

Overview of the principal types of loading and loading cases

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Symbols and terms:

A	Cross-sectional area
E	Young's modulus
F	Force
I	Moment of inertia
L	Length
M	Moment
W	Moment of resistance
b	Width
e	Outer fiber spacing
h	Height
Δ	Difference
ε	Strain
σ	Stress

Indices:

b	Bending
d	Pressure
p	Polar
t	Torsion
v	Comparative stress
x	In the x direction
y	In the y direction
z	Tension
0	At the origin

1 Fundamental concepts of engineering mechanics

Loading

Loading is defined as the action of external loads (forces, moments) on solid bodies.

Stressing

Stressing is defined as the action of internal forces (stresses) inside the material.

Stressing types

A distinction is drawn between the following two basic types of stressing:

- Normal stresses (σ) \Rightarrow act perpendicularly (in the normal direction) to the cross-sectional plane (tensile and compressive stresses)
- Tangential stresses (τ) \Rightarrow act parallel (tangentially) to the cross-sectional plane (shear stresses, thrust stresses, and torsional stresses)

Deformation

Deformation is the change in the shape of a part which results from the application of the load or stress, for example:

- Tensile stress \Rightarrow Elongation
- Compressive stress \Rightarrow Compression
- Bending stress \Rightarrow Deflection
- Shear stress \Rightarrow Distortion (twisting), displacement

1.1 Loading types

1.1.1 Tensile load

Loading \Rightarrow Forces act in opposite directions, parallel to the rod axis

The part is stretched.

Comments:

Tensile stressing is the type of stressing that is relevant for failure in plastics.

Tensile stressing is frequently combined with other forms of stressing. Pure tensile stressing rarely occurs.

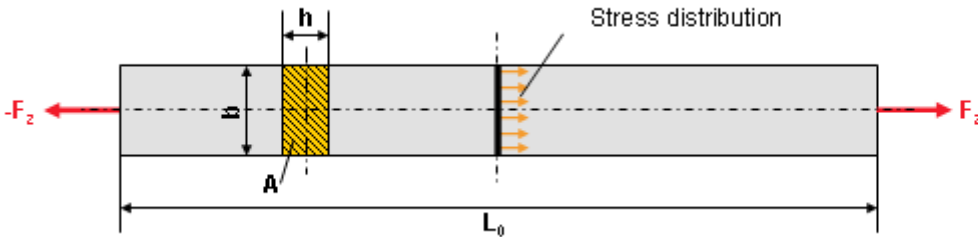
	
Stressing	Normal stress $\sigma = \frac{F_z}{A}$; where $A = b \cdot h$
Deformation	Elongation $\Delta L = L - L_0 \Rightarrow$ Strain $\varepsilon = \frac{\Delta L}{L_0}$

Table 1 Tensile stressing

1.1.2 Compressive load

Loading \Rightarrow Forces act towards each other in parallel to the rod axis

The part is compressed.

Comments:

Compressive stressing is not a form of stressing that is relevant for failure in plastics.

The compressive strength of plastics is generally considerably higher than their tensile stress.

Pure compressive stress rarely occurs and is primarily restricted to prismatic bodies with a low length to cross-section ratio (bricks). This is frequently confused with surface pressure (see also 1.1.7).

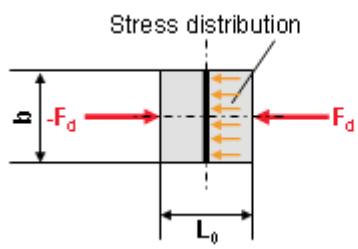
	
Stressing	Normal stress $\sigma = \frac{F_d}{A}$; where $A = b \cdot h$
Deformation	Length reduction $-\Delta L = L_0 - L \Rightarrow$ Compression $\varepsilon = -\frac{\Delta L}{L_0}$

Table 2 Compressive stressing

1.1.3 Bending load

Loading \Rightarrow Forces act transversally to the rod axis and form a bending moment (M_b).

The part is bent.

Comments:

A bending load always leads to tensile and compressive stressing at one and the same time. The

maximum tensile stress is the stress component that is relevant to failure. High compressive stressing ought to be viewed as an indicator of potential stability problems (buckling, buckling).

Bending stress is the most frequent form of stressing encountered in rod-shaped and planar parts.

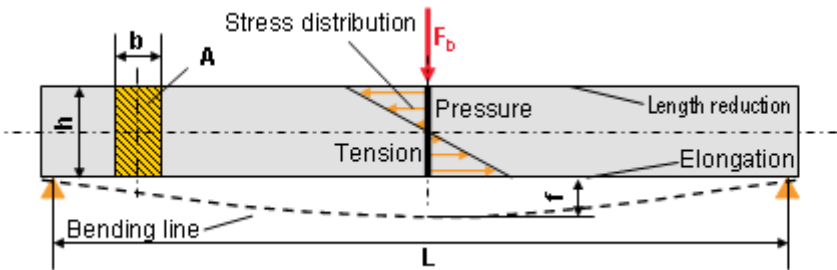
	
Stressing	Normal stress $\sigma_{b\max} = \frac{M_b}{W}$
Deformation	Deflection $f_{\max} = \frac{F_b \cdot L^3}{48 \cdot EI}$

Table 3 Bending load

1.1.4 Thrust load (transverse bending)

Load \Rightarrow Thrust loading generally occurs at the same time as bending load. It acts on both the perpendicular and the horizontal cross-sectional planes.

The load causes a displacement of the end surfaces which are parallel to each other.

Comments:

In bulky cross-sections $\left(\frac{L}{h} < 10\right)$ that are subject to bending shearing stress can be significant.

It can lead to an increase in deflection. The action of shear stressing is taken into account in the reference stress (see compound stressing).

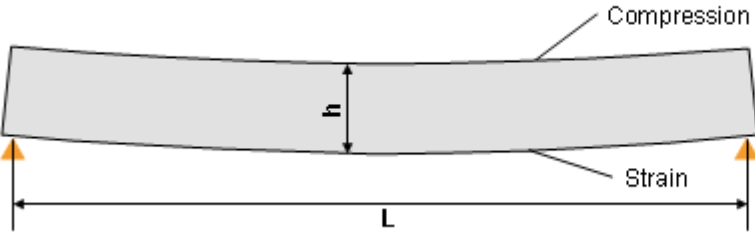
	
Stressing	Shear stress $\tau = \frac{F}{A}$
Deformation	Deflection, displacement

Table 4 Shear deformation of a solid beam in bending

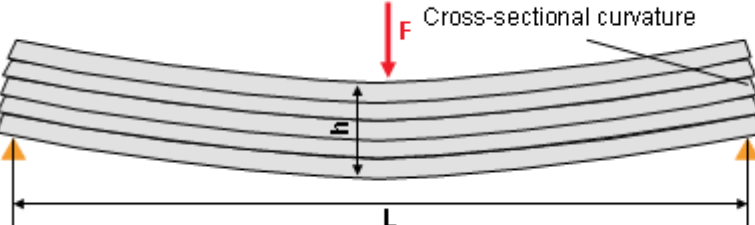
	
Stressing	Shear stress $\tau = \frac{F}{A}$
Deformation	Deflection, displacement

Table 5 Shear deformation (principle) between the longitudinal layers of a beam in bending

1.1.5 Torsional load

Load \Rightarrow Forces act in pairs in the cross-sectional plane, perpendicular to the rod axis, and form a torsional moment (M_t), which distorts (twists) the cross-section.

The part is twisted.

Comments:

Torsional load generally occurs in conjunction with bending load.

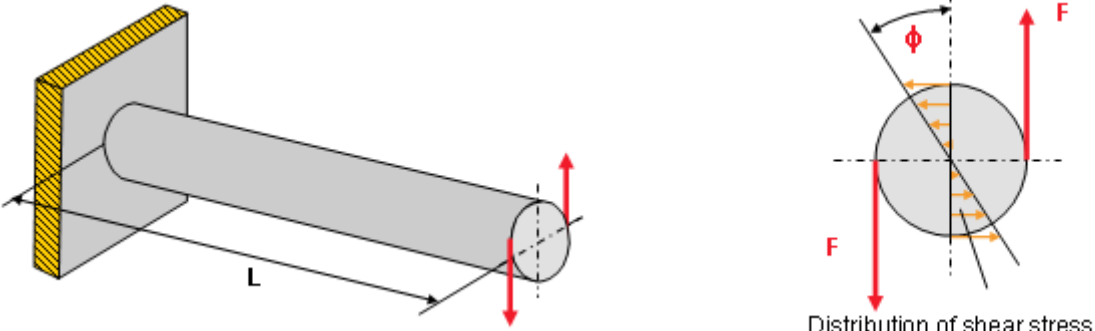
	
Stressing	Shear stress $\tau_{\max} = \frac{M_t}{W_p}$
Deformation	Distortion (twisting) $\Phi_{\max} = \frac{M_t \cdot L}{G \cdot I_p} \Rightarrow$ displacement

Table 6 Torsional load

1.1.6 Shear load

Load \Rightarrow Two identically-sized loads, directed against each other, act on a plane at right angles to the rod axis.

The part is sheared.

Comments:

Shear loading is generally combined with bending load. It plays a key role in the design of bolted con-

nections (rivets, pins, screws, etc.) that are subject to transverse loading.

The shear strengths of a number of LANXESS polymers are listed in the Technical Information brochure entitled "Shear strengths of representative LANXESS thermoplastics". They are used primarily in the design of parting tools and should not be confused with thrust resistance (e.g. for torsion).

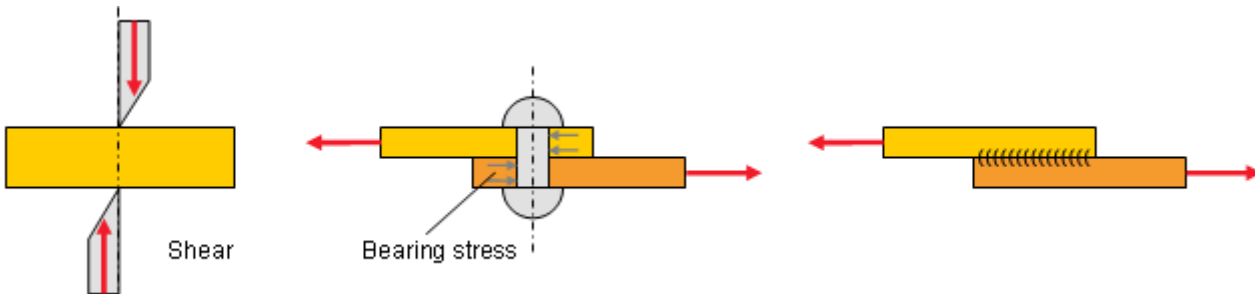
	
Stressing	Shear stress $\tau = \frac{F}{A}$
Deformation	Shearing, displacement

Table 7 Shear load

1.1.7 Surface pressure (bearing stress)

Load \Rightarrow Contact between the surfaces of two bodies.

The application of the load leads to compression of the contact surfaces.

Comments:

Surface pressure rarely leads to failure but it frequently impairs functions through local surface de-

formation. It plays a key role in the design of rollers, toothed wheels, friction bearings and bolted connections. The bearing stress that prevails with rivet connections is a special form of surface pressure.

Surface pressure is frequently confused with compressive loading.

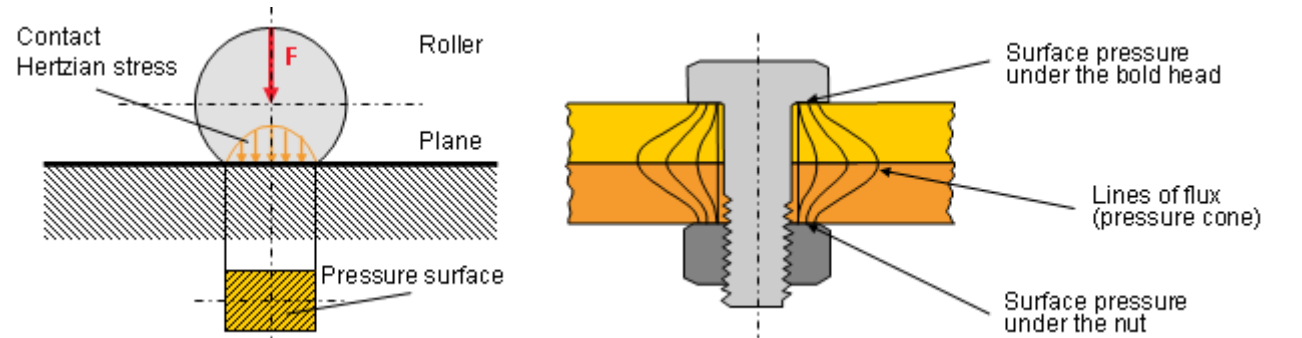
	
Stressing	Contact Hertzian stress
Deformation	Local deformation

Table 8 Surface pressure

1.2 Stability problems (Bending, buckling, tilting)

Load \Rightarrow Critical force, critical pressure

The application of the load causes rapid deformation of the part (collapse), which frequently leads to failure.

Comments:

The stability problems are essentially a stiffness problem. They can occur at below the permitted stressing of the material. Apart from slim rods and beams, it is primarily planar and ribbed structures that are affected by these problems. Care should be taken with exposed rib edges under compressive load.


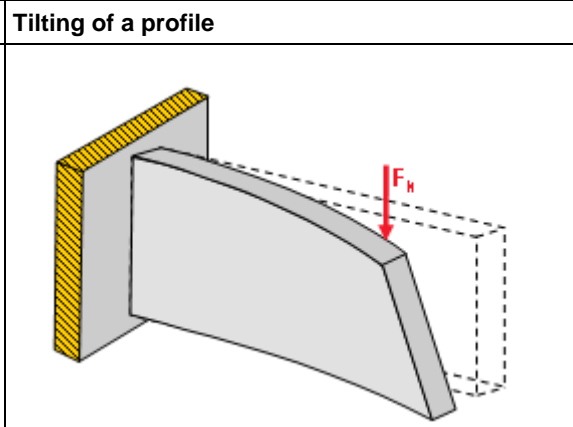
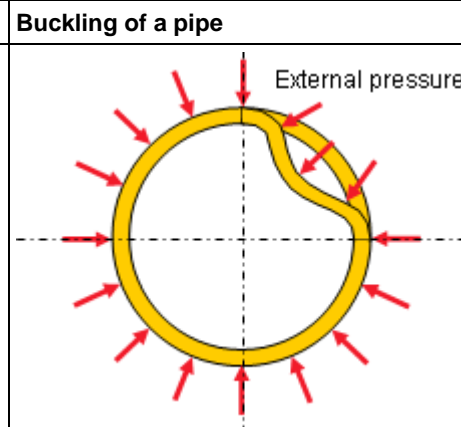
Bending of a rod	Tilting of a profile	Buckling of a pipe
		
Stressing	Compressive stresses	
Shape change	Sudden collapse (instability)	

Table 9 Stability problems

1.3 Compound loading

Both the complex part geometry and the complex load configuration mean that, in practice, the stress generally results from several different types of load. The multi-axial stressing that this gives rise to is described by the comparison stress, which is the equivalent of a uniaxial normal stress and thus permits comparability with the strength values established (uniaxially) on the test bars. The most commonly used comparison stress for plastics is the von Mises stress.

The following applies for the biaxial (planar) stress state:

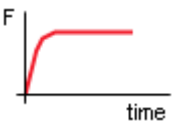
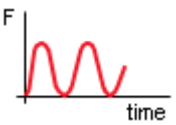
$\sigma_v = \sqrt{\sigma_x^2 + \sigma_y^2 - \sigma_x \cdot \sigma_y + 3 \cdot \tau^2}$	
Stressing	Reference stress (such as von Mises stress)
Shape change	Superimposed

Table 10 Reference stress

2 Load cases

With plastics, a fundamental distinction is drawn between the same loading cases as in classical mechanical engineering. In view of the pronounced relaxation and retardation (creep) behavior of plastics, however, it makes sense to subdivide static loading into a number of different load cases, e.g.:

- a once-only, short-term load
- a frequent, short-term load
- a long-term load

Static, once-only, short-term Static, repeated, short-term Static long-term	
Dynamic pulsating	

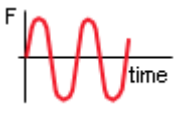
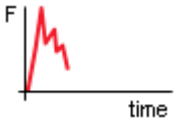
Dynamic, alternating	
Crash	

Table 11 Load cases

3 Permitted stressing

Apart from the load types and load cases, the permitted stress or strain in the case of plastics is largely conditioned by the temperature, processing and surrounding media.

Permitted stress or strain values are available as a function of these influencing factors for the chief LANXESS thermoplastics Durethan® and Pocan®. These can be requested from the responsible experts or from durethan-pocan@lanxess.com.

The magnitude of the permitted stress or strain under static load can be established for semi-crystalline materials applying the following rule:

For a once-only, short-term load:

Approx. 95 % of the tensile strain at yield for unreinforced materials

Approx. 50 % of the tensile strain at break for GF-reinforced materials

For a frequent, short-term load:

Approx. 60 % of the once-only, short-term permitted values

For long-term loading, dynamic and impact loading:

Approx. 0.5 % strain

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