WEIBULL MODULUS OF BI-DIRECTIONAL CARBON FIBRE REINFORCED CARBON COMPOSITES

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Introduction

The design of a component needs a previous knowledge of the properties of the material it is made. Among the engineering materials, the composite materials exhibit high strength/density ratio. Due to their production parameters is common a presence of a large number of inhomogeneities, such as cracks, voids, matrix pockets, and fiber bundle misalignments. These features causes an appreciable scatter in strength which is superior to conventional materials [1].

In order to design structures with some degree of reliability it is necessary to use statistical tools to cope with the variability in properties of these class of materials to avoid undesirable catastrophic failure. The Weibull distribution is one of the most used statistical tools for materials, such as ceramics, which exhibit brittle failure. The Weibull distribution is given by the cumulative fracture probability (P) equation:

$$P = 1 - \exp\left[-\frac{V}{V_o}\left(\frac{\sigma - \sigma_u}{\sigma_o}\right)^m\right] \qquad (1)$$

where: "m" is the Weibull modulus, V is the volume tested of the material, V_0 is the standard volume, σ is the stress rupture, σ_0 is the characteristic stress and σ_u is the stress below the probability of failure is zero.

Carbon Fiber Reinforced Carbon Composites (CFRC) can be used as structural elements in inert atmosphere at temperature over than 1500°C [2]. These materials exhibited a microstructure with inherent defects due to the fabrication process, such as pores, cracks, fibre/matrix debonding and consequently one can expect that these microstructural features induces a scatter in strength. The variety of raw materials from where CFRC composites can be prepared also leads to an scatter in strength values which is determinant in the values of "m".

Although there are works related to the estimation of Weibull for structural composites [1] and graphites [3] the literature lacks any reference related to the variability of mechanical properties of CFRC, which is the objective of this work.

Experimental

Two 8 ply composite laminates was prepared by using a ex-PAN carbon fiber 2x2 twill weave (340 g/m^2). The composite was moulded using the well know autoclave technique with a resol phenolic resin, Resafen 8121, as carbon matrix. The laminate was cured in a multi-stage heating cycle up to 180 ^{C}C The as moulded composite was trimmed to approximate dimensions of 3.25x10x120, corresponding to thickness, width and length. Each composite laminate gives around 30 trimmed samples. The samples were packed in a graphite crucible and carbonized just once in a tubular furnace in inert atmosphere with a heating rate of 20^{o}C/min up to 1000 °C.

A commercial CFRC composite, Sigri CC1501G, was also used in the work for to compare with the previous one. Sigri is a 10 ply laminated composite (~2.9 mm thick) with PAN-based carbon fibres in a 2x2 twill weave in a resin carbon matrix having been submitted to 3 re-impregnation cycles and heat treated up to 2000°C. Sigri CC1501G was provided by Hoechst plc.

Both composites are designated by its number of plies, CFRC-8P (8 plies) and CFRC-10P (10 plies). The CFRC-8P composite has an apparent density of ~1,05 g/cm^3 and a porosity of 30%/Vol. The CFRC-10P composite has an apparent density of 1.42 g/ cm^3 and 15%/Vol porosity. Porosity was measured by water penetration method (ASTM C-20).

Twill weave is characterised by two or more warp yarns crossed by a fill yarn, with a progression of interlacings of one fill yarn to the right or left to form a distinctive diagonal line. Twill weave can be even-sided, i.e. the same amount or warp or fill-faced, with a predominance of warp or weft yarns on the upper face.

Three point bending tests were performed in a Instron 1122 machine with a cross head speed of 0.5 mm/min and a span/depth ratio of 25:1. Flexural tests were used because their great convenience in obtaining preliminary data.

The determination of Weibull modulus is done by modifying equation (1) considering the assumption of a constant volume for the samples and resulting in a straight line equation:

$$\ln\ln(1/1\text{-}P) = m.\ln\sigma - m.\ln\sigma_0 \qquad (2)$$

Weibull modulus is obtained by plotting lnln (1/(1-P) as function of ln σ. The probability from medium position corresponding to the i-th observation is given by $P_i = 1/N+1$, where N is number of samples. The Weibull modulus (m) was obtained by linear regression. The determination of a minimum number of CFRC composite samples to give a reliable Weibull modulus (m) was done using the CFRC-8P composite.

Results and Discussions

The CFRC-8P presents discrete perpendicular (PP) fiber bundles in warp direction, e parallel fibre bundles (PL) in fill direction, sketched in Figure 1. Bundle/bundle interface pores, ~100 μm wide, and interply large pores, ~400 μm wide, can be seen. There is an absence of cross bundle cracks. These pores have possibly been formed because the resin has shrunk on carbonisation and/or bubbles of volatiles or air have been trapped on curing. The CFRC-10P, figure not shown, exhibit the same microstructural features of CFRC-8P, and some cross bundle cracks are also found.

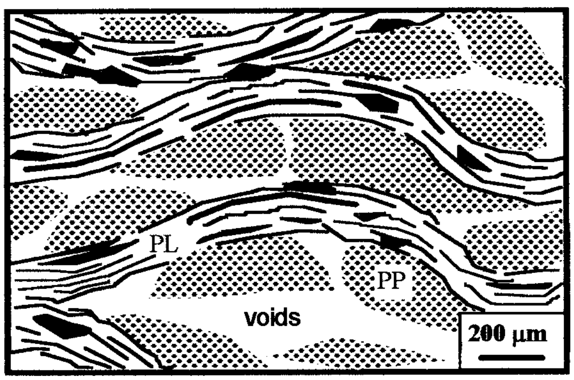

Figure 1 - Sketch of microstructural features of CRFC-8P. PP - perpendicular. PL - parallel.

The CFRC-8P and CFRC-10P composites exhibited a flexural strenght of 63.2±6.1 MPa and 208.5±19.6 MPa, respectively. The flexural modulus of CFRC-8P and CFRC-10P composites was 9.3±1.3 GPa and 52.7±3.5 GPa. Figure 2 shows a plot of Weibull modulus as a function of number of samples tested for CFRC-8P. It is clear that for sample batches over 25 the Weibull remains constant. This result agree with others from literature where the number of samples needed to characterize a statistical distribution fall between 20 to 30 specimens [4]. Figure 3 shows the Weibull plot for CFRC-8P and CFRC-10P. Both composites have the same family of defects, mainly pores, therefore resulting in a similar Weibull modulus (m = ~11). Also the Weibull plots confirms that strenght increases as the porosity reduces and density increases.

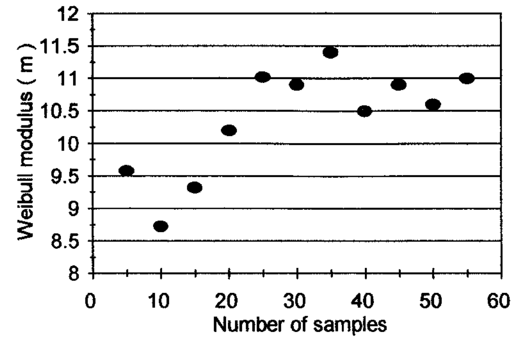

Figure 2 - Weibull modulus (m) as a function of number of tested samples for CRFC-8P.

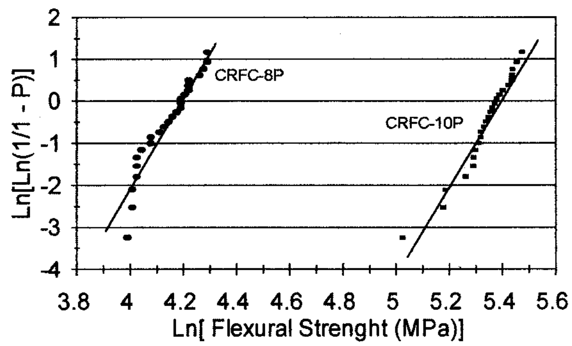

Figure 3 - Weibull plot for CFRC-8P (r^2=0,92) and CFRC-10P composites (r^2=0,95).

Conclusion

The use of Weibull statistics shows a good agreement with the results of this work, where the Weibull modulus was coerent to describe flaw population to this kind of composite. The Weibull distribution is a valuable tool to describe and quantify the variability in mechanical properties identify processing problems during the fabrication steps.

References

1 - King, R. L. - A review of statistical methods for the determination of design data for advanced composite materials, 3rd Internl Conf. Fibre Reinf. Comp. '88, The Plastics and Rubber Institute-UK, 1988, p. 17/1-17/19.

2 - Thomas, C. R. - Overview-What are Carbon-Carbon Composites and What Do they offer?, Chapter 1, in Essentials of Carbon-Carbon Composites, 1994.

3 - Muller, R. - Flexural strength statistics of fine grain graphite, in *Carbon '94*, 1994, p. 804-805.

4 - Zwaag, S. van der. - The Concept of Filament Strength and the Weibull Modulus, J. Testing Evaluation, Vol. 17, No. 5, Sept. 1989, pp. 292-298.