Deformation (engineering)

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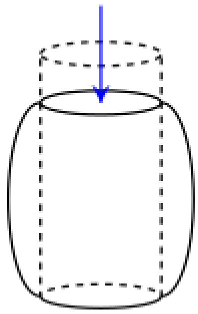
In materials science, **deformation** refers to any changes in the shape or size of an object due to-

- an applied force (the deformation energy in this case is transferred through work) or
- a change in temperature (the deformation energy in this case is transferred through heat).



Compressive stress results in deformation which shortens the object but also expands it outwards.

The first case can be a result of tensile (pulling) forces, compressive (pushing) forces, shear, bending or torsion (twisting).

In the second case, the most significant factor, which is determined by the temperature, is the mobility of the structural defects such as grain boundaries, point vacancies, line and screw dislocations, stacking faults and twins in both crystalline and non-crystalline solids. The movement or displacement of such mobile defects is thermally activated, and thus limited by the rate of atomic diffusion. [1][2]

Deformation is often described as strain.

As deformation occurs, internal inter-molecular forces arise that oppose the applied force. If the applied force is not too great these forces may be sufficient to completely resist the applied force and allow the object to assume a new equilibrium state and to return to its original state when the load is removed. A larger applied force may lead to a permanent deformation of the object or even to its structural failure.

In the figure it can be seen that the compressive loading (indicated by the arrow) has caused deformation in the cylinder so that the original shape (dashed lines) has changed (deformed) into one with bulging sides. The sides bulge because the material, although strong enough to not crack or otherwise fail, is not strong enough to support the load without change, thus the material is forced out laterally. Internal forces (in this case at right angles to the deformation) resist the applied load.

The concept of a rigid body can be applied if the deformation is negligible.

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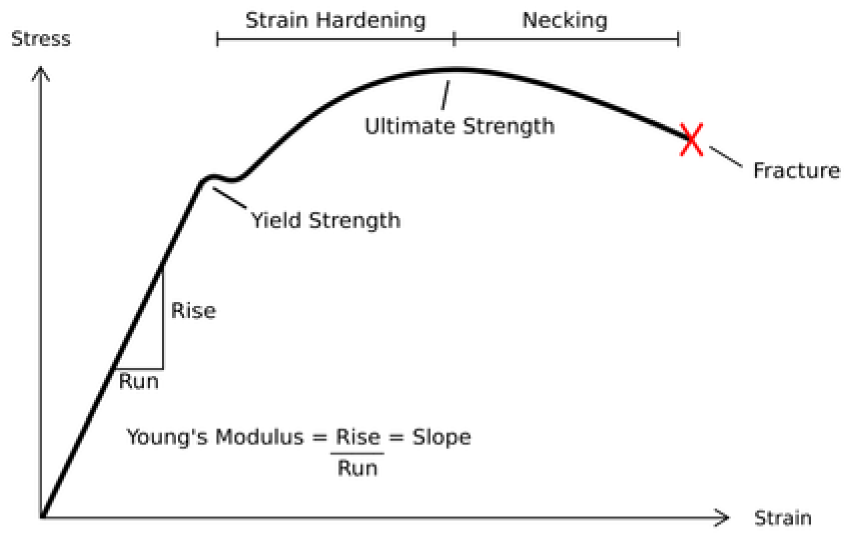
Types of deformation

Depending on the type of material, size and geometry of the object, and the forces applied, various types of deformation may result. The image to the right shows the engineering stress vs. strain diagram for a typical ductile material such as steel. Different deformation modes may occur under different conditions, as can be depicted using a deformation mechanism map.

Elastic deformation



Typical stress vs. strain diagram indicating the various stages of deformation.

This type of deformation is reversible. Once the forces are no longer applied, the object returns to its original shape. Elastomers and shape memory metals such as Nitinol exhibit large elastic deformation ranges, as does rubber. However elasticity is nonlinear in these materials. Normal metals, ceramics and most crystals show linear elasticity and a smaller elastic range.

Linear elastic deformation is governed by Hooke's law, which states:

$$\sigma = E\varepsilon$$

Where σ is the applied stress, E is a material constant called Young's modulus or elastic modulus, and ε is the resulting strain. This relationship only applies in the elastic range and indicates that the slope of the stress vs. strain curve can be used to find Young's modulus (E). Engineers often use this calculation in tensile tests. The elastic range ends when the material reaches its yield strength. At this point plastic deformation begins.

Note that not all elastic materials undergo linear elastic deformation; some, such as concrete, gray cast iron, and many polymers, respond in a nonlinear fashion. For these materials Hooke's law is inapplicable.[3]

Plastic deformation

This type of deformation is irreversible. However, an object in the plastic deformation range will first have undergone elastic deformation, which is reversible, so the object will return part way to its original shape. Soft thermoplastics have a rather large plastic deformation range as do ductile metals such as copper, silver, and gold. Steel does, too, but not cast iron. Hard thermosetting plastics, rubber, crystals, and ceramics have minimal plastic deformation ranges. An example of a material with a large plastic deformation range is wet chewing gum, which can be stretched dozens of times its original length.

Under tensile stress, plastic deformation is characterized by a strain hardening region and a necking region and finally, fracture (also called rupture). During strain hardening the material becomes stronger through the movement of atomic dislocations. The necking phase is indicated by a reduction in cross-sectional area of the specimen. Necking begins after the ultimate strength is reached. During necking, the material can no longer withstand the maximum stress and the strain in the specimen rapidly increases. Plastic deformation ends with the fracture of the material.

Metal fatigue

Another deformation mechanism is metal fatigue, which occurs primarily in ductile metals. It was originally thought that a material deformed only within the elastic range returned completely to its original state once the forces were removed. However, faults are introduced at the molecular level with each deformation. After many deformations, cracks will begin to appear, followed soon after by a fracture, with no apparent plastic deformation in between. Depending on the material, shape, and how close to the elastic limit it is deformed, failure may require thousands, millions, billions, or trillions of deformations.

Metal fatigue has been a major cause of aircraft failure, especially before the process was well understood (see, for example, the De Havilland Comet accidents). There are two ways to determine when a part is in danger of metal fatigue; either predict when failure will occur due to the material/force/shape/iteration combination, and replace the vulnerable materials before this occurs, or perform inspections to detect the microscopic cracks and perform replacement once they occur. Selection of materials not likely to suffer from metal fatigue during the life of the product is the best solution, but not always possible. Avoiding shapes with sharp corners limits metal fatigue by reducing stress concentrations, but does not eliminate it.

Analysis of the bulging factor of pressurized parts of the plane can assist in evaluating the damage tolerance of airframe fuselages.[4]

Compressive failure

Usually, compressive stress applied to bars, columns, etc. leads to shortening.

Loading a structural element or specimen will increase the compressive stress until it reaches its compressive strength. According to the properties of the material, failure modes are yielding for materials with ductile behavior (most metals, some soils and plastics) or rupturing for brittle behavior (geomaterials, cast iron, glass, etc.).

In long, slender structural elements — such as columns or truss bars — an increase of compressive force F leads to structural failure due to buckling at lower stress than the compressive strength.

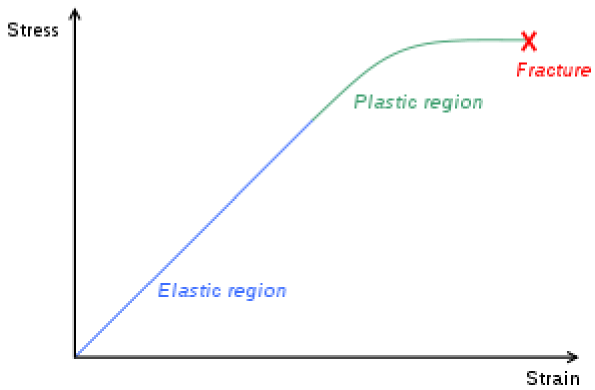


Diagram of a stress–strain curve, showing the relationship between stress (force applied) and strain (deformation) of a ductile metal.

Fracture

This type of deformation is also irreversible. A break occurs after the material has reached the end of the elastic, and then plastic, deformation ranges. At this point forces accumulate until they are sufficient to cause a fracture. All materials will eventually fracture, if sufficient forces are applied.

Misconceptions

A popular misconception is that all materials that bend are "weak" and those that don't are "strong". In reality, many materials that undergo large elastic and plastic deformations, such as steel, are able to absorb stresses that would cause brittle materials, such as glass, with minimal plastic deformation ranges, to break.[5]

See also

- Artificial cranial deformation
- Buff strength
- Creep (deformation)
- Deflection (engineering)
- Deformable body
- Deformation (mechanics)
- Deformation mechanism maps
- Deformation Monitoring
- Deformation retract
- Deformation theory
- Discontinuous Deformation Analysis
- Elastic
- Finite deformation tensors
- Malleability
- Planar deformation features
- Plasticity (physics)
- Poisson's ratio
- Strain tensor
- Strength of materials
- Wood warping

References

1. Davidge, R.W., **Mechanical Behavior of Ceramics**, Cambridge Solid State Science Series, Eds. Clarke, D.R., et al. (1979)
2. Zarzycki, J., **Glasses and the Vitreous State**, Cambridge Solid State Science Series, Eds. Clarke, D.R., et al.(1991)
3. Fundamentals of Materials Science and Engineering, William D. Callister, John Wiley and Sons, 2nd International edition (September 3, 2004), ISBN 0-471-66081-7, ISBN 978-0-471-66081-1, p.184
4. United States of America. Federal Aviation Administration. Bulging Factor Solutions for Cracks in Longitudinal Lap Joints of Pressurized Aircraft Fuselages. Springfield, 2004. pp.1-3,10
5. Peter Rice, Hugh Dutton (1995). *Structural glass* (https://books.google.com/books?id=7t9wgJEUWHYC&pg=PA33). Taylor & Francis. p. 33. ISBN 0-419-19940-3.

External links

- Table of deformation mechanisms and processes (http://virtualexplorer.com.au/special/meansvolume/contribs/jessell/glossary/defmech.html)

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