Abstract

Carbon-fibre reinforced plastics have been widely used in the aerospace industry as materials for structural components. During recent years, the focus has been on preform/RTM materials with the aim of improving material properties and reducing costs. Harnessing the full potential of these materials requires a model for assessing the properties and in particular long-term behaviour. Such a model needs to take into account the special conditions of these materials. Basic failure mechanisms have to be analysed in order to develop this kind of model.

Consequently, the aim of the work was to investigate the fatigue phenomenon in preform-CFRP materials with thermoset matrices on a microstructural level. The influence of the dynamic loading and the temperature on the emerging fracture phenomena should be identified. Based on the results, a common fracture mechanism should be found. The failure should be described on a mesoscopic level so that it is not restricted on the fatigue failure at a single crack front.

To achieve this aim, different preform materials with EP matrix (some of which had been subjected to impact) were loaded with dynamic compression load and high frequent alternate bending. The fatigue behaviour of the matrix systems was investigated by CT tests.

By means of microfractography, the only method for detecting fatigue failure as such, the failure mechanisms were analysed at submicroscopic level. The results showed correlations between microstructure and failure.

It became apparent that what in the technical literature has been given as an explanation for the appearance of the fatigue striations in the scanning electron microscope had to be corrected. As undercuts are not reflected in the SEM as dark striations, the appearance of the striations must be based on different inclinations of the local fractured surface to the primary electron beam.

On the basis of this result the shape and the formation of the fatigue striations could be shown in resin pockets and fibre imprints. Fatigue striations have a shape which sticks out from the fracture plane, preferably in the form of steps.

There was no proof for an influence of the high frequent load on the formation of fatigue striations. However, it was possible to find lamellar fracture phenomena which have not been described in the technical literature yet. Due to their shape and their

occurrence these can be understood rather as a sign of a dynamic load then as a fracture phenomenon of a high frequent cyclic loading.

The examinations of the high frequent loaded samples, where temperatures up to 120°C occurred, as well as in the CT tests with elevated temperatures (60% T_g) yielded no proof that the temperature has an influence on the mechanical failure behaviour. However, the formation of the fatigue striations in high frequent loaded specimens leads to the deduction that adiabatic heating exists at the crack tip which leads to large plastic deformations because the glass transition temperature is exceeded locally.

The microfractographic investigations showed that the fatigue striations appear as separate static fractures. On account of their shape and in relation to the matching fracture surfaces plastic processes can be held responsible for the formation of the striations. Altogether this leads to a modification of the models for the origin of fatigue striations prevalent in the technical literature. The suggested model associates the real fracture growth under fatigue loading only with a small part of the loading cycle. Crack propagation only occurs when the maximum stress intensity is reached in the area of the upper loading of the cycle. Microplastic processes by molecular rearrangement in the stress field ahead of the crack tip lead to the blunting of the crack tip, which is reflected as fatigue striations on the fracture surface. Simultaneously, the cyclic loading causes damages in the molecular network of the thermoset. This leads to the possibility of fracture formation below the static stress at break.

On the basis of the model and of fatigue crack growth diagrams it is possible to establish thresholds for the stress intensity necessary for crack propagation under cyclic load. The upper threshold of the stress intensity corresponds to K_C, because it marks the transition to unstable crack growth. The lower threshold is determined by the value of the cyclic stress intensity factor where crack growth has just ceased to be ascertainable.

With the existing model of local crack growth under fatigue loading and the results of the chronological course of failure from the microfractographic investigations of the different materials it was possible to detect a general failure mechanism for the preform-CFRP materials.

When an external alternating load is applied, an inhomogeneous stress field forms in the composite material. In areas stressed within the growth stress, fatigue growth occurs in the form of secondary fractures within the matrix. The primary crack front runs along these damaged points in the material until global failure occurs. This leads to a discontinuous, stepwise failure expiration under fatigue loading. This general mechanism permits assessment of the damage behaviour and the progression of failure in various types of fibre reinforcement.