MECHANICAL PROPERTIES, POROSITY AND DENSITY OF UNIDIRECTIONAL CARBON-CARBON COMPOSITES

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Introduction

The microstructure of porous materials significantly influences their strength. Studies done on ceramic materials were principally concerned with the dependence of their mechanical properties (strength or elastic modulus), Y, on porosity (as a volume fraction), P[1-7]. A problem arises when a closed, or inaccessible, porosity is present, because it can be estimated only indirectly, using density measurements. Since the apparent density, d, is related to closed porosity and is easy to measure, it is possible to establish a relationship between Y and d. For carbon-carbon (C-C) composites prepared by chemical vapour infiltration (CVI), the relationship between d and the open porosity, P, is given by

$$P = (q - d)/n \quad (1)$$

where q and n represent the maximum densities of the composite and of the matrix, respectively, approached at the end of infiltration, taking into account the formation of closed porosity within the matrix[8]. For a given skeleton structure, q and n are dependent on rate constants for infiltration and for matrix formation, on the starting open porosity and on the density of pore-free matrix, which enables one to relate mechanical properties directly to CVI parameters.

The aim of this study was to investigate the possibility of transposition of Y=f(P) expressions to the Y=f(d) form, as well as the applicability of the equations originally developed for ceramic materials to the porous C-C composites.

Experimental

The samples of C-C composites were prepared by CVI of carbon in the pores of the unidirectional skeletons made of Toray T-300-99 fibres. Prior to infiltration the fibres were bound either by the carbonized phenolic resin, CPR, (samples of types I, II, and III) or by pyrocarbon, PC, (type IV). The fibre content, FC, starting porosity, P_0, and density, d_0, and other properties of the skeletons are given in Table T.1. The composite samples were rectangular, having dimensions 2×5×120 mm. Different apparent densities of the samples resulted from different duration of CVI. Their flexural strengths, σ, were obtained by three-point bending test and the fractures were examined using SEM and optical microscopy in polarized light.

Results and Discussion

The equation (1) can be used to replace P in commonly used expressions, to obtain equations representing flexural strength as a function of d. The simple equation which does not account for stress concentration factor thus becomes

$$\sigma = \sigma_0 (1 - q/n) + (q/n) d \quad (2)$$

where σ_0 is the strength of non-porous material. If the stress concentration factor is denoted by b, Duckworth's equation[1] becomes

$$\sigma = \sigma_0 \exp(-bq/n) \exp(d\, b/n) \quad (3)$$

The parameters of Hasselman's equation[4] must be obtained by a numerical technique from the expression

$$\sigma[n + (A+1)q/(A+1)] - \sigma_0(n-q)/(A+1) = [\sigma_0/(A+1) + \sigma]d \quad (4)$$

The equation of Marinkovic[9], which was found to excellently fit the experimental data for all kinds of C-C composites, but which suffers from dimensional inconsistency in its original form, can be easily rearranged to give

$$\sigma = \sigma_0 (d/q)^b \quad (5)$$

Eqn. (5) corresponds to

$$\sigma = \sigma_0 [1 - (n/q) P]^b \quad (6)$$

which is a general form accommodating expressions by King[5], Phani[6] and Ondracek[7].

For each type of C-C composite, the flexural strength of 15-20 samples having different densities was measured. The parameters of Eqns. (2)-(6) were adjusted to obtain the best fit with experimental data and their values are presented in Table T.2. The results for heat-treated samples of type IV are also presented.

Table T.1. Initial properties of C-C composites

Type	P_0	d_0,kg/m^3	q,kg/m^3	n,kg/m^3	CF,%	B
I	0.585	716	1263	935	38	CPR
II	0.540	793	1308	954	42	CPR
III	0.424	967	1516	1295	52	CPR
IV	0.390	1120	1812	1774	52	PC

Table T.2. Parameters σ_0 and b estimated by different equations

Equation		(2)	(3)	(4)	(5),(6)
I	σ_0,MPa	110	101	95	98
	b		1.63	-1.21*	1.77
II	σ_0,MPa	156	149	136	139
	b		1.96	-1.48*	2.05
III	σ_0,MPa	927	389	405	380
	b		4.06	-5.51*	4.19
IV	σ_0,MPa	73	156	83	155
	b		0.20	-0.83*	0.16
IV_{HT}	σ_0,MPa	3178	2596	-491	2050
	b		7.60	7.23*	5.81

*) Hasselman's parameter A

fractures which propagates through the sample straightforwardly, with no dissipation of energy. Thus, σ is small and does not depend on d. Besides the structural changes in the matrix, heat treatment results in the formation of microcracks parallel to the fibre surface which influences the increase in σ.

The results obtained reveal again the question of the physical meaning of different equations especially Hasselman's one, which gives the negative values of σ_0 for IV_{HT} samples. This is due to the fact that the equation is a hyperbola which shifts the point of discontinuity into 1st and 4th quadrant in the cases of "strong dependence" of σ on d.

The attempt to use parameter b to calculate the axial ratio of the pores, as defined by Ondracek[7], resulted in the values z/x=3.1 for type I, 4.8 for II, 41 for III, 2×10^{-3} for IV and 111 for IV_{HT}. The observed behaviour of the composites may be well explained in the light of the z/x values obtained. Thus, the low strength of IV can be attributed to the existence of pores perpendicular to the fibres and parallel to the external force, playing the role of initial cracks. During heat treatment, long, narrow, pores parallel to the fibres are formed. They help the dissipation of the energy of the fracture in the direction perpendicular to the direction of the external force.

References

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