Failure of structural elements can be defined in a different manner. As in the case of buckling, a structural element may be considered failure though the material is still intact, but there are excessive deformations. In Chap. 6 failure will be considered to be the loss of integrity of the composite material itself.

The failure analysis procedures for metallic structures were well established a long time ago. In the case of monolithic materials stress concentrations, e.g. around notches and holes, cause localized failures. For brittle materials local failures may lead to fracture and therefore to a total loss of load-carrying capability. For ductile materials local failure may be in the form of yielding and remains localized, i.e., it is tolerated better than brittle failure. The fail-safe philosophy has been employed in the design of metallic structures and is standard in engineering applications. Similar procedures for composite materials are not well defined and are the object of intensive scientific research up to now. Failure of fibre-reinforced materials is a very complex topic. While it is important to understand the principal mechanisms of failure, for many applications it is impossible to detail each step of the failure process. Main causes of failure are design errors, fabrication and processing errors or unexpected service conditions. Design errors can be made in both material and structure. The stress level carried by each lamina in a laminate depends on the elastic moduli. This may cause large stress gradients between laminae which are oriented at considerably large angles to each other (e.g. 90°). If the stress gradients are close to a limit value, fracture may occur. Such high levels of internal stresses in adjacent laminae may develop a result of external applied loads but also by temperature and moisture changes. Though manufacturing control and material inspection tests are carried out, structural composites with abnormalities can be produced. The mechanical properties of composites may be significantly reduced by high temperature variations, impact damage, etc. Service anomalies can include improper operation, faulty maintenance, overloads or environmental incurred damage.

If structural loadings produce local discontinuities inside the material we speak of a crack. Micro-cracking is considered as the nucleation of micro-cracks at the microscopic level starting from defects and may cause the initiation of material fracture. Macro-cracking is the propagation of a fracture by the creation of new
fracture surfaces at the macroscopic level. For composite materials the fraction initiation is generally well developed before a change in the macroscopic behavior can be observed.

If in a laminate macro-cracks occur, it may not be catastrophic, for it is possible that some layers fail first and the composite continues to take more loads until all laminae fail. Failed laminae may still contribute to the stiffness and strength of the laminate. Laminate failure estimations are based on procedures for finding the successive loads between the first and the last ply failure of the laminate. The failure of a single layer plays a central function in failure analysis of laminates.

In this section the elastic behavior of laminae is primarily discussed from a macroscopic point of view. But in the case of failure estimations and strength analysis of a laminate it is important to understand the underlying failure mechanisms within the constituents of the composites and their effect to the ultimate macroscopic behavior. For this reason some considerations on micro-mechanic failure mechanisms are made first and then failure criteria are discussed more in detail.

Summarizing one can say that the ability of failure prediction is a key aspect in design of engineering structures. The first step is to consider what is meant by failure. Material failure of metallic structures is mostly related with material yielding or rupture, but with composites it is more complex. Therefore research is ongoing in developing failure mechanisms and failure criteria for unidirectional fibre laminae and their laminates and in evaluating the accuracy of the failure criteria.

### 6.1 Fracture Modes of Laminae

Composite fracture mechanisms are rather complex because of their anisotropic nature. The failure modes depend on the applied loads and on the distribution of reinforcements in the composites. In continuous fibre reinforced composites the types of fracture may be classified by these basic forms:

- Intralaminar fracture,
- interlaminar fracture,
- translaminar fracture.

Intralaminar fracture is located inside a lamina, interlaminar fracture shows the failure developed between laminae and translaminar fracture is oriented transverse to the laminate plane. Inter- and intralaminar fractures occur in a plane parallel to that of the fibre reinforcement.

Composite failure is a gradual process. The degradation of a layer results in a redistribution of stresses in the laminate. It is characterized by different local failure modes:

- The failure is dominated by fiber degradation, e.g. rupture, microbuckling, etc.
- The failure is dominated by matrix degradation, e.g. crazing.
- The failure is dominated by singularities at the fiber-matrix interface, e.g. crack propagation, delamination, etc.