Discontinous fibers

Influence of discontinous fiber

Ordered discontinuous fibers (1D systém) with the tensile load in the main direction.

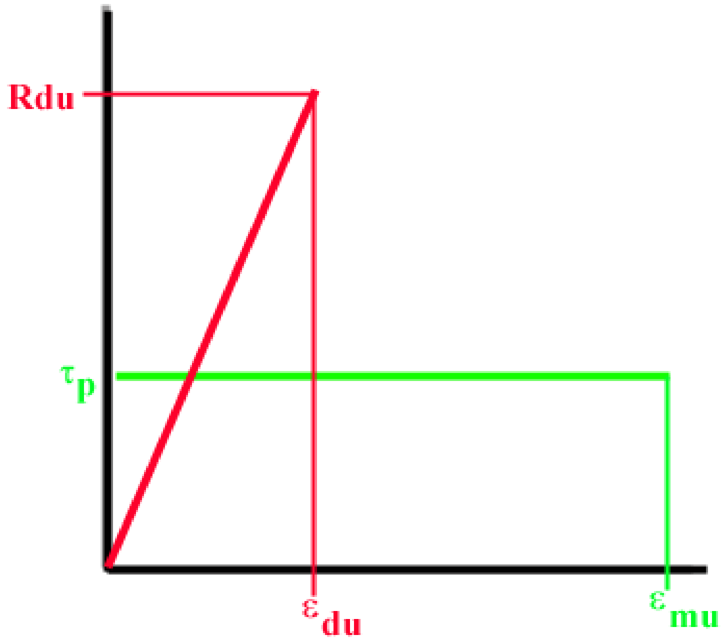
Because the fibers are very thin, we neglect the load transmitted through the fiber bases.

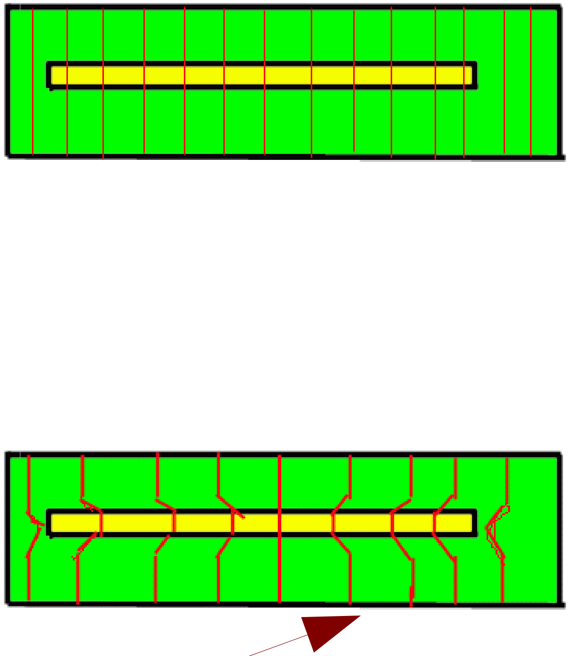
All the load is transmitted into the fiber doe to tangent matrix adhesion forces.

To assess the influence of that load is to be expected, the behavior of the matrix and fibers under load - the proportion of elastic and plastic deformation.

The simplest model is perfectly elastic fibers and perfectly plastic matrix.

Elastic fibers – plastic matrix





Plastic deformation of matrix around fiber

Calculation of equilibrium

Equation of equilibrium

$\sigma * \pi r^2 + \tau_p * 2\pi r * dx$

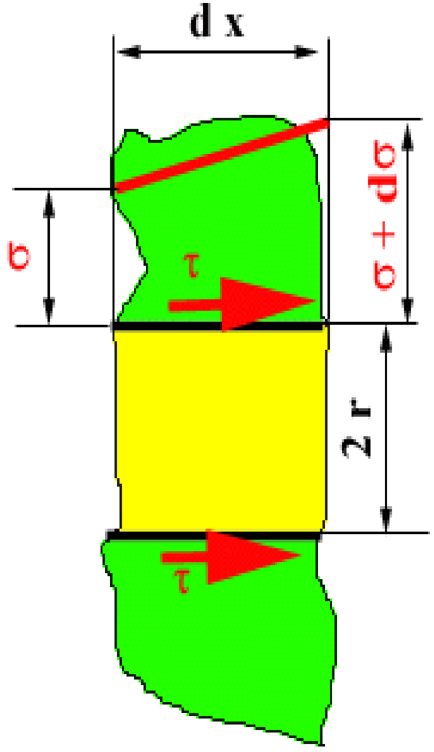
$= (\sigma + d\sigma) * \pi r^2$

Modification of equation

$d\sigma = 2\, \tau_p / r * dx$

By integrating from the edge to the middle of fiber 2 * l

$$\sigma_{dmax} = \tau_p * 2 * l \;/\; r$$



τ_p is tangent stress between matrix and fiber

Little stress in fibers

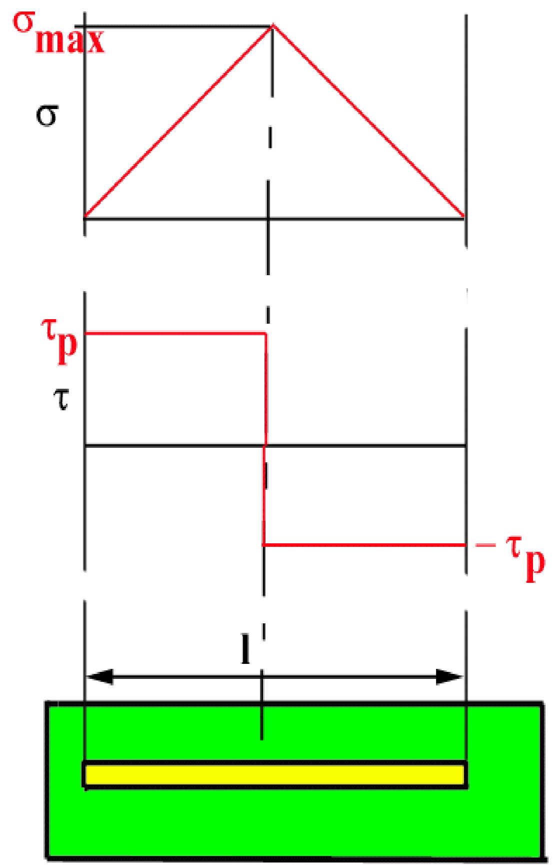
Change the stress in such short fibers, that σ_{max} is less than σ_d corresponding Voigt model for continuous fibers, thus

$$\sigma_{max} < \sigma_c * E_d/E_c$$

Mean stress in the fiber is

$$\sigma_s = \sigma_{max}/2$$

The use of such fiber is ineffective – there is nowhere such great stress as achieved on long fibers



Greater stress in fibers

Change the stress in such fibers, tha the middle stress is corresponding to Voigt's model - stress can not further increase.

So $\sigma_{max} = \sigma_c * (E_d/E_c)$.

On each side the stress increases on length

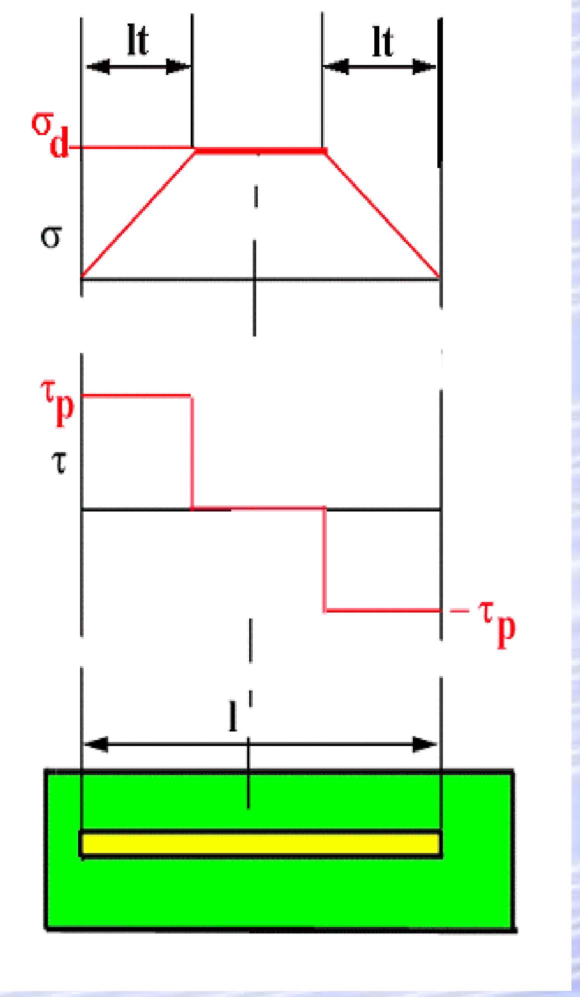
$$l_t = (E_d/E_c) * \sigma_c * (r/2\ \tau_p)$$

Mean stress tension in the fiber is

$$\sigma_s = \sigma_{max} * (1 - l_t / l)$$

The fiber has inefficiet length

$$2 * l_t = (E_d/E_c) * \sigma_c * (r/\tau_p)$$



Break of fibers

If in the center of the fiber achieves stress value R_{du} , fiber breaks.

It has together a length of $2 * l_t$.

While $l_t = l_k$ .... The critical fiber length.

This is so

$$\mathbf{l_k = R_{du} * r / 2 \tau_p}$$

Ineficient length by break

Fiber length of less than 2 * l_k can never break.

In break of such fiber composite thus occurs tearing of the fibers of the matrix.

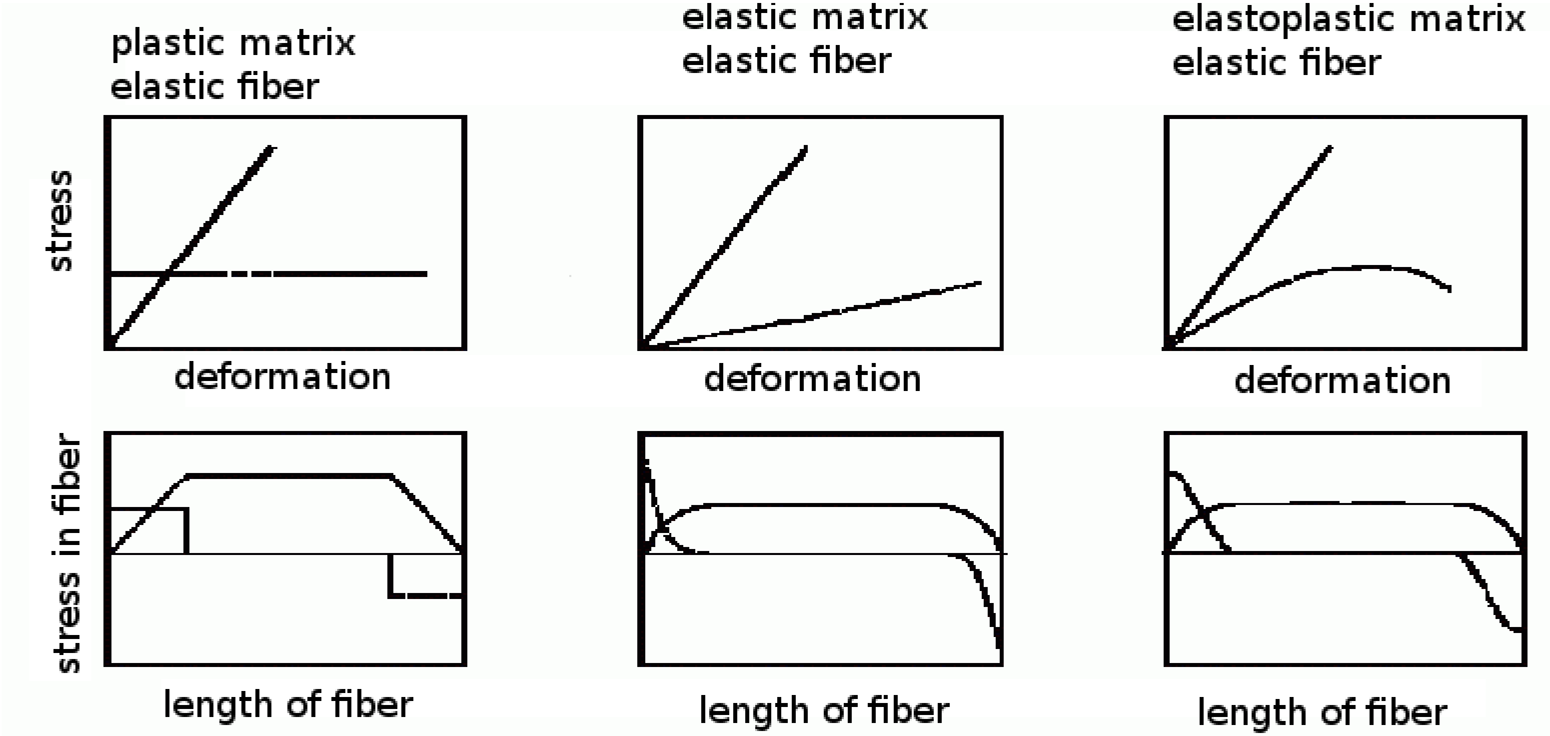
These are the so-called **short fibers**.

The fiber length of 2 * l_k can either tear or break, even if it is in the middle stresse R_{du}, while it is mean stress in fiber only R_{du} / 2.

The fiber longer then 2 * l_k breaks

- **<u>Long fiber</u>** (but not continuous)

Another matrix and fiberJ



Relations are more complicated, but curve of stress is near the same.

Young's modulus

For discontinuous fibers is the Young's modulus in the longitudinal direction E_{kd} less than that for continuous fibers - marking E_k.

The exact calculation from Halpin Tsai equations.

Approximate relationship

$$\mathbf{E_{kd} = E_k * (1 - l_k/l * \varepsilon/\varepsilon_u)},$$

l_k is the critical length, fiber length l,

ε_u is the deformation of fibers by break.

It can be seen that the longitudinal Young's modulus of composite decreases with increasing deformation.

Transverse Young's modulus is not affected by the length of fiber

Tensile strength of composite with long fibers

For long fibers we can use derived relations for the longitudinal tensile strength of composite with continuous fibers, if we substitute instead of R_{du} the mean stress in fibers by their break

$$R_{dus} = R_{du} * (1 – l_k / l)$$

Tensile strength of the composite :

$$R_{ku} = v_f * (R_{du} * (1 – l_k / l)) + R_{mu} * (1 – v_f)$$

Tensile strength - short fibers

If l <2 * l_k, we do not apply a tensile strength of fiber – fibers are pull out. The relation for the composite tensile strength affects only the force required to pull out the fibers, that depends on how big a piece of fiber is pulled out. It can be pulled up half the fiber length (on each side), the average length of the pulled out fiber is half this value, ie l / 4 Voltage that falls on each thread, thus

$\tau_p * (2\pi r * l / 4) / \pi r^2$. Composite tensile strength must be

$$\mathbf{R_{ku} = v_f * \tau_p * l/2r + R_{mu} * (1 - v_f)}$$

Decrease of the composite tensile strength

Table of decrease of tensile strength with the length of short fibers

l/l_k	2	4	10	20	100	200
R_{kuk}/R_{kus}	0,5	0,75	0,90	0,95	0,99	0,995

- R_{kuk} – short fiber composite,
  R_{kus} - continous fibre composite
- We can see that with accuracy to 10 % is the decrease from ten critical lengths neglective

Nanofibers

If we consider the strongest nanofibers with a diameter of 100 nm, corresponds to aspect ratio s_k = 100 fiber length 10 microns!

In most cases, therefore nanofibers are (due to its minimal thickness) so long that it is possible for them to use relationships and models for continuous fibers

Different orientation of fibers

The continuous fibers, if they are parallel, the structure must be 1D

The discontinuous fibers can have also 2D and 3D structures.

Then just apply effectively only the number of fibers in the load direction.

Therefore, stiffness (Young's modulus) and strength are correspondingly smaller

2D structure

Properties in the main direction is the same as in 1D structure (in the direction perpendicular to the fibers).

In the plane of isotropy is applied effectively only 3/8 of the total number of fibers, therefore:

$$E_k = v_m * E_m + 3/8 * v_d * E_d$$

Similarly, the tensile strength.

3D structure

In each direction is applied effectively only one fifth of the total number of fibers, therefore:

$$E_k = v_m * E_m + 1/5 * v_d * E_d$$

Similarly, the tensile strength.