CIRCULAR AND RIBBON SHAPED CARBON FIBERS: COMPARATIVE ANALYSIS OF STRENGTH AND THE EFFECT OF SURFACE OXIDATION

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Introduction

Single filament tensile testing results of brittle materials, such as carbon fibres, are difficult to analyse due to the high scatter observed. This scatter is a consequence of the nature of the test, dimensions of the sample and the presence of various types of flaws in the fibres [1,2]. Furthermore, the presence of flaws randomly distributed along the fibres axis, results in the dependency of fibre strength on length. The longer the fibre length, the larger the number of flaws and the higher the probability of a severe flaw being present. Thus, a statistical interpretation of the data is necessary.

A Weibull distribution function [3], adapted to account for the length dependency of strength, is normally used for that purpose. Assuming the "weakest link" approximation, the Weibull cumulative distribution function, $F(\sigma;\sigma_0,m)$, and corresponding mean strength ($\bar{\sigma}$), is described by:

$$F(\sigma;\sigma_0,m) = 1 - exp\left(-L\left(\frac{\sigma}{\sigma_0}\right)^m\right) \qquad (1)$$

$$\bar{\sigma} = \sigma_0 L^{-1/m}\Gamma(1+1/m) \qquad (2)$$

A more elaborate model to interpret fibre strength was developed by E.G. Stoner [4]. It accounts for the stresses that develop around the grip system, over a fixed distance along the fibre length, when the filament is tensile tested. This model separates the contribution of "end-effects" and true flaws, describing the true flaw population by a length dependent, simple Weibull distribution (equation 1), and the stress concentration at the fibre ends as a gauge length independent failure mode. The two flaw populations (considering "end-effects" as one) are independent, and the total probability of fibre survival is the product of the probabilities associated with each flaw population. The cumulative distribution function for fibre failure, for this mixed ("end-effect") model, is given by equation 3:

$$F(\sigma;\sigma_{01},m_1,\sigma_{02},m_2) = 1 - exp\left(-L\left(\frac{\sigma}{\sigma_{01}}\right)^{m_1} - \left(\frac{\sigma}{\sigma_{02}}\right)^{m_2}\right) \qquad (3)$$

In the present work the parameter estimate was performed using Stoner's method and calculation programmes [4,5]. The Weibull parameters were determined using the "maximum likelihood" method. This method allows the estimate of a set of parameters that simultaneously fit all the gauge lengths tested, for a given type of fibre.

Experimental

The present work compares several types of carbon fibres with different characteristics: ultra-high and high modulus pitch-based circular and ribbon shaped fibres, and high strength PAN-based fibres. The cylindrical pitch-based fibres are P120J and P75S from Amoco. The non-cylindrical (ribbon) pitch-based fibres were produced at the Center for Advanced Engineering Fibers and Films, at Clemson University. The cylindrical PAN-based fibres, C320, were produced by Sigri Great Lakes. All the fibres were obtained untreated and unsized, except the P75S, that had a proprietary treatment. The untreated fibres were plasma oxidised in a Technics Plasma reactor model 200-G, equipped with a microwave power generator working at a frequency of 2.45 GHz. The treatments were performed at several power conditions and application times, and 100 Pa pressure of O_2. The P120J fibres were treated at 75W and 150W for 3 and 10 minutes, and at 100W for 3 minutes. The remaining unsized fibres were treated at 75W for 3 minutes.

The single filament tensile tests were performed according to the method described by E.G. Stoner [5], adapted from the ASTM standard [6]. The tensile tests were done in an Instron 1122 universal testing machine equipped with a load beam of 5N at a cross-head speed of 0.5 mm/min. Three to four gauge lengths were tested for each fibre type.

The tensile strength distribution for the various types of carbon fibres was analysed on the basis of the simple Weibull distribution and the end-effect model.

Results and Discussion

An extensive analysis of strength for all fibre types has been presented previously [8]. A set of parameters that fits all gauge lengths simultaneously, for each type of fibre, was obtained for the simple Weibull distribution and the end-effect model. The results are presented in table 1.

Table 1. Parameter estimates for the Weibull and end-effect models.

Fibres	Simple Weibull		End-effect	
	m	σ_0	m_1	σ_{01}
P120J, untreated	3.850	4.161	2.770	10.075
P120J, 75W/3min	3.424	4.458	3.419	4.519
P75S	6.453	2.903	6.265	2.983
Ribbon, untreated	4.037	5.966	2.578	12.389
Ribbon, 75W/3min	4.770	4.733	4.767	5.317
C320, untreated	5.890	5.388	9.070	5.091
C320, 75W/3min	7.741	4.559	7.246	4.962

The experimental average strength results for the P120J, ribbon and C320 untreated and surface treated at 75W for 3 minutes, and the P75S fibres, at several gauge lengths, are presented in figure 1. Figures 2 and 3 represent the Weibull strength and end-effect true strength, respectively, obtained by fitting the models to the experimental results. The numbers in figures 2 and 3 correspond to the types of fibres indicated in the caption in figure 1.

Figure 1. Experimental strength results

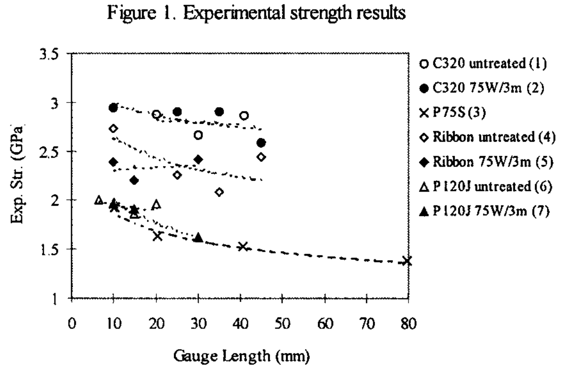


Figure 2. Weibull strength results

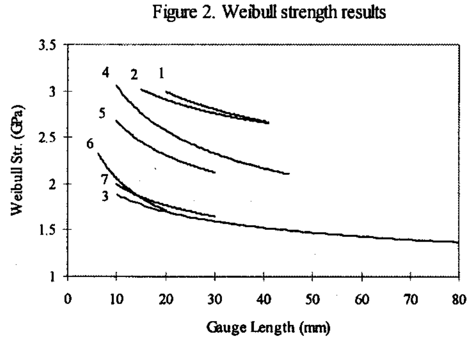
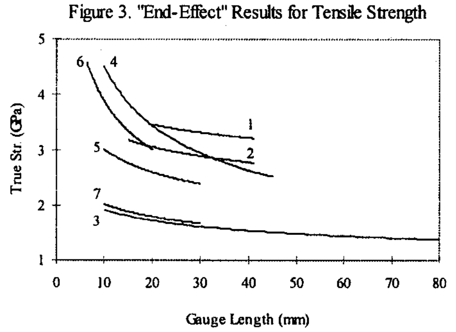


Figure 3. "End-Effect" Results for Tensile Strength



The estimates of fibre strength at 1 mm gauge length were done using the simple Weibull function and the end-effect model. The results are presented in table 2.

Table 2. Predicted strength (GPa) at gauge length of 1 mm.

Fibre	Simple Weibull	End-Effect
P120J, untreated	3.76	8.97
P120J, 75W/3 m	4.01	4.06
P75S	2.70	2.77
Ribbon, untreated	5.41	11.00
Ribbon, 75W/3 m	4.33	4.87
C320, untreated	4.99	4.82
C320, 75W/3 m	4.29	4.61

Conclusions

The present results show that the PAN-based fibres have the highest strength, and that the ribbon fibres are stronger than the P120J, which are similar to the P75S.

End-effects were found to influence significantly the results at small gauge lengths, and results for fibres with high moduli.

When end-effects are not important, a simple Weibull distribution is adequate to describe the tensile strength data at all gauge lengths. In this case, the estimates of strength at small gauge lengths are similar for both models.

In general terms, surface treating the fibres seems to slightly decrease their tensile strength.

References

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