NUMERICAL AND EXPERIMENTAL INVESTIGATIONS CONCERNING BRANCHED THERMAL CRACK SYSTEMS ORIGINATED IN SELF-STRESSED MODELS OF FIBROUS COMPOSITES

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INTRODUCTION

Studies of thermal fracture phenomena in multiphase materials are important for the failure analysis of modern composites. Thereby the appearance of curvilinear crack paths in thermally loaded composite materials has been observed several times by Herrmann and Ferber (1) and Ferber (2). Therefore, a very interesting problem in today's fracture mechanical research poses the prediction of the prospective path of extending thermal cracks as functions of the geometrical configuration of a self-stressed nonhomogeneous solid as well as on the applied thermal load distribution. The micromechanical aspect in thermal cracking of unidirectionally reinforced composites has been stressed in several papers by Herrmann (3) and Herrmann and Braun (4). Finally, the crack path prediction of extending thermal cracks as functions of the geometrical configuration of self-stressed multiphase solids as well as on the applied thermal load distribution has been investigated recently by Herrmann and Grebner (5).

FRACTURE MECHANICAL INVESTIGATION OF A BRANCHED THERMAL CRACK SYSTEM

In this paper, curvilinear thermal cracks are studied running as interface cracks as well as along special principal stress trajectories of thermal stress fields originated in plane models of fiber reinforced composites by a steady cooling process. These two-phase composite structures consist of homogeneous, isotropic and linearly elastic materials with differing thermoelastic properties varying discontinuously at the circular fiber-matrix interfaces from the values E_f, ν_f, α_f of the fibers to the values E_m, ν_m, α_m of the matrix. Moreover, perfect contact of the fibers and the matrix at the material interfaces is presumed.

A continuum mechanical treatment of these cracked thermally loaded composite structures requires the solution of mixed boundary-value problems of the plane stationary thermoelasticity. Because of the complicated structure of the stress-free boundary a closed form solution of these boundary-value problems could not be obtained. Therefore, photoelastic analysis along with the finite element method were applied in order to determine the fields of principal stress trajectories as well as fracture mechanical data governing the propagation behaviour of curved thermal cracks, Herrmann (6)

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and Herrmann and Ferber (7). Further, for an assessment of the growth of two crack tips belonging to a matrix crack and an interface crack, respectively, a crack growth criterion has been proposed. Thereby, this criterion just mentioned bases on the assumption that those of the two possible crack enlargements Δa^{F1} and Δa^{F2} (cf. Fig.1), respectively, will be realized causing the larger elastic strain energy release for the corresponding crack step. Therefore, by using an appropriate finite element discretization of the cracked composite structure, the crack growth criterion for the matrix and interface cracks, respectively, could be given by $G(a + \Delta a^{F1}) \lesseqgtr G(a + \Delta a^{F2})$. Furthermore, it could be shown that first of all the matrix crack will be grown between two fibers and afterwards an intermittent growth of two interface cracks takes place up to a point where crack arrest is reached. These finite element calculations could be confirmed by experimental investigations where Fig.2 shows the stress intensity factor K_I at the tip of a matrix crack in comparison of the experimental K_I-values obtained by the shadow optical method of caustics.

At present branched thermal crack systems are investigated by means of a finite element discretization of an appropriate platelet representation of a ply of a unidirectionally fiber reinforced composite.

REFERENCES

(1) Herrmann, K.P. and Ferber, F., VDI-Berichte 552, 1985, pp.375-388.

(2) Ferber, F., Ph.D.-Dissertation, Paderborn University, 1986.

(3) Herrmann, K.P., "Curved Thermal Crack Growth in the Interfaces of a Unidirectional Carbon-Aluminum Composite", Proceedings of the IUTAM-Symposium on "Mechanics of Composite Materials". Edited by Z.Hashin & C.T.Herakovich, Pergamon Press, New York, 1983, pp.383-397.

(4) Herrmann, K.P. and Braun, H., Engng. Fracture Mechanics 18, 1983, pp.975-996.

(5) Herrmann, K.P. and Grebner, H., Theoretical and Applied Fracture Mechanics 2, 1984, pp.133-155.

(6) Herrmann, K.P., "Micromechanical Analysis of Basic Fracture Effects in Self-Stressed Fibrous Composites", Proceedings of the ASME/ASCE Mechanics Conference on "Fracture of Fibrous Composites". Edited by C.T.Herakovich, AMD-Vol.74, 1985, pp.1-13.

(7) Herrmann, K.P. and Ferber, F., "Failure Mechanisms in Thermally Loaded Models of Fibrous Composites with a Brittle Matrix", Proceedings of the International Symposium on "Composite Materials and Structures", Edited by T.T.Loo & C.T.Sun, Technomic Publ. Co., Lancaster, USA, 1986, pp.483-488.

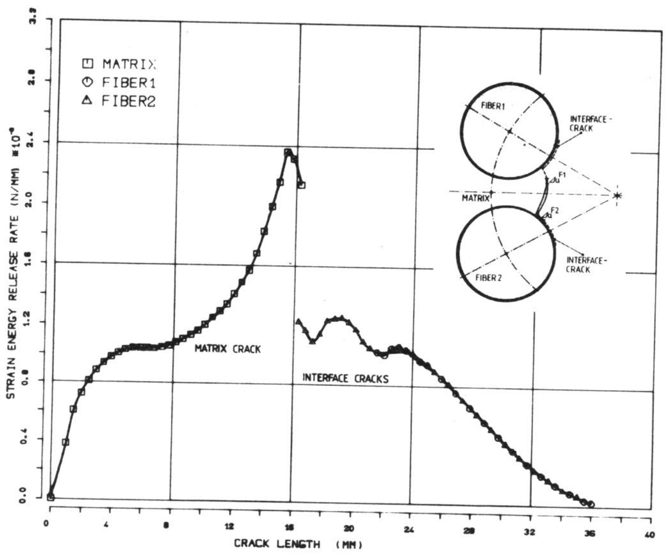

Figure 1 Strain energy release rate as function of crack length for a branched thermal crack system

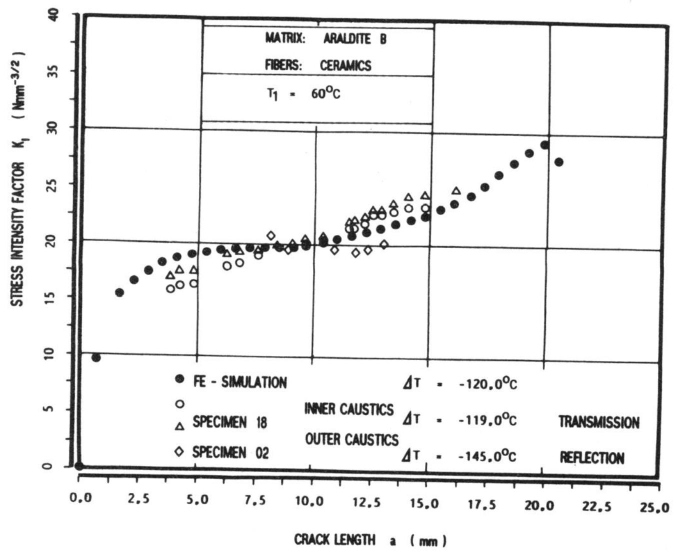

Figure 2 Stress intensity factor K_I as function of crack length