DAMAGE AND FAILURE CONDITIONS FOR CONTINUOUS FIBRE COMPOSITES

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SUMMARY

Initial damage, damage progression and final failure of structures from laminated fibre composites comprise a complex process. That may be one reason for the tremendous number of simulation models available. This survey is limited to laminates from unidirectional layers out of straight continuous fibres in a polymer matrix under quasi-static loading. An overview will be provided over those models which in the opinion of the author have reached some level of acceptance. Furthermore, not every detail of the respective theory can be outlined; only those aspects will be referred to which the author regards important.

Fibres and the matrix material are characterized by a large disparity in stiffness and strength. Homogeneous models smear out this disparity, but specific aspects of the damage behaviour are generally accounted for. Comparison with test results within the framework of the World-Wide Failure Exercise revealed that even the most sophisticated models could not predict damage and failure to complete satisfaction. Heterogeneous models treat fibres and the matrix as separate entities. Hence, they can describe the real behaviour in more detail. However, obtaining relevant material properties is difficult, especially since the behaviour in a composite differs from that of separate phases.

An outlook will provide hints about the current status and the probable development in the foreseeable future. Furthermore, needs for model improvement will be given.

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1: The Aim

Structures from composite materials are often designed as laminates from unidirectional layers with different orientation. An optimum exploitation of the inherent material potential can be achieved only if the load carrying capacity of such structures is reliably predicted. The failure process, however, is rather complex. In many cases damage starts with a crack in a 90°-layer. Under increasing load more cracks appear until they have reached a ‘characteristic density’. Delaminations connect the cracks, and finally fibre brakeage in the 0°-layers marks the structural failure.

There are many models and conditions to describe initial damage and its progression up to the final failure. Damage progression is commonly characterised by a change in the material stiffness. Either the stiffness is immediately set to zero or gradually reduced. The former is usually applied in case of fibre brakeage; one way to formulate the latter is the damage mechanics approach as proposed by Ladevèze and Le Dantec[1]. After explaining some basic conditions regarding the failure of fibre composites this contribution will provide an overview over existing models and give some indications about the current development. It will further be discussed how well the models capture the real behaviour.

2: Homogeneous Models

Many failure models smear out the inhomogeneity between fibres and the matrix. The easiest approach limits every stress component separately, not accounting for any interaction. Astonishingly enough this rather crude procedure has shown a comparatively favourable performance in the WWFE-I as was highlighted by Hinton et al.[2]. More evolved are conditions which account for interaction of stresses. Most popular is the tensor polynomial $F_{ij}\,\sigma_i\,\sigma_j + F_i\,\sigma_i = 1$ proposed by Tsai and Wu[3], but the interaction terms F_{ij} for $i \neq j$ require difficult tests under biaxial load. More close to reality especially with respect to matrix or interface failure are the models by Hashin[4], Puck[5], Cuntze[6] or Pinho et al.[7]. As an example Figure 1 depicts the fracture modes accounted for by Cuntze. In a detailed analysis Catalanotti et al.[8] described certain pitfalls of existing 3D failure criteria and proposed an improved one. They stressed the requirement of using in situ strength properties in order to account for the ply thickness effect. However, by means of micromechanical analysis, Herráez et al.[9] concluded that strength must be independent of ply thickness.

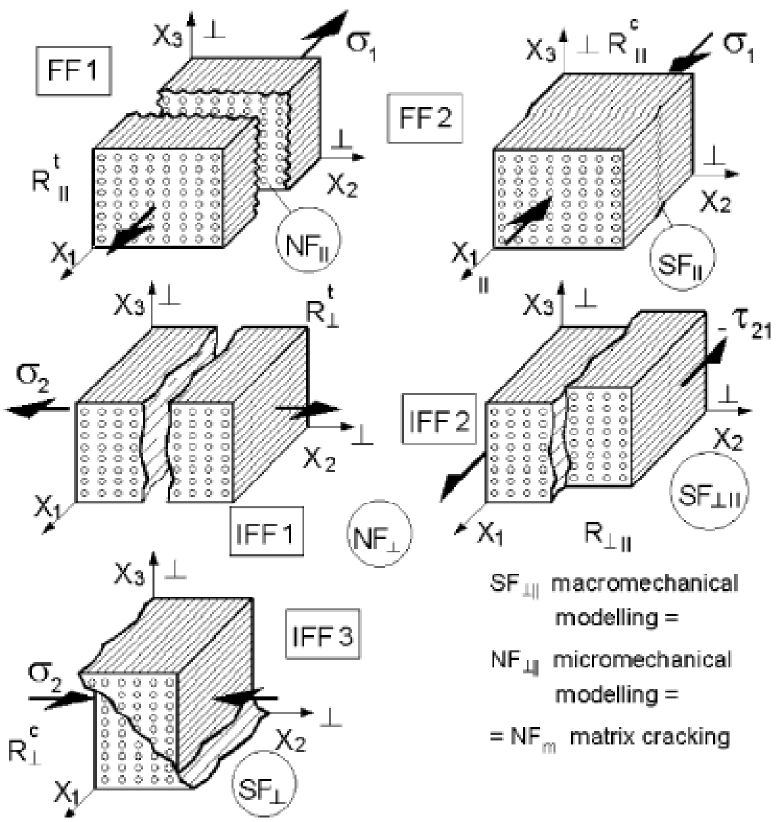

Figure 1: **Fracture Modes after Cuntze[6]**

3: Heterogeneous Models

More close to reality are models which take into account the large disparity in stiffness and strength between fibres and matrix. Resin strengths are typically measured with neat material though it is well known that ductile polymers behave brittle when used in fibre reinforced composites. Shear strength of the fibre-matrix interface can be obtained from fibre pull-out or push-out tests. Measured fibre tensile strength depends on the specimen length. Wang et al.[10] have proposed a tensile recoil method to obtain the fibre compressive strength.

Some approaches consider inhomogeneity but still show relations to the homogeneous models, as for instance the discrete damage mechanics approach by Barbero and Cortes[11]. By means of fracture mechanics they determined parameters for stiffness reduction of the homogenized structure. Another one is the hybrid procedure as proposed by Chowdhury et al.[12]. Fully heterogeneous models usually specify representative volume elements (RVEs). Simple RVEs consider quadratic or hexagonal fibre arrangements together with symmetry boundary conditions. Ha et al.[13] have shown that the effect of different fibre arrays is but marginal. More advanced RVEs are characterised by random fibre distribution and periodic boundary conditions as for instance applied by Canal et al.[14] and Troty et al.[15].

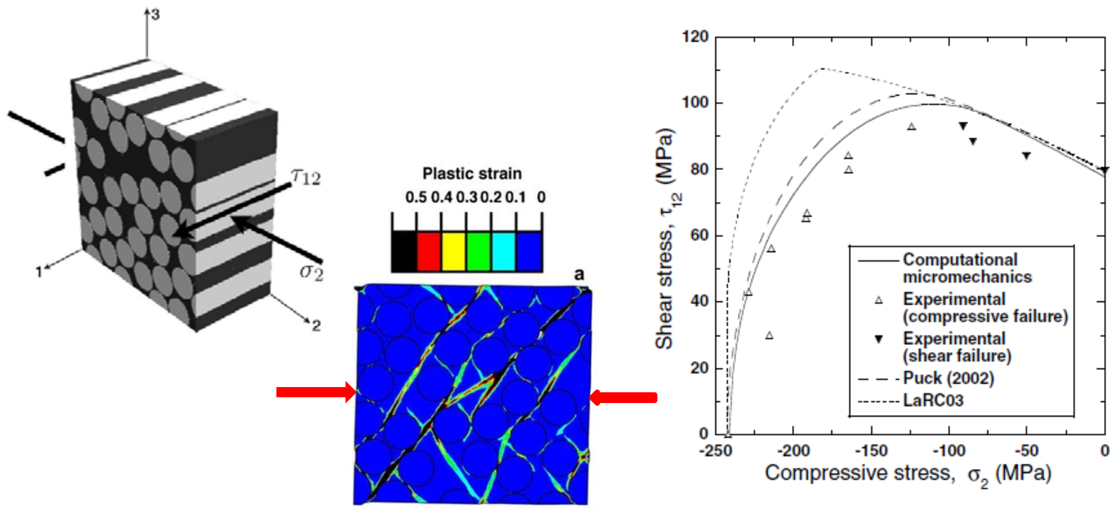

Figure 2: **Damage under Compression and Shear after Troty et al.[15]**

4: Conclusion and Outlook

Considerable effort has been put into the development of suitable models to reliably predict damage and failure of fibre composites. In spite of the inhomogeneity of the material homogeneous models were first choices for quite some time. On looking at the frequency of publications in this field the development seems to have passed the top.

More close to the behaviour of fibre composites are heterogeneous models. The greater computational effort required with heterogeneous models is no longer a major handicap thanks to the rapid increase of computational power and storage capacity. It is more the difficulty to determine relevant material properties. Inverse methods cannot be considered as the general solution to that problem since they require the choice of a micromechanical model in the first place.

All in all it must be concluded that models for predicting fibre composite damage and failure have not yet reached a fully satisfying state.

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