APPLICATION OF FRACTURE MECHANICS FOR C/C-COMPOSITES

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C/C-Composites are known to be a carbon material with high strength and high stiffness. As described by TERWIESCH,1972, HILL et al., 1974, and FITZER et al.,1976 the properties of the reinforcing fibres can be utilized up to 100% in unidirectionally reinforced C/C-composites. All C/C-composites however show brittle fracture behaviour with a maximum strain to failure of about 1% only. Our studies are based on C/C-composites prepared with pitch as carbon matrix precursor. All samples have been carbonized up to 1400°C preceded by an autoclave baking under elevated gas pressure up to 550°C, and densified by repeated impregnation/recarbonization cycles. The resulting carbon/carbon-composites have typical bulk densities of about 1,7 g/cm^3 and maximum flexural strengths up to 1200 MN/m^2 in the case of unidirectional reinforcement with 50 vol.% of the fibre. C/C-composites with similar properties can be prepared by CVD impregnation of preformed carbon fibre frameworks with pyrocarbon.

In modern fracture mechanics critical stress intensity factors are widely used for characterization of fracture behaviour of common engineering materials. Also for fibre reinforced composites critical stress intensity factors were published by McGARRY et al.,1972, GAGGAR,1975,but only for glass-and carbon-fibre reinforced composites with epoxy matrix. The authors pointed out that meaningful results can only be obtained if the crack is growing in direction of a notch, which is parallel to the reinforcing fibre-or fabric-direction. Because of limitations in the size of the available sample material, it was necessary to modify the ASTM Norm STP 463 for our own measurements. The geometry of the samples is shown in Fig.1. The sample size was varied with maximum values of B=10mm, 2 H=4 mm, and w=36 mm . As far as primary notches are concerned notch lengths between 0,4 and 5 mm were tested. In the case of notches parallel to the fibre direction no infinitesimal curvature at the tip of the notch is necessary, as has been proved for ceramic material by PABST, 1973.

There might exist principal doubts whether stress intensity factors of C/C-composites can be meaningful, especially if the limited sample size is taken into consideration. The present study should indicate, whether reproducible measurements can be performed and useful fracture mechanical data can be obtained.

Systematic studies of the effect of geometrical sample dimensions on the stress intensity factor were performed with C/C-compsoites containing 35 vol.% of stacked graphitized fabrics, type SIGRATEX GDS 8-30. The layers of fabric were oriented perpendicular to the tensile direction, the notch being applied parallel to the warp direction of the fabric.

Typical diagrams showing the dependence of crack mouth opening as function of the applied tensile force can be recognized in Fig.2. The analytical calculation of stress intensity factors from the experimental data was performed using the following equation 1 which is valid for a compact tension specimen:

$$K_Q = \frac{P \cdot \sqrt{a}}{B \cdot w} \left[0{,}295 - 1{,}855\left(\frac{a}{w}\right) + 6{,}557\left(\frac{a}{w}\right)^2 - 10{,}17\left(\frac{a}{w}\right) + 6{,}389\left(\frac{a}{w}\right)^4 \right] \cdot 10^2$$

It has been found that neither the width of the crack nor the specimen thickness have an influence on the resulting stress intensity factor K_Q. The influence of normalized distance H/w on the values of the stress intensity factor is shown in Fig.3. It can be recognized that the K_Q-value is independent on H/w if the H/w-ratio exceeds values of 0,2. It was also confirmed experimentally (Fig.4) that the K_Q-value is independent on the normalized depth of the notch a/w.

Results concerning the stress intensity factor calculated with the compliance method (Fig.5), and with the analytical method (equation 1) are compared in Table 1. It can be seen, that there is a good agreement of the calculated K_Q-values at 15,1 $N \cdot mm^{-3/2}$. Therefore only the upper value, which is given in Fig.3, can describe the critical stress intensity at the tip of the notch for this material, sample configuration and test method described above.

The experimental data seem to be reproducible provided that the samples are reproducibly prepared and have homogeneous structures.

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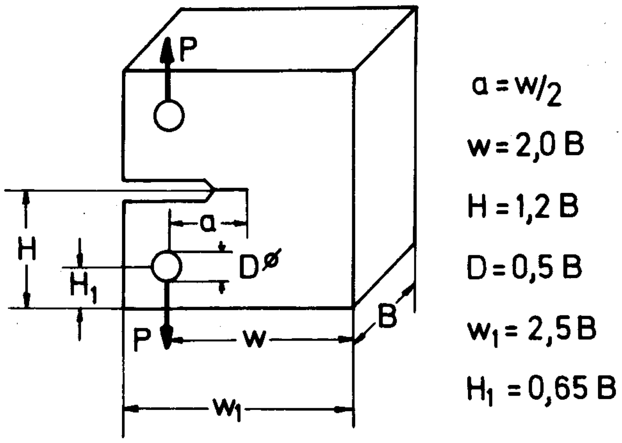

Fig.1: Sample geometry

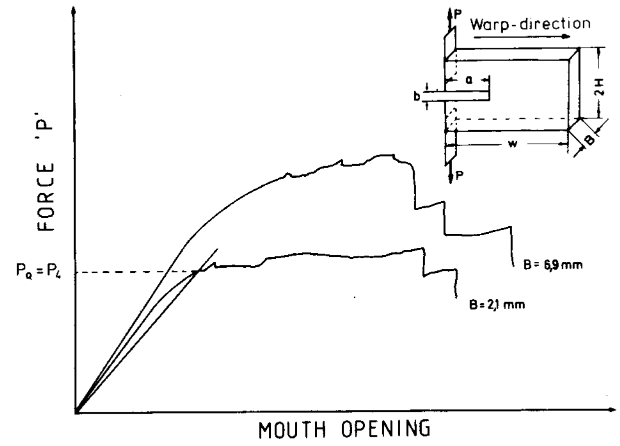

Fig.2: Crack mouth opening as function of the applied tensile force for composites with fabric reinforcement

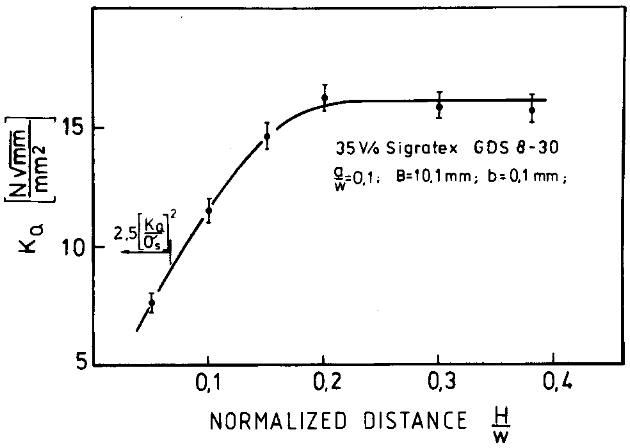

Fig.3: Dependence of the stress intensity factor on H/w (see fig.1)

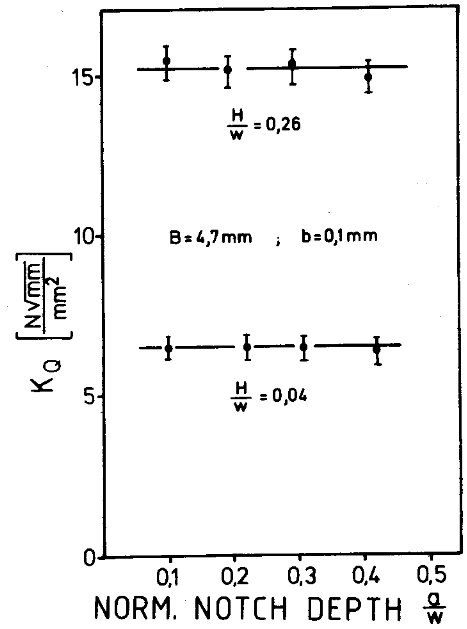

Fig.4: Stress intensity factor as function of a/w (see fig.1)

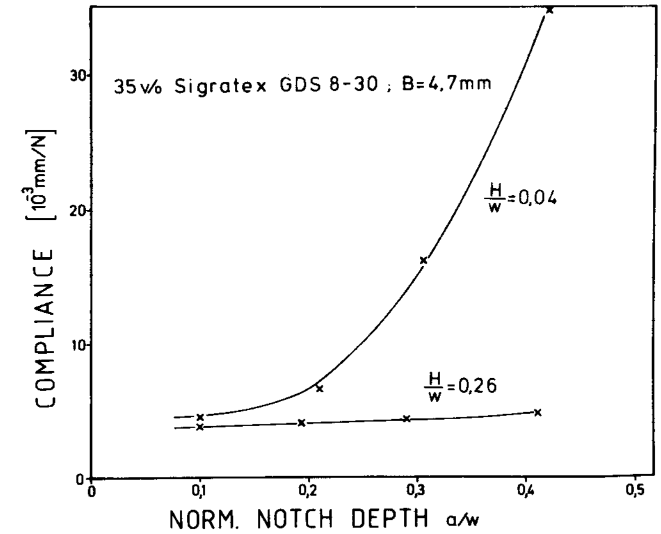

Fig.5: Compliance as function of dimension ratios

H/w	a/w	G_c N mm/mm^2	K_c ber. N mm$^{-3/2}$	$\bar{K}_Q$ N mm$^{-3/2}$	Differenz %
0,04	0,1	0,0108	10,8	6,5	+ 66
0,04	0,22	0,1375	12,4	6,5	+ 91
0,04	0,31	0,1702	13,6	6,5	+109
0,04	0,42	0,1950	14,5	6,4	+127
0,26	0,1	0,0325	18,8	15,5	+ 21
0,26	0,19	0,0253	15,5	15,1	+ 3
0,26	0,29	0,0201	14,8	15,3	- 3
0,26	0,41	0,0229	15,8	14,9	+ 6

Tab.1: Comparison of stress intensity factors determined by the compliance and the analytical method