Polymeric fiber technology
lecture (4)
Structure of reinforcement fiber

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- **Structure of the Reinforcement Fiber:**
- The structure of a fiber is responsible for all of the properties, Therefore, a basic overview on the structures present in a fiber shall be given. The structure of the common reinforcement fibers can be considered as hierarchical, in which a certain structural element is used to build the next larger part of structure, so that the size of structures in a single filament range over several orders of magnitude (from 10−10 m, the distance between two atoms, to 10−5 m, the diameter of a filament). Due to the anisotropy of

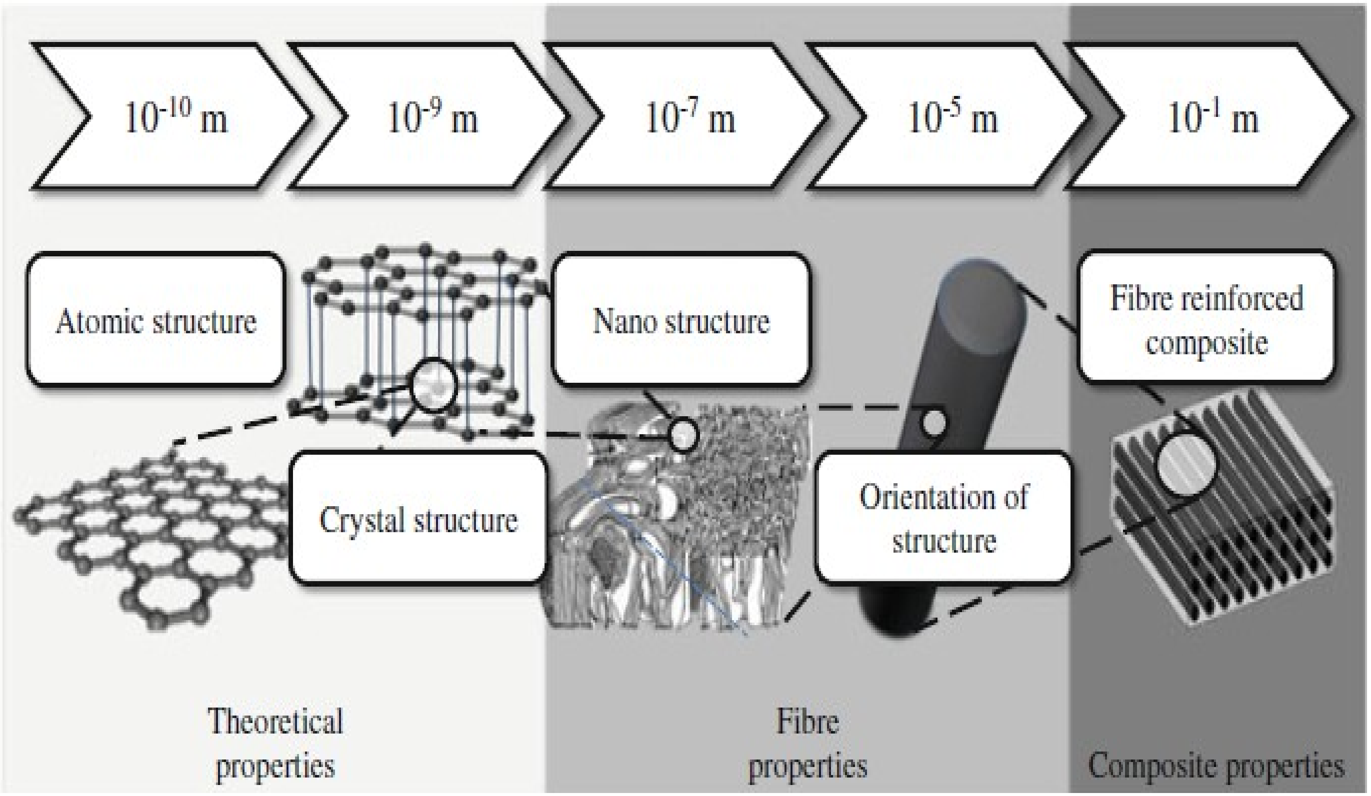

Fig. (1): types of structures in a reinforcement fiber with their size indicated (structure illustrated).exemplarily for carbon fibers

- **Description of Structure:**
- **Atomic or molecular structure:**
- The atomic or molecular structure is being formed by the interaction of single atoms and the resulting type of chemical bonding.
- Depending on the type of chemical bonding, anisotropic structures can be formed on the molecular level .Usually, covalent bonding between atoms causes such an anisotropy (such as graphene layers in carbon fibers and the backbone in polymeric fibers), whereas metallic or ionic bonds are isotropic.

- Depending on a regular or non-regular atomic or molecular structure, the atoms respectively molecules can be arranged to a crystalline structure or non-crystalline (amorphous) structure. In crystalline structures, atoms or molecules have fixed distances to each other in all space directions over a long distance, which are described by the unit cell. Amorphous structure is contrarily characterized by a medium (most probable) distance to the next atom or molecule.
- In a fiber, crystallites of different sizes and shapes can be formed.
- The crystalline or amorphous structure of a

- **Nano structure:**
- Different crystallites or amorphous structures are combined to the nano structure of a fiber. It is characterized by the arrangement of the single elements, which may differ over the diameter of a filament. Crystalline and amorphous structures as well as nano-sized pores coexist in the nanostructure of a filament.
- The nano structure is usually anisotropic, and can even be anisotropic if the single elements are isotropic or amorphous, such as in glass fibers. The different elements of the nano structure as well as the nano structure itself may have a distinguished orientation in

- **Fiber reinforced composites:**
- The most outer parts of the nano structure form the surface of a filament. Therefore, the arrangement and orientation of structures in the outer parts of a filament can have an effect on the surface morphology (and roughness) as well as the possibilities of adding chemical functionalities to the surface. This part of the structure is then responsible for the interaction with the matrix material and has an influence on the composite properties such as wetting behavior and adhesion.

- **Load Transfer and Critical Fiber Length (Lc):**
- A parameter which allows the quantification of the fiber-matrix-adhesion (FMA) is the interlaminar shear strength τFMA. The interlaminar shear strength (ILSS) is the maximum force per surface area with the unit [N/mm2]. In other words: when the shear stress between fiber and matrix exceeds the interlaminar shear strength, a delamination of the inter layers will take place.

- When stress is transferred from the matrix

- **Pull-Out of the fiber:** the interlaminar shear strength is lower than the tensile strength of the fiber. Therefore, a delamination takes place and, due to de bonding, no more stress can be transferred into the fiber. The reinforcement of the fibers is only possible up to a force which does not exceed the interlaminar shear strength.

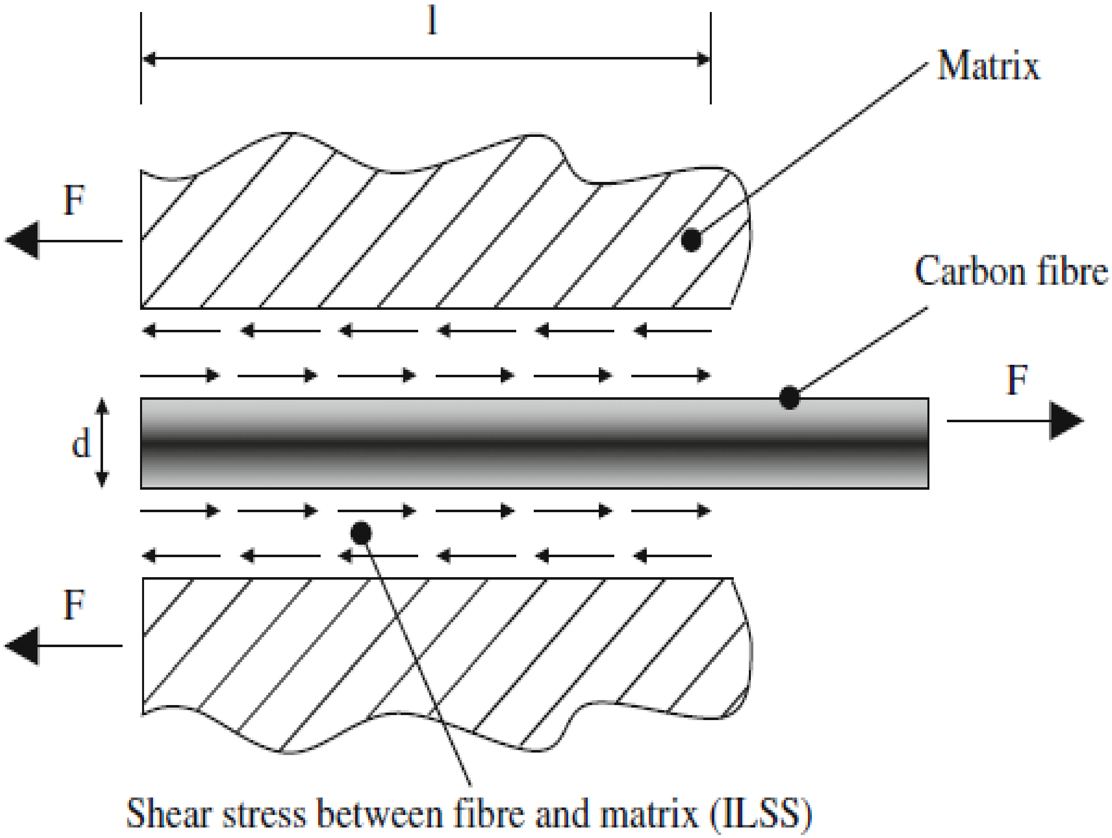

Fig. (2): Definition Of The Interlaminar Shear Strength (ILSS), .Illustrated For The Case Of Pull-out Test

- **Fiber breakage:** the matrix can conduct more stress into the fiber than the fiber’s tensile strength can support. Hence, the fiber breaks into smaller pieces and the fiber’s reinforcement is ideally used until the critical fiber length (length of the fiber where no more stress can be transferred from the matrix to the fibers) is reached.

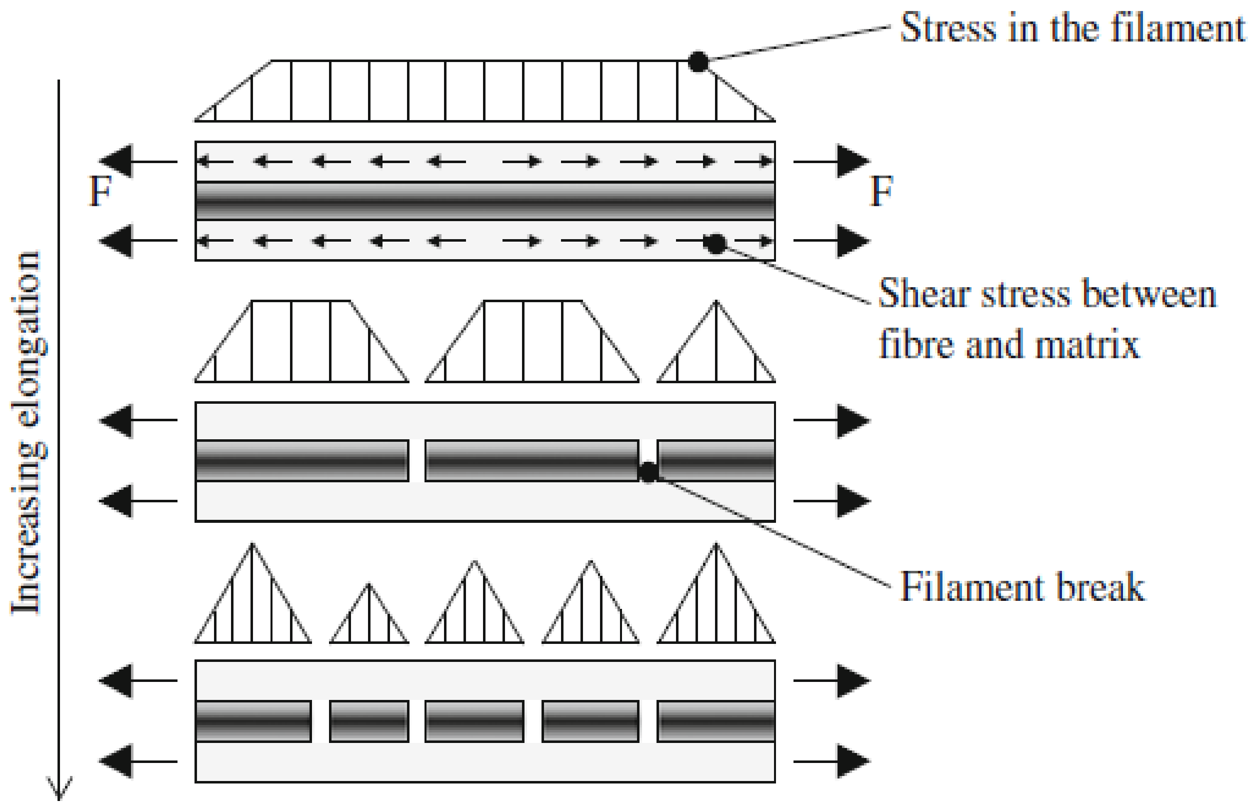

Fig. (3): Stress And Fracture Development For The Case Of A Composite's Elongation: Load Is Transferred To The Fibers Until .The Critical Fiber Length Is Reached By Filament Breakage

- No more reinforcement is possible when the shearing force is at the same level as the maximum tensile force the fiber can withstand:

- F shear= A surface. τ FMA= (∏. d). (Lc/2). τ FMA…. (1)
- F max fiber = A fiber. σ = ∏. (d/2)2. σ……. (2)

- Equalizing the two equations lead to the critical fiber length Lc:

$$Lc = \frac{\sigma}{2\tau FMA} \cdot d$$

- **Fiber Durability:**
- The durability of fibers has to be taken into account both for the manufacturing of composites as well as during their period of application (even if the fibers are covered with matrix material in the composite, smaller cracks or pores allow the interaction of surrounding media with the fiber). The most suitable test method for all types of durability are to expose to the fibers (or composites) to the specific environmental conditions and test the relevant fiber properties after exposition. The following

- **Thermal stability and degradation:** The influence of temperature is present during the curing of the matrix material (especially in thermoplastic matrices or high-temperature matrices) and also in specific applications. Specific temperature ranges to be tested are defined for certain fields of application such as aerospace or automotive. Especially, the influence on tensile properties should be taken into account. Materials can shrink, melt or degrade at high temperatures or become brittle at low temperatures. Periodic changes in temperature, even if temperature ranges do not exceed certain limits, can lead to structural changes in the fibers which

- **Chemical stability:** During the curing of matrix systems (e.g. in special systems like concrete), pH values can drastically change from a neutral value. Furthermore, fiber materials may get in contact with alkaline solutions oracids in their fields of application. The stability can be tested by exposing the material to the specific pH value for a period of time and, if necessary, atelevated temperatures. For assessing long-term effects, which may occur after years of application, more harsh conditions can be chosen to study possibleeffects qualitatively. After exposition, the specific fiber properties can be tested.Degradation due to exposure to chemicals can be tested by determining

Mechanical stability: Even if fibers or composites are loaded far below their maximum strength in the linear elastic region, fatigue can occur in the material in the form of plastic deformation, creep or cracks. The behavior can be examined by fatigue tests, where a certain load is applied periodically.