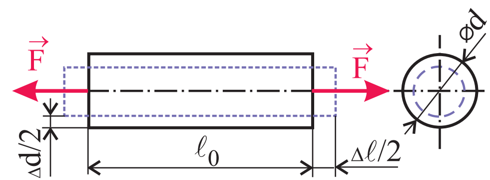
9. Tension and compression tests

For practical use of stress-strain analysis and evaluation of failure risks, it is necessary that the significant material properties of real bodies are expressed by constitutive relations and material characteristics, which must be determined experimentally. We suppose your basic knowledge on material tests from your previous studies. Now we remember about the **tension and compression tests** which are fundamental among the mechanical tests of materials.

In these tests, the specimen is loaded by elongation Δl of a monotonously increasing magnitude (positive in tension test, negative in compression test), while the dependencies of loading (reaction) force F and changes of lateral dimensions Δd are measured in the defined part of the specimen and recorded.



The measured part of the specimen is defined in such a way that the stress state in it be **uniaxial and homogeneous** (i.e. stress tensors in all the points are identical, that means all the stress components are identical). homogeneous

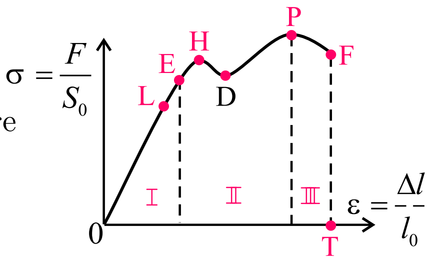
uniaxial s.s.

9.1. Tension test of material in ductile state

The results of the tension test are recalculated **into** dependencies $\sigma(\varepsilon)$ (engineering strain vs. engineering stress); for a typical ductile material, the shape of the dependence is presented in the figure.

Following significant points can be distinguished here:

0 – unloaded state
L – limit of linear dependence
E – limit of elastic behaviour
H – upper yield stress
D – lower yield stress
P – ultimate stress
F – initiation of fracture
T – fracture



Further, three typical regions can be distinguished:

I. region of elastic deformations, II. region of homogeneous elastic-plastic deformations and III. region of non-homogeneous elastic-plastic deformations.

9.1.1. Region of elastic deformations (I)

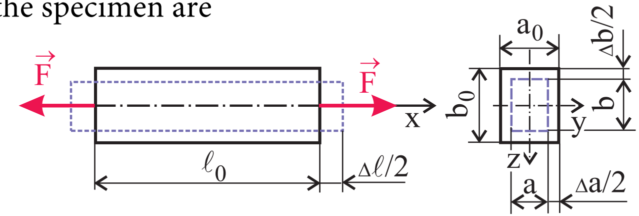
- The dependence $\sigma(\varepsilon)$ is the same in loading and unloading (at the usual technical level of resolution).
- The linear part of the dependence $\sigma(\varepsilon)$ can be expressed by Hooke's law for the uniaxial **state of stress** in the form $\sigma = E\varepsilon$ with the proportionality parameter E (modulus of elasticity in tension). For steel holds $E \in (1,9; 2,4) \cdot 10^5$ MPa.
- For length strains in the mutually perpendicular lateral directions holds

$$\varepsilon_y = \varepsilon_z = -\mu\varepsilon_x .$$

In the region of elastic deformations, Poisson's ratio μ is constant and its magnitude is approximately $\mu = 0,3$ for all types of steels. If a bar with initial dimensions l_0, a_0, b_0 is loaded in tension, its length is increased to l and lateral dimensions are decreased to a and b.

The length strains in the measured part of the specimen are

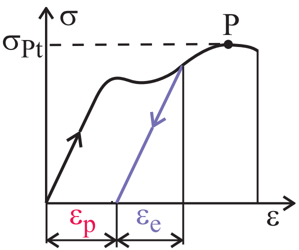
$$\varepsilon_x = \varepsilon = \frac{l - l_0}{l_0}, \varepsilon_y = \frac{a - a_0}{a_0}, \varepsilon_z = \frac{b - b_0}{b_0}$$



- The region of elastic deformations is limited by the yield stress. It is a conventional value lying under the points L, E, H, D on the tension curve of the material.

9.1.2. Region of homogeneous elastic-plastic deformations (II)

It holds for most materials:



- the deformation of the measured part of the specimen remains homogeneous, i.e. a cylindrical bar remains cylindrical;
- changes in specimen dimensions can be large so that the true stress is not equal to the values calculated using the initial specimen cross section;
- the dependence $\sigma(\varepsilon)$ is **nonlinear** during loading;
- the dependence $\sigma(\varepsilon)$ is **linear** during unloading (at the usual technical level of resolution;

- this region ends in the point P where the loading force reaches its maximum value corresponding to the conventional (engineering) ultimate stress σ_{Pt} (**strength of material**). In contradiction to its title, this characteristic does not represent that the

> material strength was achieved, when a crack is initiated and it comes to fracture, but it corresponds to the **transition** from **homogeneous** plastic deformations to **non-homogeneous** deformations.

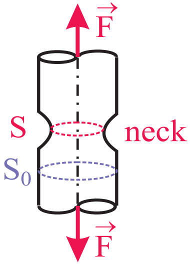
In this course, the range of elastic-plastic analyses will be very limited because it is too demanding for basic studies. Moreover this region is not applicable in most of designs because large plastic deformations are not allowable at most machinery components and structures.

9.1.3. Region of non-homogeneous elastic-plastic deformations (III)

triaxial s.s.

The dependence $\sigma(\varepsilon)$ is decreasing in this region, which means that the elongation of the bar occurs under decreasing engineering (conventional) stress. This is a consequence of the fact that deformation is localised in a small region where local taper occurs, the so called **neck**. In the surroundings of the neck, a *non-homogeneous triaxial stress state* occurs. Globally the non-homogeneous deformation of the specimen is characterised by **contraction**

$$z = \frac{S_0 - S}{S_0}.$$



This region ends by rupture of the bar, i.e. by a ductile fracture, which is the final stage of **failure** under conditions of the monotonously increasing deformation.

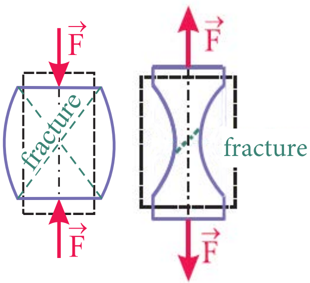
failure

9.2. Compression test of material in ductile state

There are substantial problems in carrying out of compression tests, because

– it is necessary to avoid bending of the specimen (change of its straightness), therefore short specimens must be used ($l_0 < 1,5d$),

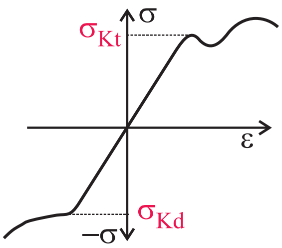
– we want to achieve a homogeneous deformation and, as a consequence, a homogeneous stress state, thus it is necessary to ensure a uniform load of the specimen facings by pressure during the whole loading process; the problem is that, because of shortening of the specimen, its lateral dimension increase, which is inhibited by friction between the facings of the specimen and the jaws of the testing machine. Consequently, shear stresses in the specimen occur and the uniaxial stress state is changed into a more general stress state. The shape of the specimen becomes spindle-like (non-uniform magnitude of section along the specimen length).



stress state

The compression test brings these important conclusions:

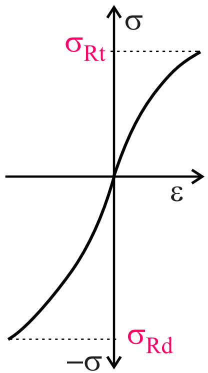
1. yield stress is the same in compression as in tension for most materials ($\sigma_{Kt} \doteq \sigma_{Kd} = \sigma_K$),
2. elastic constants E and μ are approximately equal in tension and in compression,
3. in contradiction to the tension test, no localisation of plastic deformations occurs during the compression tests,
4. the force necessary for an increase of plastic deformation increases during the whole loading process,
5. at highly ductile (formable) materials no ductile fracture (nor cracks) occurs in compression.



9.3. Tension and compression tests of material in brittle state

tension test

Under certain conditions (temperature, loading rate, stress state, . . .) no macroplastic deformations of materials occur. Then a brittle crack can occur in any material. In the conditions of tension tests (low loading rate, uniaxial stress state) the brittle fracture occurs especially in materials showing
– a characteristic structure (grey cast-iron, ceramic materials),
– at steels with pronounced *transition behaviour* (in dependence on certain factors, especially on temperature, they can fail by either ductile or brittle fracture).



The rate of propagation of a brittle fracture is high (approximately 1000 ms^{-1} in steels), so that it comes to the brittle fracture immediately after the crack initiation. The elastic strain energy accumulated in the deformed body in the moment of crack initiation is sufficient for the brittle crack propagation. Therefore the propagation cannot be **stopped** by any changes in the loads of the body.
The dependence $\sigma(\varepsilon)$ of a brittle material contains some significant points corresponding to **brittle strength limit in tension** σ_{Rt} and **brittle strength limit in compression** σ_{Rd}.

The realisation of a **compression test** brings the same problems as at materials in ductile state. Its analysis gives the following conclusions:

1. the strength limit in compression is always higher than the strength limit in tension ($\sigma_{Rd} > \sigma_{Rt}$),
2. the brittle fracture occurs in the direction parallel to the longitudinal axis of the specimen. If the friction between the specimen facings and the machine jaws is not avoided, the fractures occur under a certain angle (approximately 45^o).