STRENGTH OF CARBON FIBERS WITH VARIOUS GAUGE LENGTHS AND THE OPTIMUM WEIBULL MODULI

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INTRODUCTION

The strength of carbon fiber is one of the essential parameters in designing fiber reinforced composite materials. The critical length of carbon fiber for stress transfer is believed to be less than 0.5 mm [1-4]; thus, knowledge of the fiber strength at very short gauge lengths is desired. However it is very difficult to measure the tensile strength of a single carbon fiber with a gauge length under 3 mm (especially for the fibers with high Young's modulus) [1-4]. The method presented in this study enables the strength of a single carbon fiber to be measured at a gauge length as short as 1.5 mm with a high rate of data return.

Weibull parameters are often used to characterize the fracture behavior of structural materials. To determine the Weibull parameters, an experimental program often involves more than one kind of test. In this case, the fibers were tested at different gauge lengths. Due to the experimental scatter, the Weibull parameters for the subsets of test data can be expected to differ somewhat, even though as material properties they should be the same. Because more test data give more accurate results, the measured parameters from the subsets of test data were combined for the best possible values.

EXPERIMENTAL

The materials used in this study were E130 and C700 mesophase pitch-based carbon fibers manufactured by E. I. DuPont de Nemours & Co. The average diameter of the E130 fibers was 8.69 microns with the standard deviation of 1.24 microns. The average diameter of the C700 fibers was 9.29 microns with standard deviation of 1.90 microns [5]. The Young's moduli for E130 and C700 are about 860 GPa [6].

A specimen was made by mounting a single carbon fiber to a piece of heavy paper across a pre-cut window (see Figure 1). The fiber was glued to the paper by epoxy. The gauge length is the length of the window. The paper measured 40 mm x 20 mm. Heavy paper was chosen to ensure that the fiber would not be damaged during the sample preparation. After the specimen was mounted in an Instron machine, the paper had to be severed. However severing the paper became problematic when the paper was cut mechanically; slight deflections often fractured the carbon fiber due to the extreme high Young's modulus of the fibers especially so for short gauge lengths. In order to overcome this difficulty, two small pieces of cigarette paper (3 mm x 6 mm) were pasted on each side of the window, and ignited with a soldering iron. The combustion consumed the paper on both sides of the window and successfully prevented damage to the fibers. This new testing technique allows the high modulus fibers to be tested at a gauge length as short as 1.5 mm.

The E130 fibers were tested at gauge lengths of 1.5 mm, 3 mm, 6 mm, 12 mm and 24 mm. The C700 fibers were tested at gauge lengths of 3 mm, 6 mm and 12 mm. All the tensile tests were conducted on an Instron with a crosshead speed of 0.254 mm/min. The tests of C700 fibers at gauge lengths of 1.5 mm and 24 mm were unsuccessful. It was very difficult to separate a single fiber from a bundle that is long enough to be tested at gauge length of 24 mm.

RESULTS & DISCUSSION

The measured tensile strength of E130 and C700 carbon fibers under various gauge lengths are listed in Table 1 and 2. The strengths increase as the gauge lengths decrease. This indicates that the strength of the E130 and C700 fibers are controlled by a statistical distribution of flaws.

The alignment of the specimen is of paramount importance when brittle material is tested. The extraordinary high Young's modulus makes pitch-based carbon fibers very sensitive to fracture from bending which is usually caused by misalignment. In the this study, the alignment of carbon fibers was ensured by gluing the fiber to a piece of heavy paper. Although great care was exercised to avoid bending of the fibers, the possibility of bending must be recognized. Since bending and the attendant premature fractures can and will decrease tensile strength, these measurement artifacts must be countenanced. Therefore, these results should be interpreted as minimum values.

The Weibull modulus m is the slope of a straight line that is determined by plotting log log[1/1-G(s)] against log (s-s_u). In this study, s_u was assumed to be zero because the data fell close to being linear. Linear regression was used to find the best fit to the experimental data. The probability G(s) was calculated by the estimator G(s)=(i-0.5)/N because it leads to less biased m values for sample sizes less than about 50 [7-10].

The resulting Weibull moduli derived from the test data differed for different gauge lengths (see Table 3). Theory indicates that Weibull plots of such data should result in straight lines with the same slope but different vertical intersections for different gauge lengths. This discrepancy can be attributed to the experimental scatter. Batdorf *et al* [11] proposed a method to combine the data to find the parameters best representing all the data. The Weibull moduli for E130 and C700 carbon fibers are combined and listed in Table 3.

Table 1. Tensile strength of E130 carbon fibers

Gauge length	Number of specimens	Mean strength	Standard deviation
1.5 mm	11	4.38 GPa	0.85 GPa
3 mm	16	4.37 GPa	0.83 GPa
6 mm	15	3.54 GPa	0.82 GPa
12 mm	17	3.55 GPa	0.79 GPa
24 mm	18	3.38 GPa	0.84 GPa

Table 2. Tensile strength of C700 carbon Fibers

Gauge length	Number of specimens	Mean strength	Standard deviation
3 mm	16	4.53 GPa	1.11 GPa
6 mm	19	4.23 GPa	0.96 GPa
12 mm	12	3.67 GPa	0.84 GPa

Table 3. Weibull moduli

Gauge length	Weibull modulus E130 fibers	Weibull modulus C700 fibers
1.5 mm	5.74	
3 mm	6.07	4.81
6 mm	4.66	4.82
12 mm	5.42	4.88
24 mm	4.68	
Combined modulus	5.14	4.83

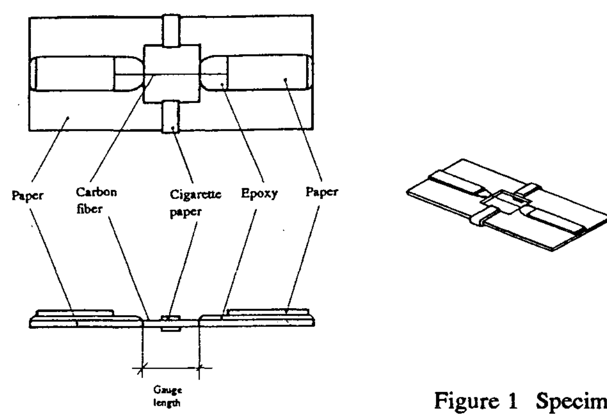

Figure 1 Specimen

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