# Mechanical properties of solid polymers

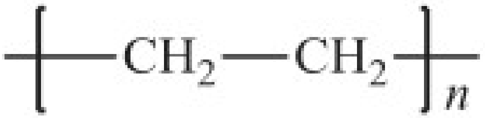
Before we discuss the mechanical properties,
let’s understand polymers better!

- *Define polymeric materials*
- Find a few common examples of polymers.
- What are the types of bonds typically found in polymers?
- What are typical applications of polymers?

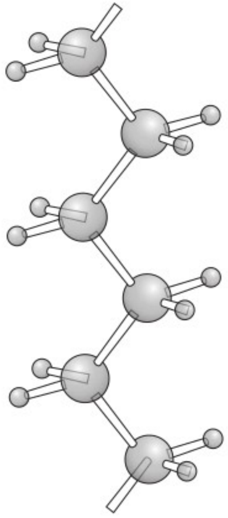
# Introduction

Mechanical properties of polymers are a consequence of the <u>chemical composition</u> of the polymer and also of its <u>structure</u> at the molecular and supermolecular levels.

## Chemical Composition



- <u>Polymerisation</u>



Linear polymers consist of long molecular chains of covalently bonded atoms, each chain being a repetition of much smaller chemical units.

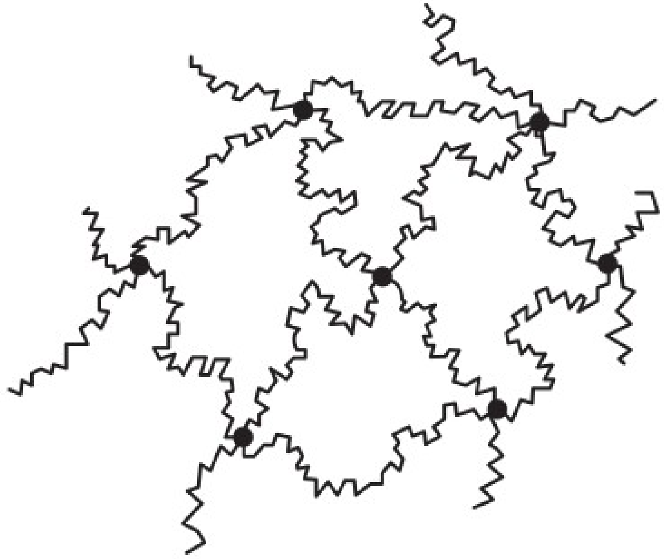
One of the simplest polymers is polyethylene, which is an addition polymer made by polymerising the monomer ethylene, $CH_2{=}CH_2$, to form the polymer.

# Cross-Linking and Chain-Branching

Linear polymers can be joined by other chains at points along their length to make a cross-linked structure

Chemical cross-linking produces a thermosetting polymer, because the cross-linking agent is normally activated by heating, after which the material does not soften and melt when heated further.

<u>Examples:</u>
Bakelite and epoxy resins.
Small amount of cross-linking through sulfur bonds is needed to give natural rubber its characteristic feature of rapid recovery from a large extension.



Cross-linking of polymers

Very long molecules in linear polymers can entangle to form temporary physical cross-links

# Average Molecular Mass and Molecular Mass Distribution

Each sample of a polymer contains molecular chains of varying lengths, that is of varying molecular mass

Number average $\bar{M}_n$
weight average $\bar{M}_w$
are defined as

$$\bar{M}_n = \frac{\sum N_i M_i}{\sum N_i} \qquad \bar{M}_w = \frac{\sum (N_i M_i) M_i}{\sum N_i M_i},$$

where $N_i$ is the number of molecules of molecular mass $M_i$, and denotes summation over all i molecular masses.

- Fundamental measurements of average molecular mass must be performed on solutions so dilute that intermolecular interactions can be ignored
- Two techniques commonly used are <u>osmotic pressure</u> for the number average and <u>light scattering</u> for the weight average.

## Mechanical Properties of Polymers

- A polymer can show all the features of a glassy, brittle solid or an elastic rubber or a viscous liquid depending on the temperature and time scale of measurement.

- Polymers are usually described as **viscoelastic** materials.

- At low temperatures, or high frequencies of measurement (short time scale), a polymer may be glass-like with a Young's modulus of 1–10 **GPa** and will break (brittle fracture) or flow at strains greater than 5%.
- At high temperatures or low frequencies, the same polymer may be rubber-like with a modulus of 1–10 **MPa**, withstanding large extensions (~100%) without permanent deformation.
- At still higher temperatures, permanent deformation occurs under load, and the polymer behaves like a highly viscous liquid.

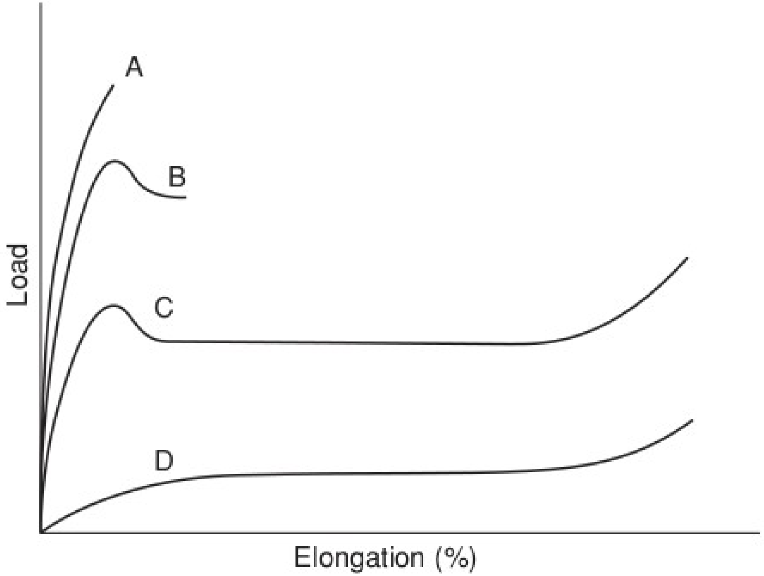
Let us now understand the concept of viscoelasticity!

# What happens to polymers at higher temperatures

The beauty of polymers is that the whole range of phenomena of mechanical behaviour can be displayed by a single polymer as the temperature is changed.

Temperatures well <u>below</u> the glass transition (curve A),

- brittle fracture occurs,
- load rises to the breaking point linearly with increasing elongation,
- and rupture occurs at low strains (−10%)




Load–elongation curves for a polymer at four different temperatures.

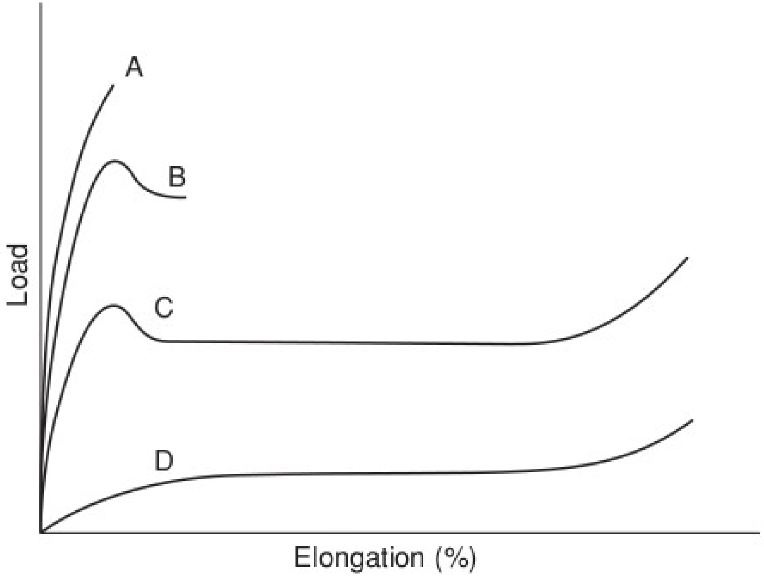
Curve A, brittle fracture;
curve B, ductile failure;
curve C, cold drawing;
curve D, rubber-like behaviour.

At high temperatures (curve D),

- the polymer is rubber-like and the load rises to the breaking point with a sigmoidal relationship to the elongation,
- and rupture occurs at very high strains (~30–1000%).

In an intermediate temperature range below the glass transition (curve B),

- the load-deformation relationship resembles that of a ductile metal, showing a load maximum, i.e. a yield point before rupture occurs.

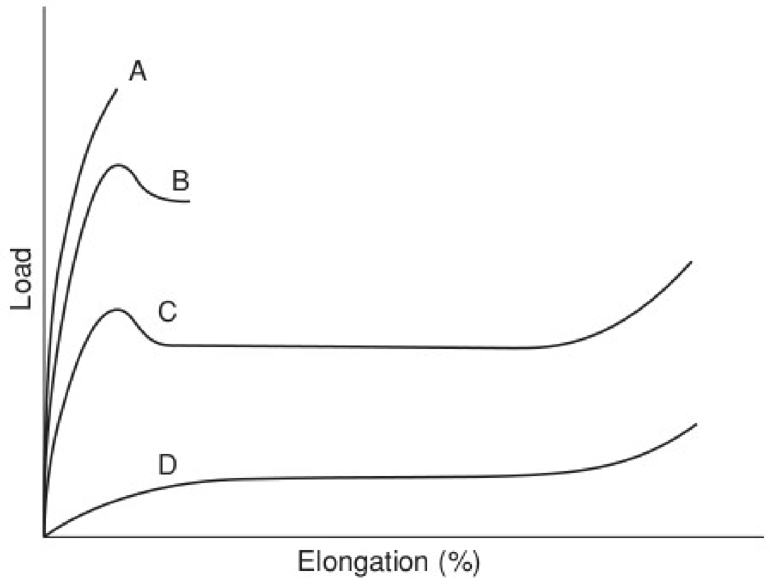



Load–elongation curves for a polymer at four different temperatures.

Curve A, brittle fracture;
curve B, ductile failure;
curve C, cold drawing;
curve D, rubber-like behaviour.

At slightly higher temperatures (curve C), still below the glass transition,

- the phenomenon of necking and cold drawing is observed.
- Here, the conventional load–elongation curve again shows a yield point and a subsequent decrease in conventional stress.
- However, with a further increase in the applied strain, the load falls to a constant level at which deformations of the order of 300–1000% are accomplished.
- At this stage, a neck has formed and the strain in the specimen is not uniform.

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