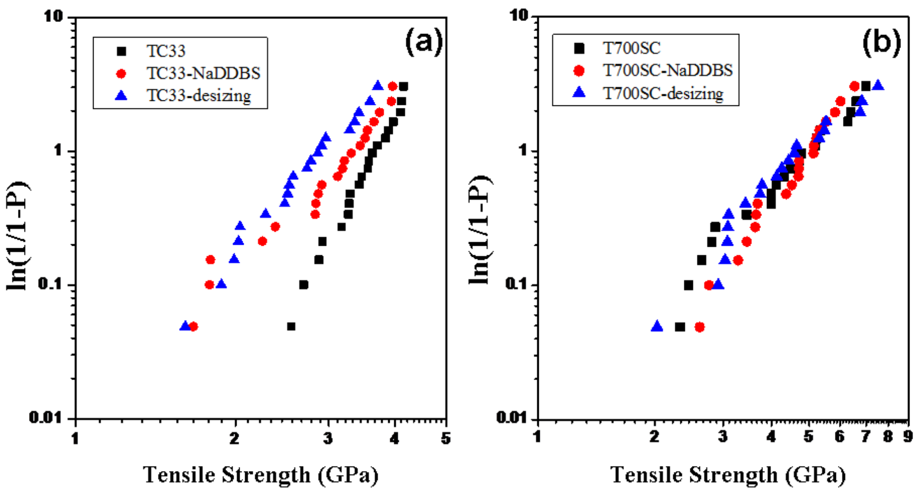

Figure 2. Weibull plots for (a) TC33 and (b) T700SC PAN-based CFs with and without sizing.

3.2. SEM and AFM Characterizations

Fig. 3 shows the SEM surface morphology after desizing for TC33 (Fig. 3(a) and 3(b)) and T700SC (Fig. 3(c) and 3(d)) CFs. Comparison among Fig. 1(b), Fig. 3(a) and Fig. 3(b) shows clearly that desizing using acetone deepened the grooves of the surface striations along the fiber axis and that less

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deepening of the grooves was found with desizing using NaDDBS. However, due to the originally smooth surface of the T700SC CFs, no obvious change can be observed after desizing.

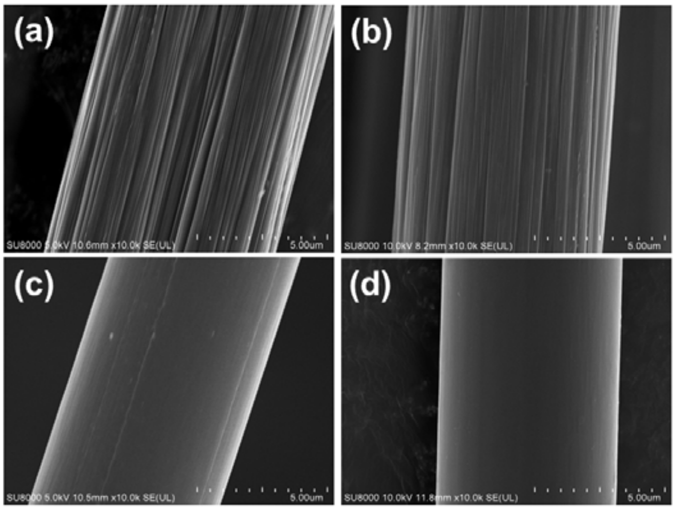

Figure 3. SEM images of CFs after desizing: (a) TC33-desizing, (b) TC33-NaDDBS, (c) T700-desizing, (d) T700-NaDDBS.

The results of AFM surface morphology scan are also consistent with those from SEM observations, and are presented in Fig. 4. Observation of Fig. 4(a), 4(b) and 4(c) reveals that more deepening of the surface grooves along the fiber axis for TC33-desizing samples as compared with that of TC33-NaDDBS samples, which is consistent with the SEM observations. The deepening of the surface grooves creates a sharper inner tip with high stress concentration, which is very likely the surface defect initiating the failure and, therefore, decreasing the fiber strength. Less deepening of the surface grooves was observed for TC33-NaDDBS samples and, consequently, decrease of fiber strength was also less. For the T700SC CFs, due to the much smoother surface without striations (Fig. 4(d) and 4(e)), the surface morphology and consequently the fiber strength were not affected by desizing.

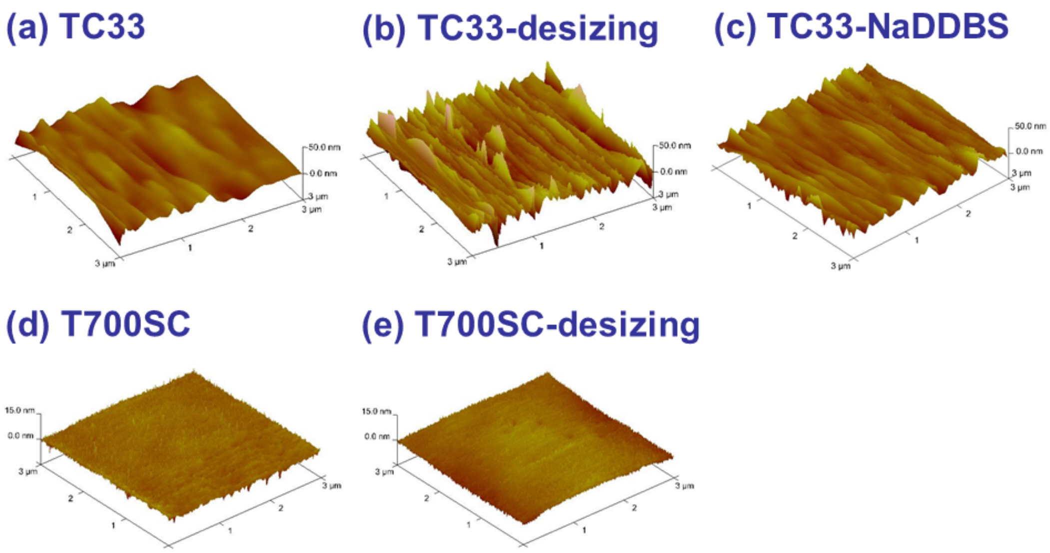

Figure 4. AFM surface morphology of CFs: (a) TC33, as-received, (b) TC33-desizing, (c) TC33-NaDDBS, (d) T700SC, as-received, (e) T700SC-desizing.

As discussed previously, the deepening of the grooves after desizing resulted in the decrease of the fiber tensile strength due to the creation of surface defects with higher stress concentration. However, less effect of these defects on the fiber modulus (~8% decrease) was measured since the modulus is less sensitive to the defects. Therefore, as expected, both the strength and modulus remained relatively constant after desizing for T700SC CFs due to the much smoother surface. The electrical resistivity is also not expected to be affected by the creation of surface defects. However, the removal of sizing results in better electrical contacts, which leads to a small amount of decrease (~7.6% for TC33-desizing samples and ~10.6% for T700SC-desizing samples) in the electrical resistivity. Larger decrease for the T700SC-desizing samples was measured presumably due to the more improvement of electrical contacts for the smoother surface.

4. Conclusions

The effects of sizing on the mechanical and electrical properties of CFs were investigated by performing the single fiber tensile test and measuring the single fiber electrical resistivity for CFs with sizing and after desizing. Desizing was found to decrease the fiber tensile strength significantly for TC33 CFs with surface striations. On the other hand, both the strength and modulus remained relatively constant after desizing for T700SC CFs due to the much smoother surface. A small amount of decrease (less than ~13%) in the electrical resistivity after desizing was measured presumably due to the better electrical contacts without sizing on the fiber surface.

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