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Building Materials

Lecture 12

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Bituminous materials

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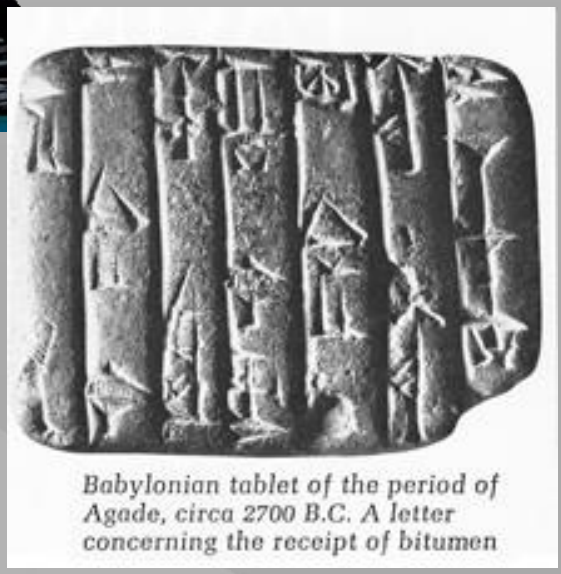
Bituminous materials

- an amorphous, black or dark-colored, (solid, semi-solid, or viscous) cementitious substance, composed principally of high molecular weight hydrocarbons
  - **asphalts**
  - **tars**
  - nonvolatile
  - nontoxic
  - soften when heated
  - soluble in carbon disulfide



Babylonian tablet of the period of Agade, circa 2700 B.C. A letter concerning the receipt of bitumen

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Bituminous materials

- **asphalt**
  - natural
  - from petroleum processing
- **tar**
  - do not occur in nature
  - condensates in the processing of coal, petroleum, oil-shale, wood or other organic materials
- pitch
  - formed when a tar is partially distilled so that the volatile constituents have evaporated off from it

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Natural asphalt

Gilsonite (natural asphalt) **mine**
Iran

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Petroleum asphalts

- refined residue from the fractional distillation of crude oils = **primary asphalt**
  - **oxidised a**. - passing air through asphalt at elevated temperature
    - **less sensitive to thermal changes**
  - **modified a.** - their properties (elasticity, adhesive or cohesive strength) have been modified by the adition of polymer
    - **SBS** (styren-butadien-styren, 7-15%)
      - **higher ductility** (several hundred %)
    - **APP** (atactic polypropylene, 15-35 %)
      - **higher resistance against UV radiation**
      - **better adhesion**

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Asphalt properties

General:

- insoluble in water
- no absorptivity
- density ≈ 1000 $kg.m^{-3}$
- $\lambda \approx 0{,}75\ w.m^{-1}.K^{-1}$
- soluble in organic solvents
- thermal elongation ≈ $600.10^{-6}\ K^{-1}$
- combustible
- ageing by UV radiation and O_2

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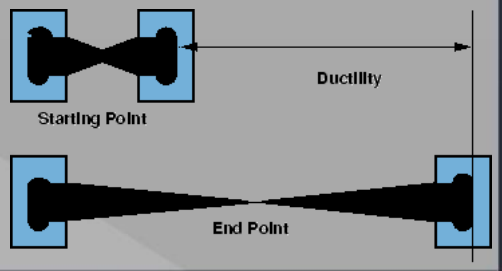
Influence of modification on properties

Property Asfalt type	Breaking point [°C]	Thermal stability [°C]	Softening point [°C]	Ductility [%]
oxidized	0 – 4	70	85 – 90	2 – 5
APP modification	-5 až -15	115 – 130	135 – 150	20
SBS modification	-15 až - 35	90 – 110	110 – 125	> 100
SBS-SIS-SEBS modification	- 45	105	125	



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Asphalts testing

Special tests:

- **penetration**
- **softening point**
- **breaking point**
- **ductility**
- viscosity
- coating ability

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Penetration test

- the depth to which a needle penetrated an asphalt sample under specified conditions of load, time and temperature
- units: 0,1 mm

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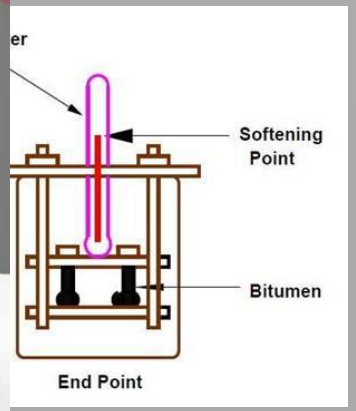
Softening point test

- **Ring-and-ball method**
- the **softening point** is the temperature at which a material softens beyond some arbitrary softness
  - heating by 5°C/min

mperature,
specimen
mm)



Breaking point test

- **Fraass method**
- to determine the temperature bellow which a bitumen tends to break rather than to flow when stressed
  - the

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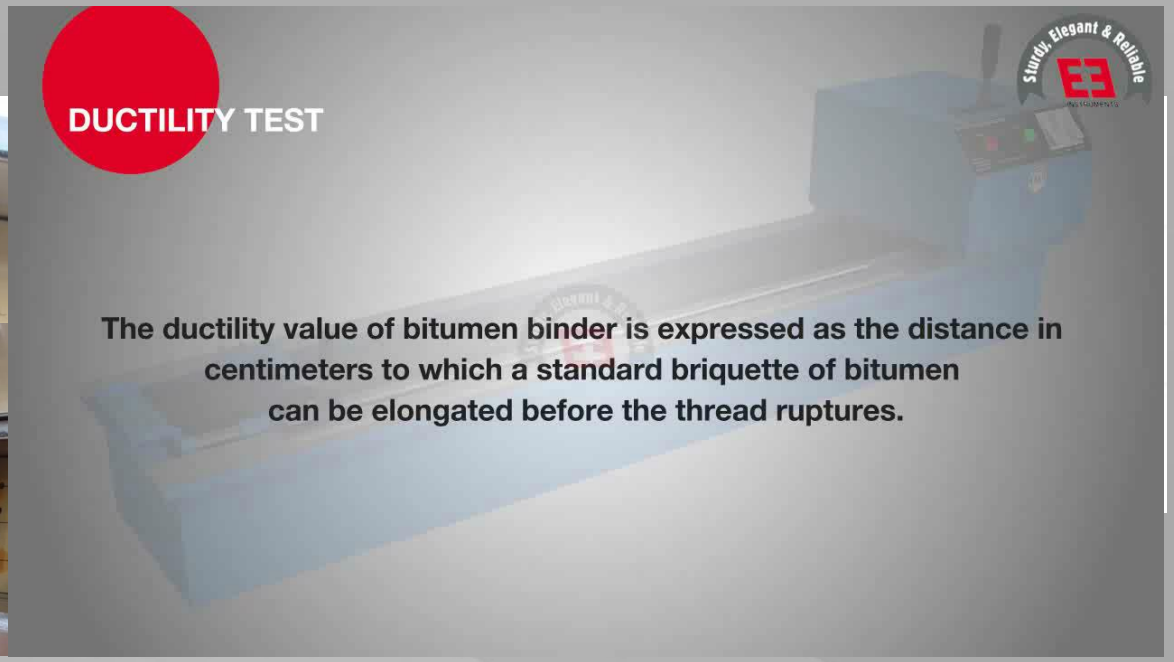
Ductility test

- stretching a standard-sized briquette of asphalt binder at standard temperature to its breaking point
  - **ductility** = stretched distance in cm at breaking



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Asphalt products

- paints
- mastic
- **asphalt cement**
  - asphalt concrete
- emulsions
- suspensions
- **membranes** (felts)
- roofing

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Asphalt waterproof membranes

release film
bitumen layer
base (PE, glass-fibre, copper)
bitumen layer
mineral granules (sand, slate)
protective strip

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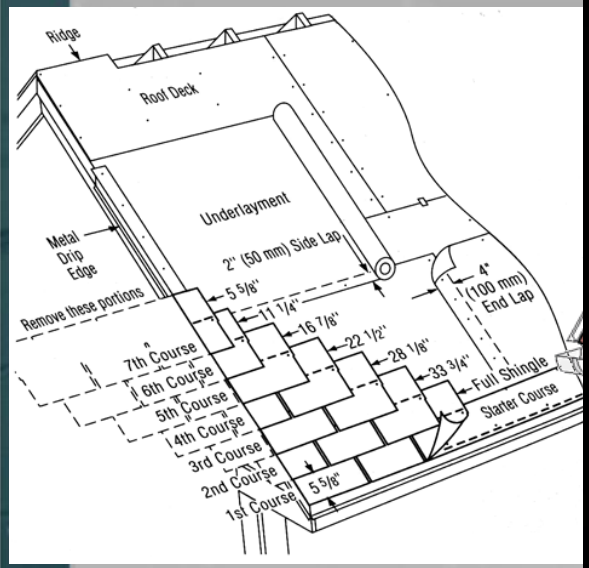
Asphalt shingles

- roof covering
- cutted from asphalt membranes
- wood roof decking
- fixation by g



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Asphalt shingles - roof

- minimal **roof slope** - 15°
- **square weight** - 9,5 to 14 kg/m^2
- **life expectancy** - 30 to 50 years

+ lightweight
+ price

– lower fire resistance
– softening at higher temperatures
– high demands on realization
– shorter durability
– decking under shingles

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Asphalt paints

- **asphalt + organic solvents**
  - **cold applied -** primers, insulating coats, reflex paints, waterproof varnish, **mastic** (+aggregates)
  - **hot applied** – grouts, sealants, asphalt concrete
- **asphalt + water + emulsifying agent**
  - **emulsions**
  - **suspension** (+ filler)
  - waterproofing layers, joining, grouts, sealants

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Asphalt concrete

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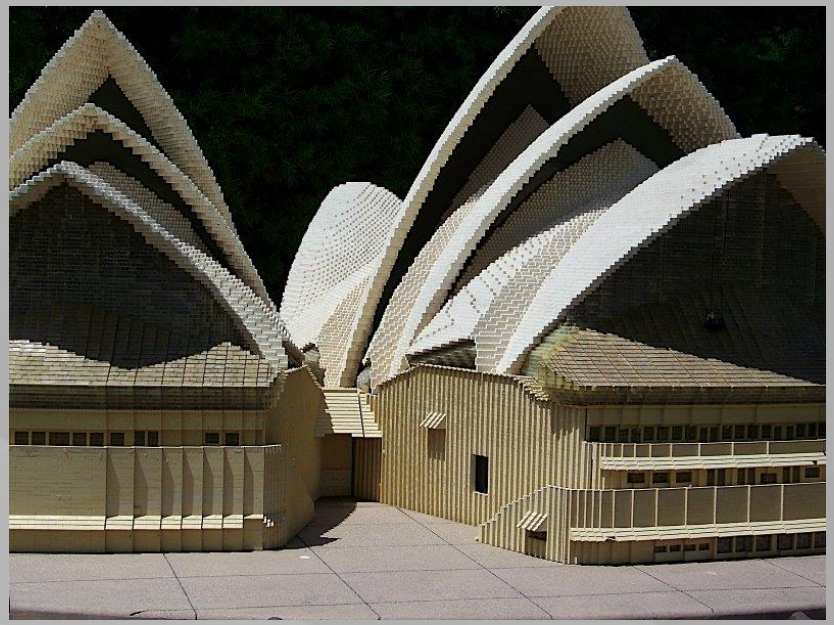
POLYMERS



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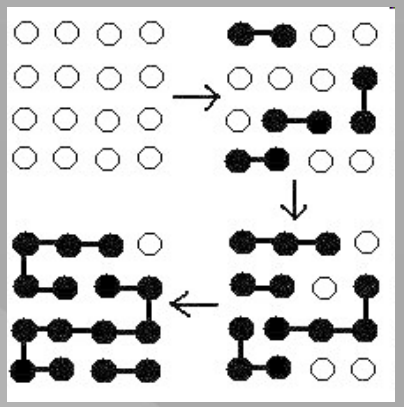
Polymers = plastics

- *polys = many, meros = parts*
- a large molecule (macromolecule) composed of repeating structural units (100 -100 000)

  $H—(CH_2)_n—H$ (polyethylene)
- **polymerization** - a process of reacting monomer molecules together in a chemical reaction to form polymer chains or three-dimensional networks
  - polycondensation
  - polyaddition
  - radical polymerization



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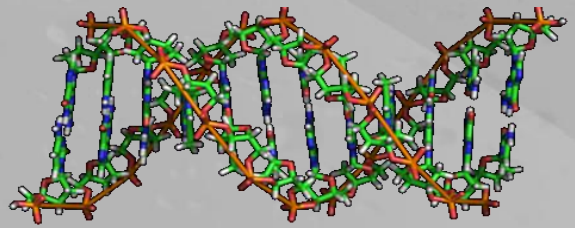
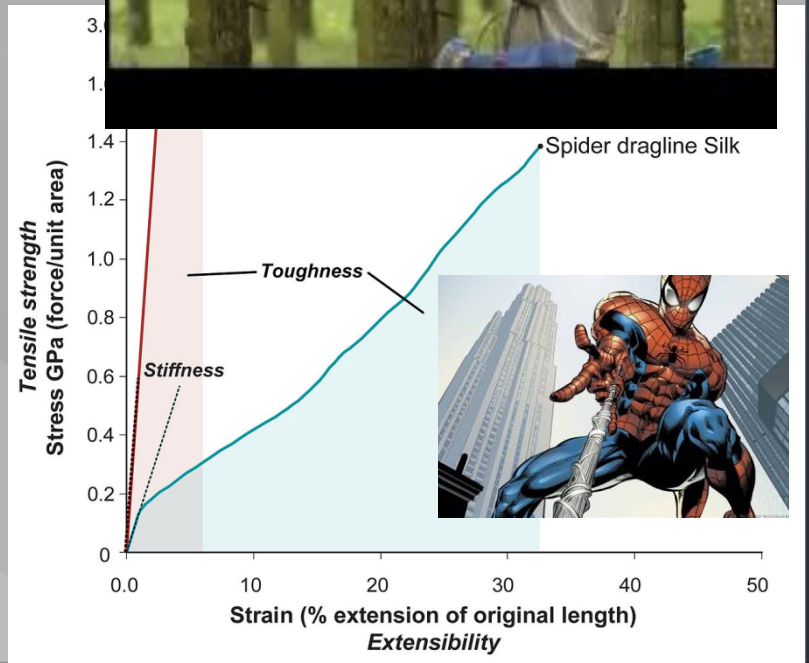
Natural polymers

- **rubber** – ruber tree *(Hevea brasiliensis)*
- **cellulose** – cotton, wood – viscose, cellophane
- **starch**
- **proteins** – keratin, collagen, casein, DNA





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Polymer abbreviations

- **CE** cellulose / cellophane
- **EP** epoxy
- **MF** melamine formaldehyde
- **PA** polyamide
- **PE** polyethylene
- **PET** polyethylene terephthalate
- **PF** phenolformaldehyde
- **PP** polypropylene
- **PS** polystyrene
- **PU,PUR** polyurethane
- **PVC** polyvinyl chloride

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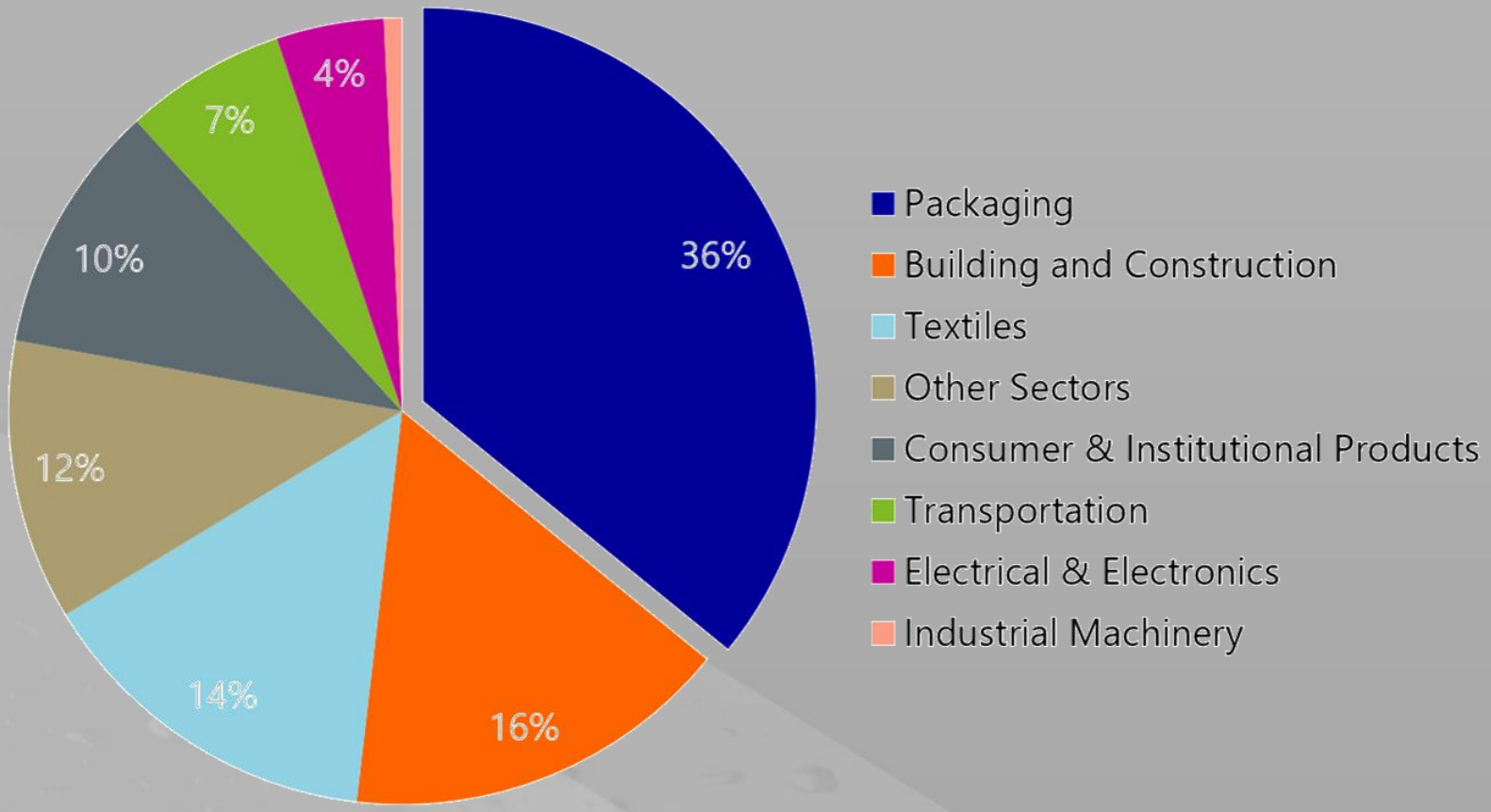
Polymer consumption



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Polymers

Thermoplastics

- turns to a liquid when heated and freezes to a rigid state when cooled sufficiently
- can be remelted and remoulded
- **PE, PVC, PS**

Thermosets

- undergo an irreversible chemical change by curing
- the cure may be done through heat, a chemical reaction or irradiation
- molecular chains are cross-linked into rigid 3-D structure
- **PF, PU, EP**

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Polymers - mechanical properties

Polymer	Density (kg/m^3)	Tensile Strength (N/mm^2)	Elongation (%)	Young's Modulus (GN/m^2)	Brinell Hardiness Number	
PVC	1330	48	200	3.4	20	thermoplastics
Polystyrene	1050	48	3	3.4	25	
PTFE	2100	13	100	0.3		
Polypropylene	900	27	200-700	1.3	10	
Nylon	1160	60	90	2.4	10	
Cellulose Nitrate	1350	48	40	1.4	10	
Cellulose Acetate	1300	40	10-60	1.4	12	
Acrylic (metacrylate)	1190	74	6	3.0	34	
Polyethylene	950	20-30	20-100	0.7	2	
Epoxy resin, glass filled	1600-2000	68-200	4	20	38	thermosets
Melamine formaldehyde, fabric filled	1800-2000	60-90		7	38	
Urea formaldehyde, cellulose filled	1500	38-90	1	7-10	51	
Phenol formaldehyde, mica filled	1600-1900	38-50	0.5	17-35	36	
Acetals, glass filled	1600	58-75	2-7	7	27	

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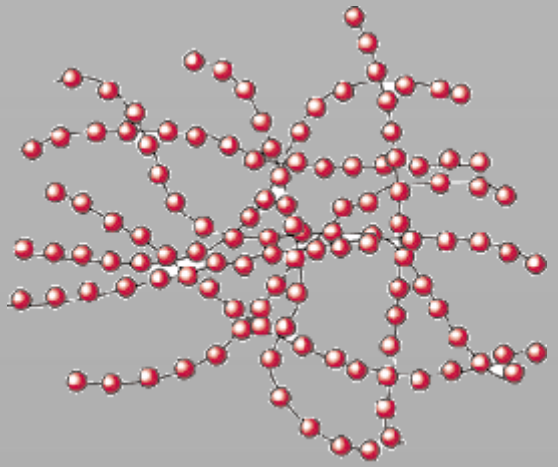
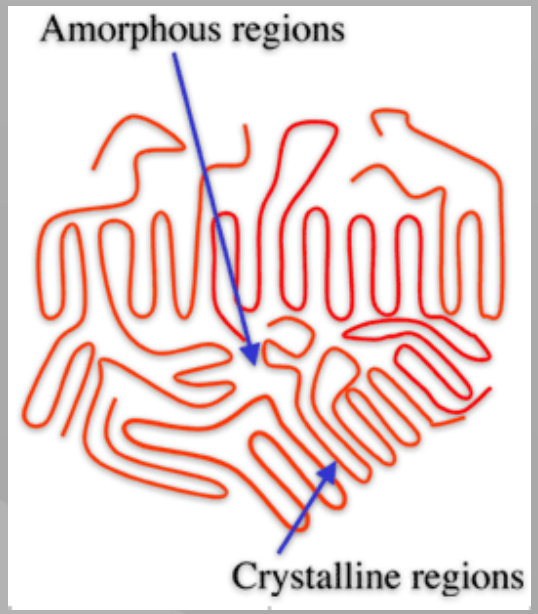
Thermoplastics

- consist of long molecular chains with no (or very little) regular structure
- chains are tangled (Brownian motion)
- **semi-cristalline regions** - a regions in a plastic in which the molecule arrangement is ordered and structured
  - increase the melting point of the plastic (more heat is needed to encourage molecular movement)





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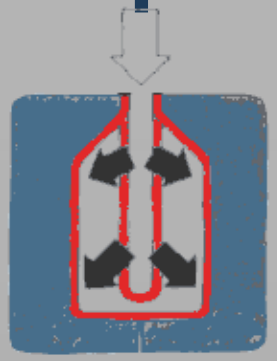
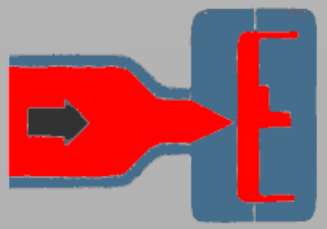
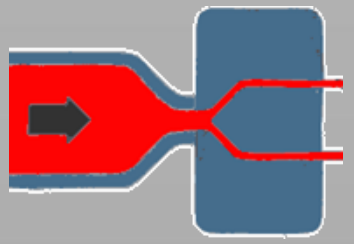
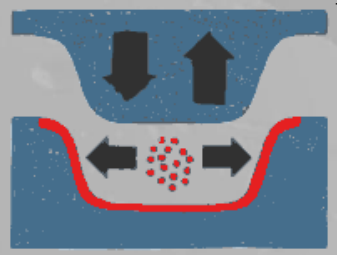
Thermoplastic processing

- pellets or powder
  - extrusion
  - blow molding
  - injection molding
  - compression forming
  - thermoforming
  - calendering (rolling)









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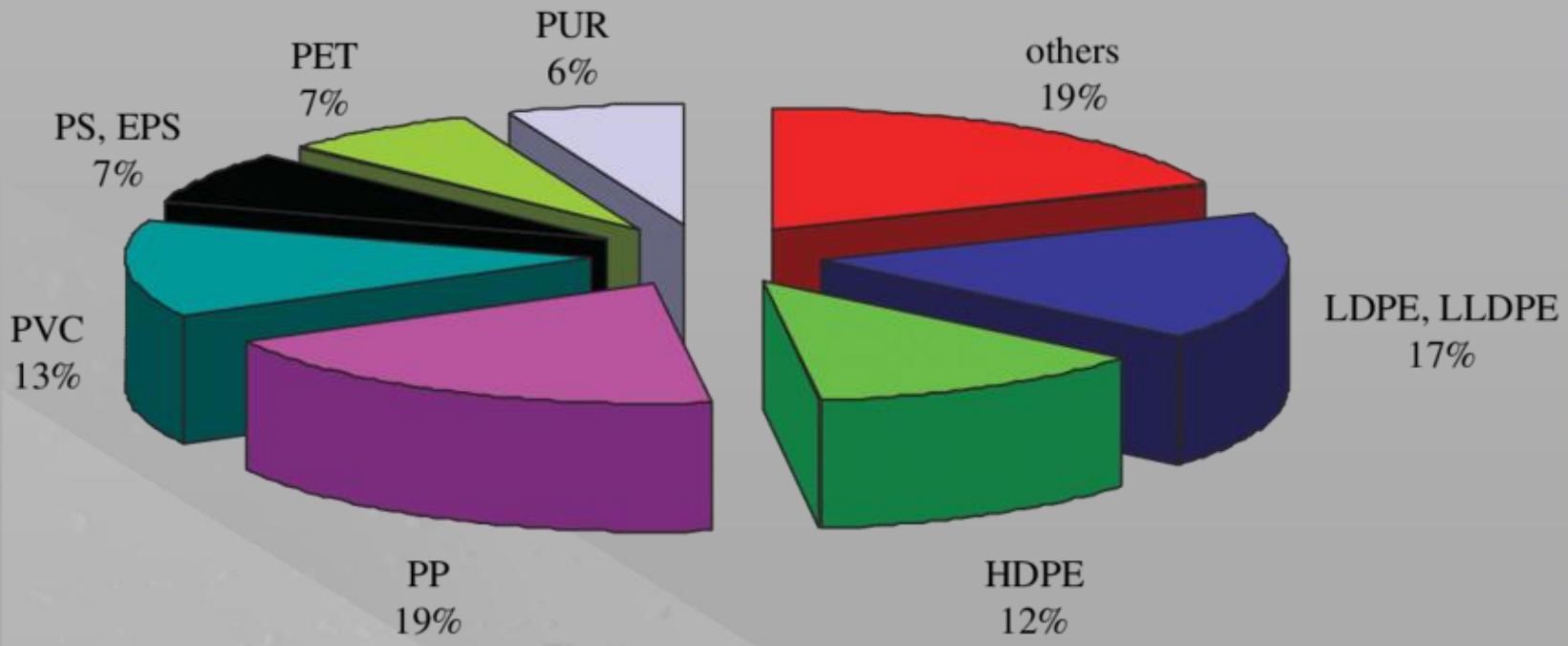
Polymer consumption according type



Europe, 2013

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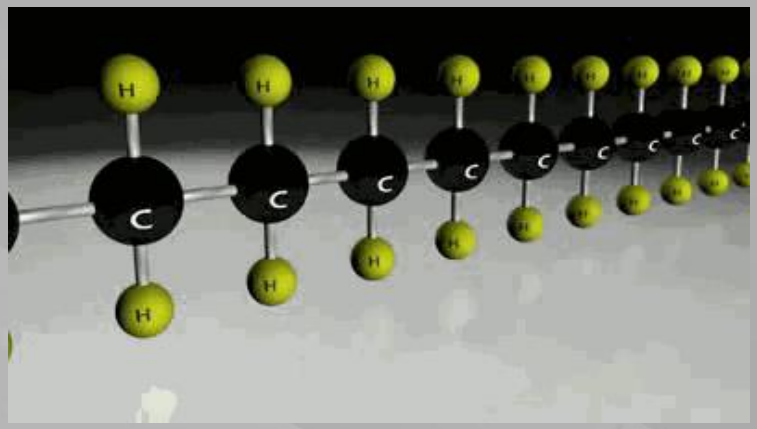
Polyethylene PE

- most common plastics (80 mil. tons /year)
- polymerization from ethylene

$$n\ (CH_2 = CH_2) \rightarrow -(CH_2-CH_2)_n-$$



- low-density polyethylene - **LDPE**
- high-density polyethylene - **HDPE**

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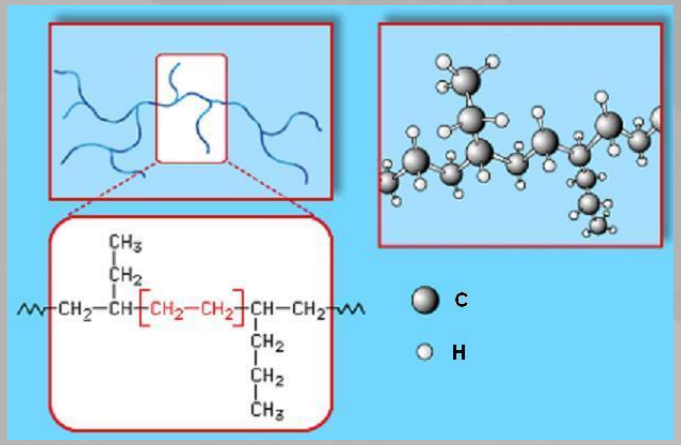
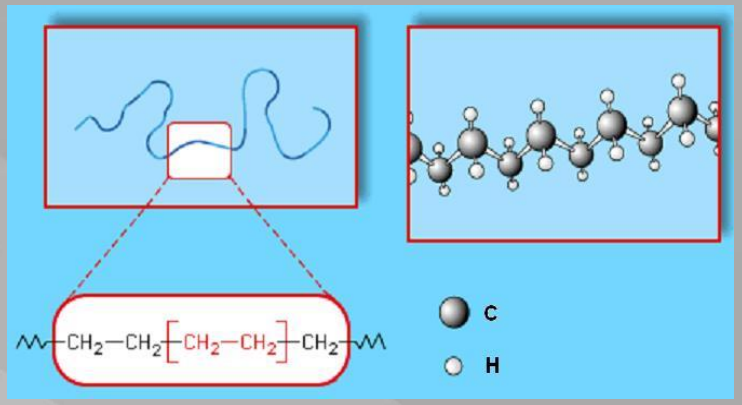
LDPE + HDPE

- **LDPE - low density** (density 0,910– 0,940 g.cm³)
  - a high degree of short and long chain branching
  - chains do not pack into the crystal structure
- **HDPE - high density** (≥ 0,940 g/cm³)
  - a low degree of branching
  - stronger intermolecular forces and tensile strength





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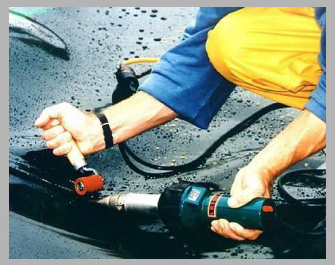
Polyethylene



+ **pliable** (in thin layer)
+ good **shape memory (**LPDE)
+ high **strength** and **thermal resistance** (HDPE)
  – utilization above 100 °C
+ excellent **chemical resistance** at normal temperature
  – strong acids and alkalis, HF!
+ **no health risks**
+ good **recyclability**
- **difficult gluing** → joining by hot air welding
- **dissolution** in organic solvents at elevated temperatures
- **diffusion of some materials** into PE (fats, oils)
- **low weather resistance** – UV stabilization
- **flammable**, **drips** at burning

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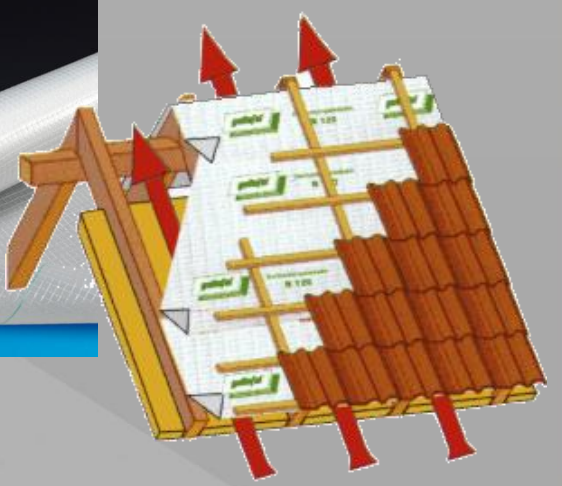
LDPE products

- stretch and bubble wraps
- vapor permeable roof foils
- corrosion inhibiting foils
- waterproof insulation of tunnels (better fire behavior than HDPE)
- expanded foam – thermal insulations
  - closed cell,
  - $\lambda \approx 0{,}045\ W.m^{-1}.K^{-1}$



HDPE products

- membranes – smooth, textured, drainage, radon-proof
- sheets – corrosion resistant wall coverings, radiation shielding,
- pipes – water, chemical resistant
- wood-plastic composites

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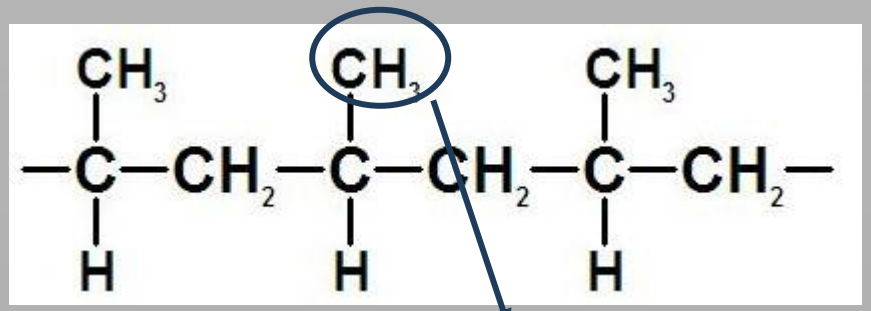
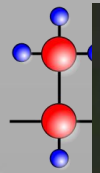
Polypropylene PP

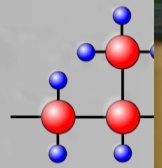


methyl

- isotactic



- syndiotactic
- atactic



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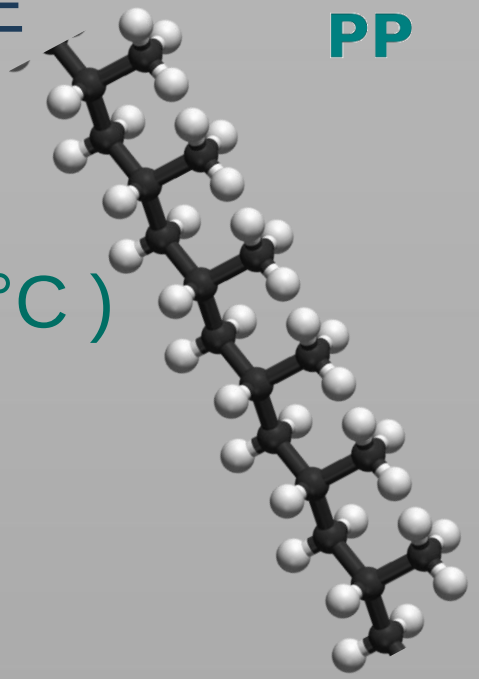
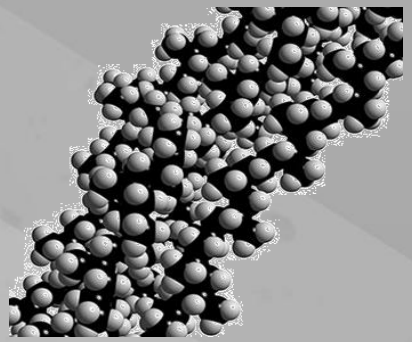
PP properties

- **isotactic PP** – similar to HDPE
  - higher strength
  - good resistance to abrasion
  - higher melting point (~ 165 °C)
  - brittle at temp. < 0°C (modification by rubbers)
  - low weather resistance
- **atactic PP**
  - amorphous
  - rubbery
  - low strength





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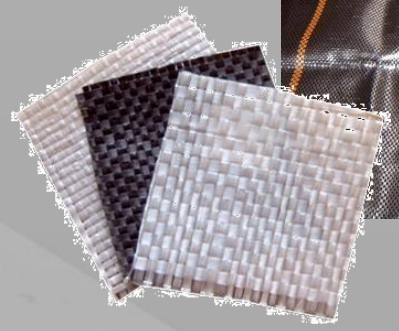
PP products

- tubes and pipes
- sheets, boards
- fibers
  - concrete, plasters
  - textiles (woven and non-woven)
- geomembranes



- **APP** – asphalt modification, additive to adhesives

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PP fibres in concrete

- 0,9 kg /1 m^3 of concrete
  - 150 millions of fibres
- surface treatment
  - easy dispersion in mixture
- mixing in normal mixer

- < shrinkage and cracking
- > impact and shatter resistance
- > resistance to frost
- > durability
- < spalling (at fire)

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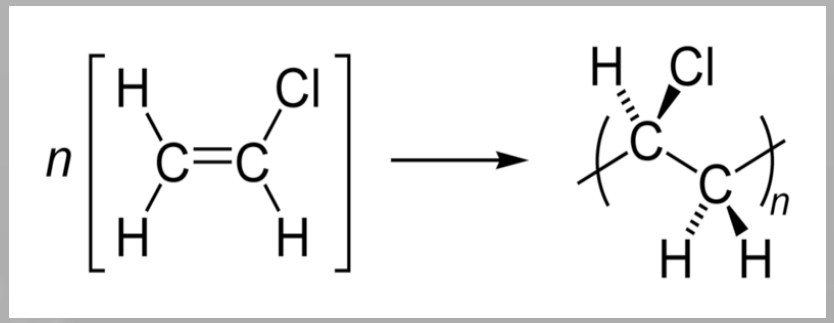
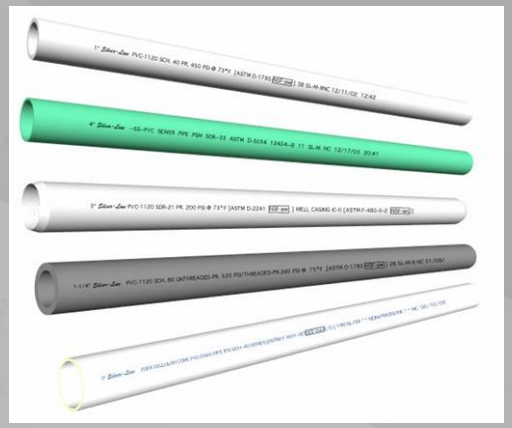
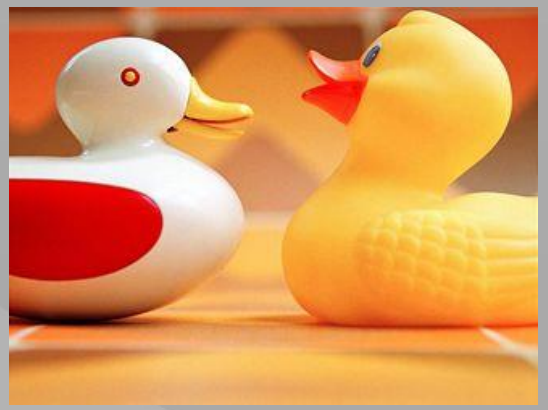
Polyvinylchloride PVC

- $n\ ClCH{=}CH_2 \rightarrow -(ClCH{-}CH_2)_n -$







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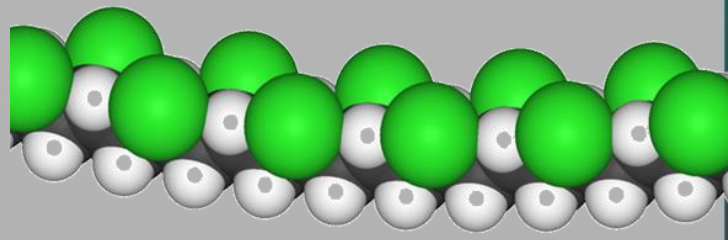
PVC properties



- density: 1380 kg/m^3
- boiling point: 212 °C
- pure PVC – rigid and brittle → plasticizing
- temperature range: -25°C to + 70°C
- thermaly sensitive – heat stabilizers
- self-extinguishing
- glueable

— production of toxic gases, when burning (dioxins, hydrochloric gas)

— difficult to recycle

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PVC plasticizing

Plasticizers:

- phtalates (CMR ? = carcinogenic, mutagenic or toxic to reproduction), adipates, citrates

- **rigid PVC**
  - less than12 % plasticizers
- **flexible PVC**
  - 20 - 40 % plasticizers
- **unplasticized PVC** (uPVC)
  - only minimal amount of plasticizers necessary for production - “vinyl“

Waldo Semon
(1898-1999)

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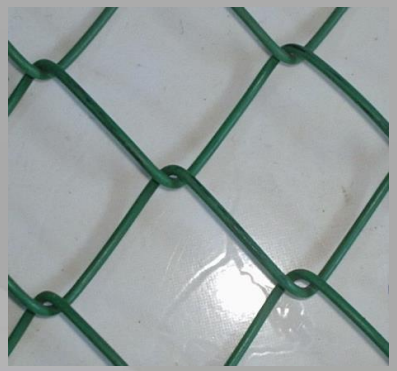
PVC products

- hard
  - sheets, boards, pipes and fittings, vinyl siding

- soft
  - waterproof membranes, insulation on electric cables, flooring, coating on steel



PVC suspended stretch ceiling

- biaxialy stretched film
- at instalation heating to 60 °C
- stretches after cooling

  → perfectly smooth surface

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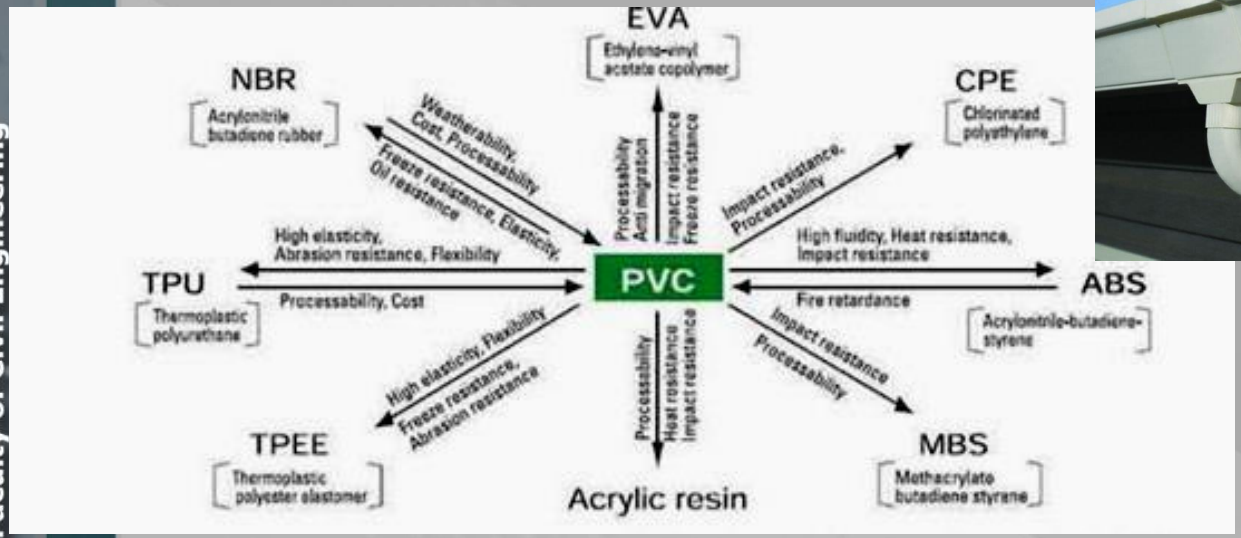
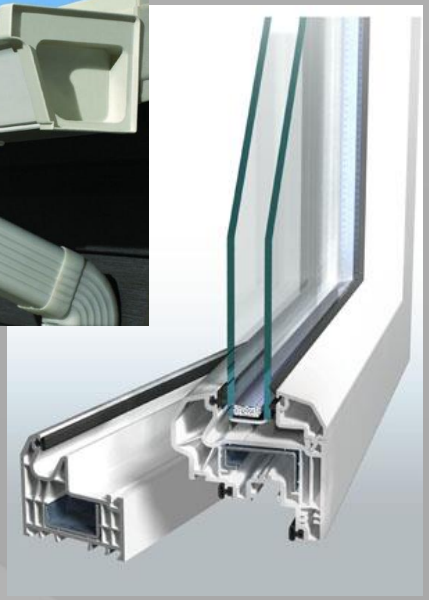
PVC copolymers

- chlorinated **PVC** (CPVC)
  - addition of chlorinated polyethylene → weather resistance
  - window frames, gutters, facade boards





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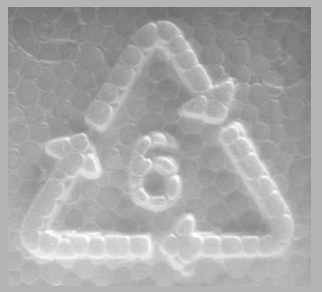
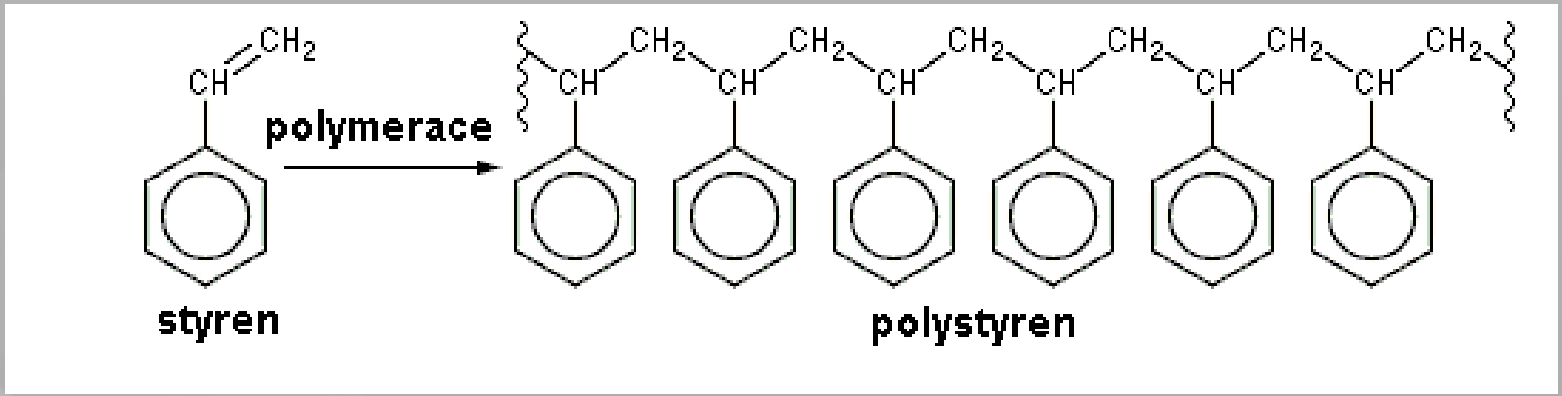
Polystyrene PS



- $nC_6H_5\text{-}CH{=}CH_2 \rightarrow \text{-}(CH(C_6H_5)\text{-}CH_2)_n\text{-}$



- hard and brittle
- mostly used foamed
  - **expanded EPS**
  - **extruded XPS**

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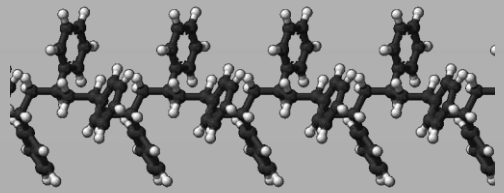
Expanded polystyrene EPS

Production:

- styrene is made by combining ethylene and benzene
- suspension polymerization → raw **polystyrene beads** (Ø 1 mm)



- heating to 100°C and blowing by pentane → pre-expanded beads
- after several days final expansion into blocks

EPS production

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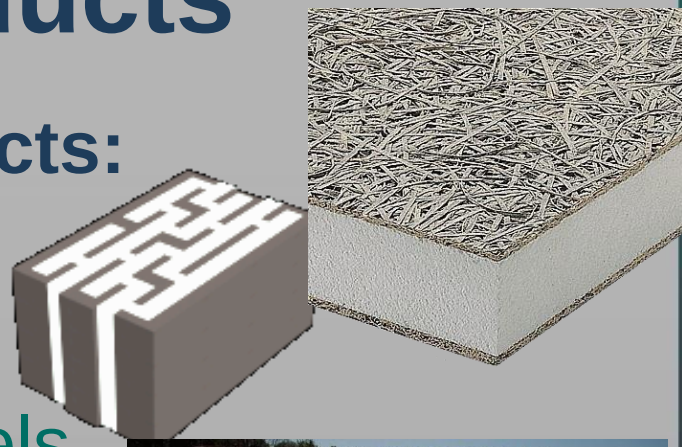
Expanded polystyrene EPS

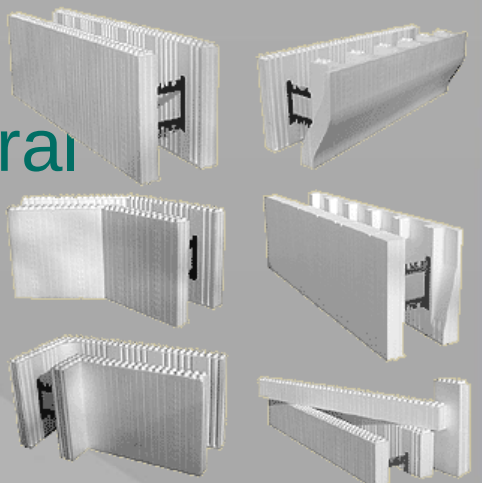
Properties:

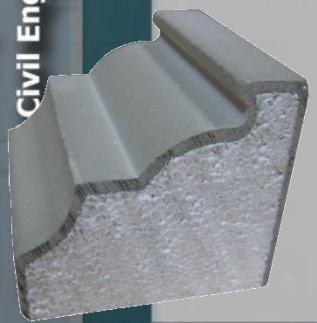
- ρ_V **= 5-100 kg.m^{-3}** (20, 25 a 35 kg.m^{-3})
- $\lambda \approx$ **0,04 W.m^{-1}K^{-1}**
- **flammable** $\rightarrow$ addition of retarder - self extinguish
- **volume changes** – off-gassing of pentane, thermal elongation
- water **sorptivity** 2 - 5 % (volumetric)
- water vapor diffusion resistance ≈ 30-70
- easy cutting and gluing

EPS - products

- **thermal insulating products:**
  - blocks and boards
  - pipes insulations
  - structural insulated panels (sandwich + gypsum board, fiberboard, asphalt felts)
  - insulating concrete forms
  - loose beads
  - non-weight-bearing architectural elements
    - ornamental molding
    - ceiling tiles,







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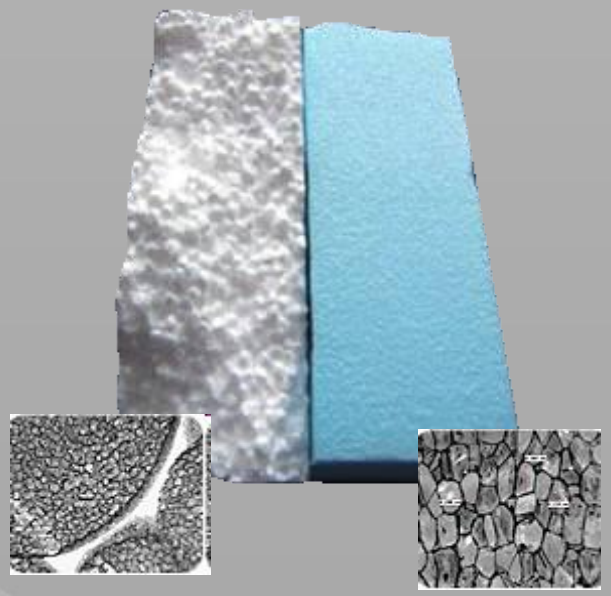
Extruded polystyrene XPS

- **polystyrene beads + additives** are melted in an extruder and a **blowing agent** is injected into the extruder under high pressure where it dissolves into the polystyrene melt
  - **closed cells**
- **properties**
  - ρ_V = 25, 40, 45 kg.m^{-3}
  - $\lambda \approx$ 0,025 W.m^{-1}K^{-1}
  - lower sorptivity (0,2%)
  - higher strength



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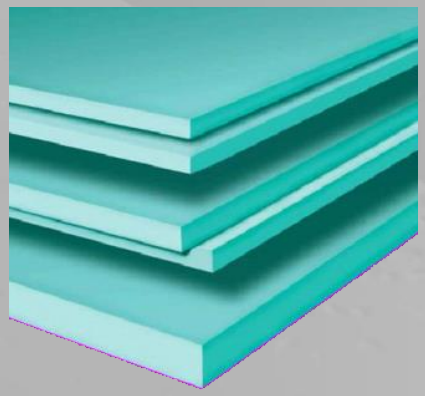
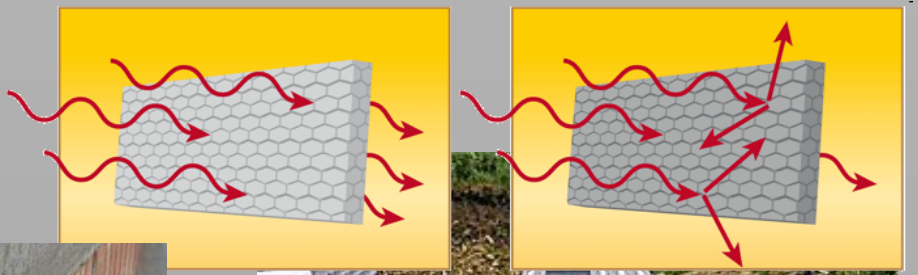
XPS - products

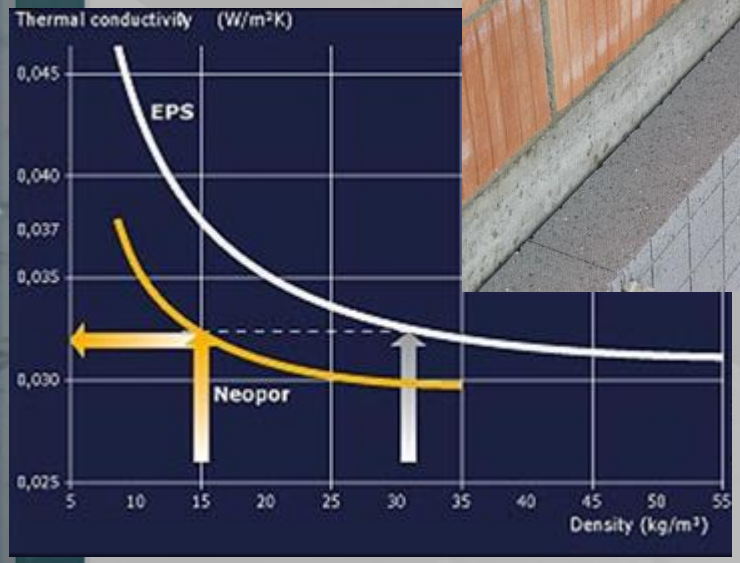
- similar to EPS
- where lower sorptivity and higher strength is necessary
  - roofs (green roofs)
  - under tiles
- usually colored



Grey polystyrene - Neopor

- adding of fine graphite powder → lower thermal radiation through material
- lower λ at lower ρ_V





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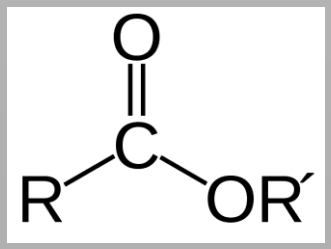
Polyesters

- contain the ester functional group in their main chain
- fibers



- **PET** (polyethylene terephthalate)
  - bottles
  - cloth
  - geomembranes
  - recycled PET

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Recycled PET

- membranes
- geotextiles
- fence elements
- paving elements
- boards

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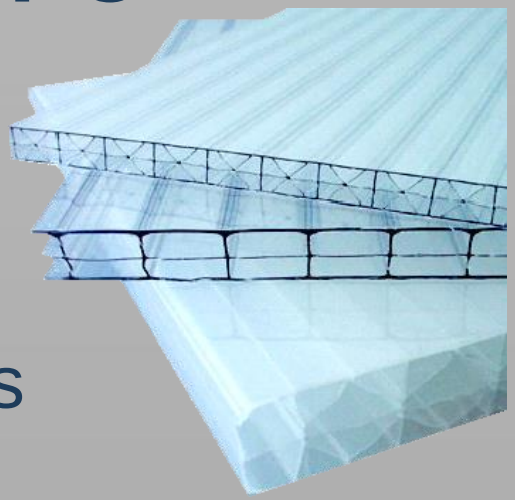
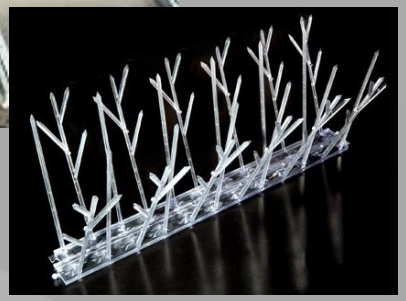
Polyesters

Polycarbonates PC

- transparent, colorless
- good mechanical properties
- weather resistance
- relatively small volume changes

→ replacement of glass





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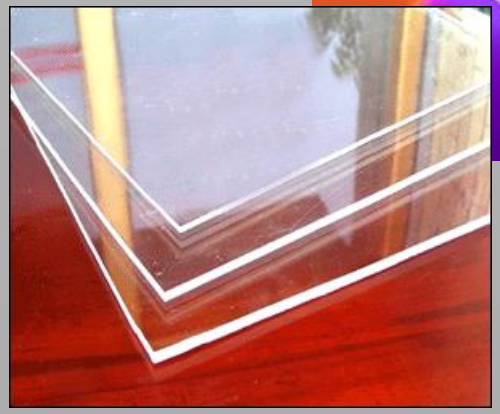
Polyesters - **- polymetylmetacrylate PMMA**



- acrylic glass, „Plexiglass“
- density ~1200 kg.m^{-3}
- low surface hardness
- good impact strength
- transparent
- relatively high thermal expansion
  → heat stabilization
  - a lightweight and shatter-resistant alternative to glass

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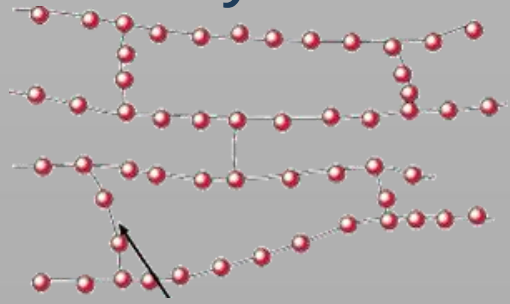
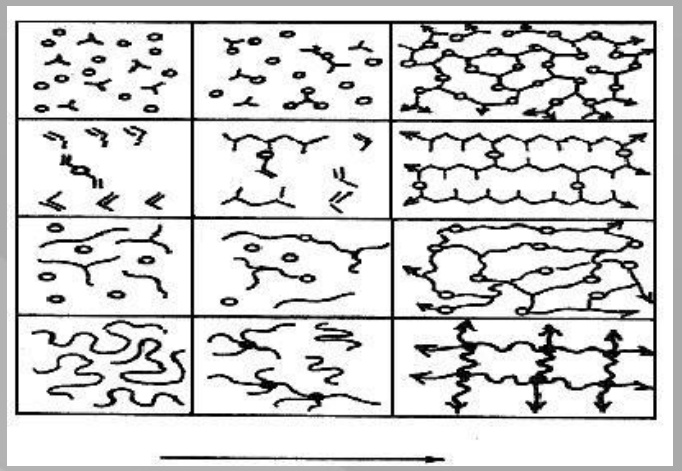
Thermosets

- the polymer chains are cross-linked by intermolecular bonding into 3-D structure



- after curing are irreversibly changed (hardened) and cannot be melted
- curing – heat, chemical reaction, irradiation
- **cured** – solid products
- **uncured** - adhesives, paints, glues



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Formaldehyde resins

- **phenol formaldehyde resin**
  - thermal insulating boards and laminates from glass or mineral fibres
  - boards with wood flour (Bakelite)
  - binding agent in acid-resistant mortars
  - released formaldehyde
- **urea-formaldehyde** is not used now – health risks

L. H. Baekeland
(1863-1944)

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Fenolic foam

- ρ_V = 30 - 80 kg.m^{-3}
- $\lambda \approx$ 0,04 W.m^{-1}K^{-1}
- low strength
- good thermal and fire resistance
- low price
- caused corrosion on corrugated steel roofs

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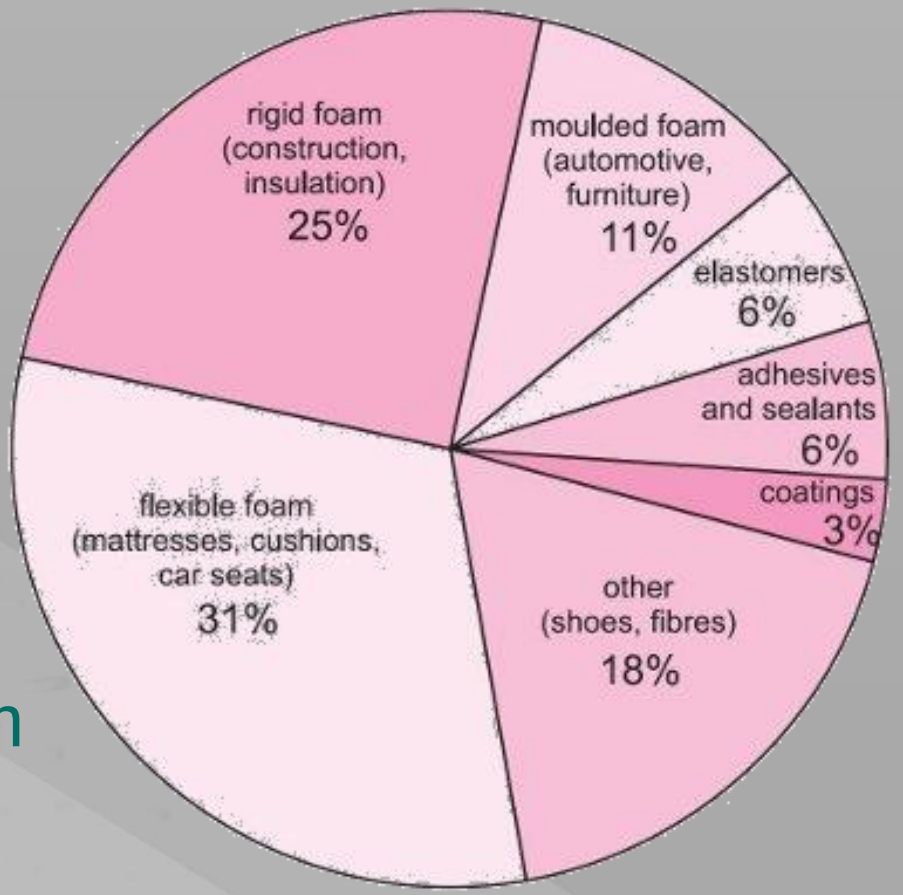
Polyurethanes PUR

- reaction of a polyol with a diisocyanate or a polymeric isocyanate in the presence of suitable catalysts and additives

- coatings
- adhesives
- sealants
- binder
- rigid or flexible foam



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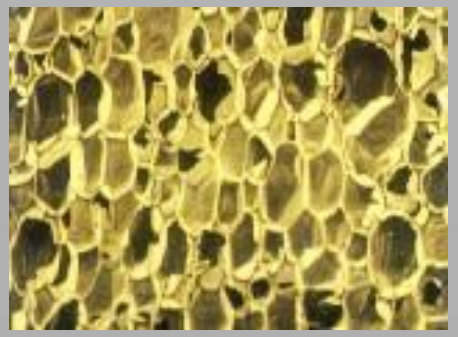
Rigid PUR foam



- two components
- high strength
- ρ_V = 28 – 34 kg/m^3
- λ = 0,03 W.m^{-1}K^{-1}
- closed cell – low sorptivity - waterproofing
- low vapor diffusivity
- not UV resistant

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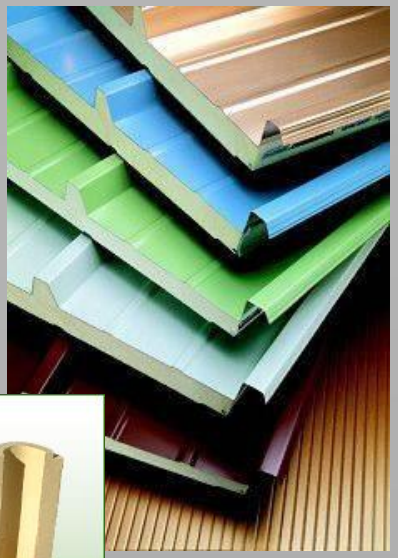
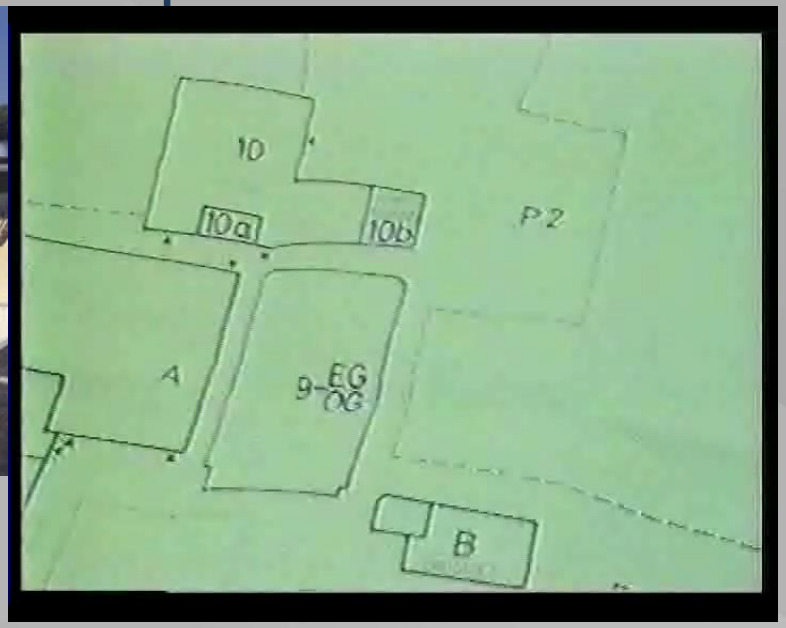
Rigid PUR foam products

- thermal and waterproof insulation
  - **sprayed insulation**
  - need protective coating against UV radiation
  - **structural panels** and composites





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PU montage foam

- **for montage only!**
- lower strength and durability
- open pores

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Epoxy resins

- reaction of an epoxy resin with polyamine hardener
- excellent adhesion to substrate
- large range of temperatures
- hardened product - high chemical and mechanical resistance
- low volume changes

- paints and coatings
- adhesives
- polymer concretes
- flooring

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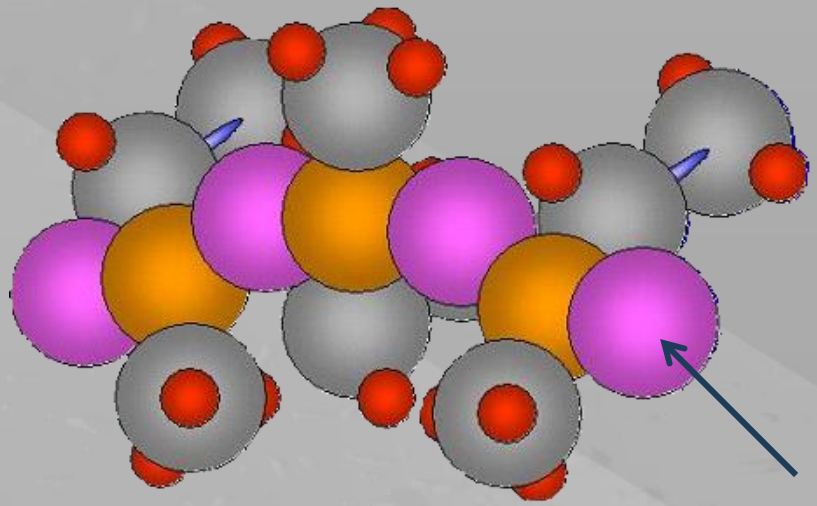
Silicones

- $[R_2SiO]_n$
- rubbers
- resins



sailoxan chain

(…-Si-O-Si-O-Si-O-…)

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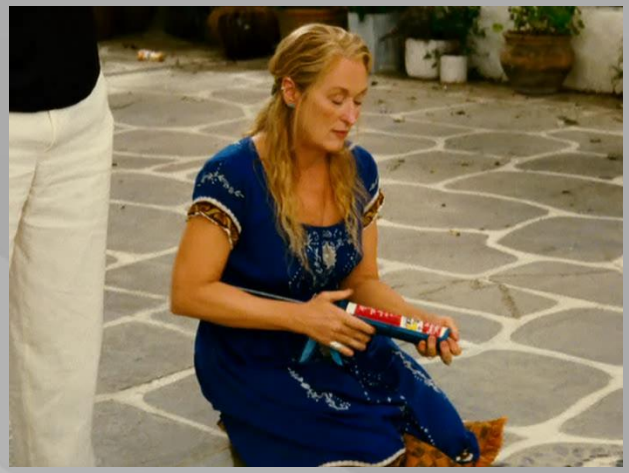
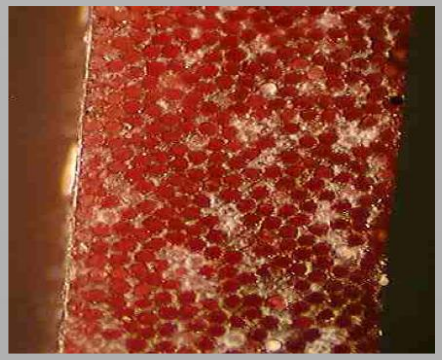
Silicones - products

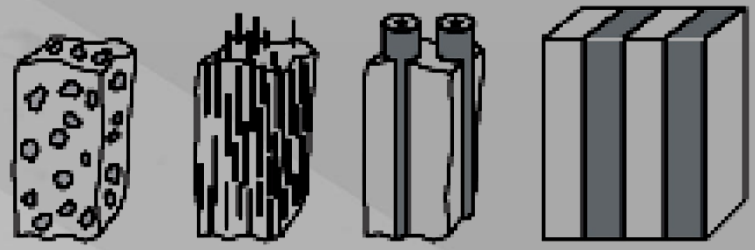
- **„one-component“ caulks**
  (hardening by air moisture)
  - very god adhesivity
  - some caulks react acidly → not suitable for concretes, mortars
  - different chemical resistance
- **two-components rubbers** – more liquid
- silicon **gaskets**
- **hydrophobization**
  (plasters, mortars, paints)



Composites with thermosets

- **polymer matrix** (binder)
  - **polyester**
  - epoxy
  - vinyl ester
  - phenolic
- **reinforcement**
  - granular (particles)
  - short fibers (glass,carbon, aramid …)
  - continuous fibers
  - laminate





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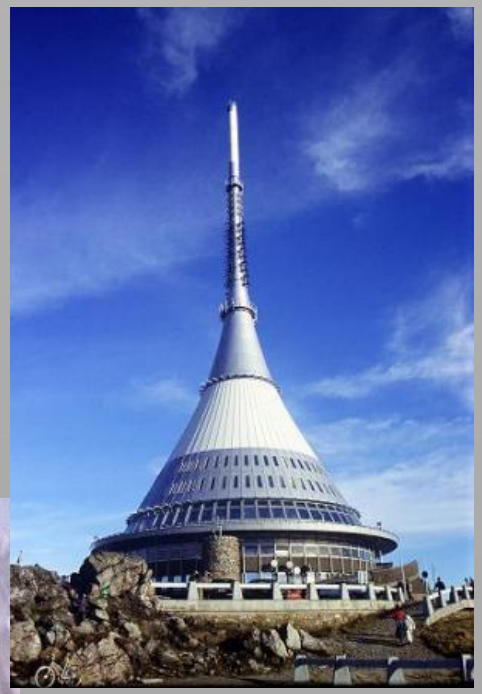
Glass reinforced composites

- glass fibres, woven and nonwoven fabric, (50 - 80% of glass), microspheres



transmission tower Ještěd, CR

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Polymer concretes

- **use polymers to supplement or replace cement as a binder**

+ high strengths
+ rapid curing
+ good adhesion to most surfaces
+ good chemical resistance
+ lightweight

– worse fire resistance
– price
– high demands on quality of mixing

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Polymer concretes - properties

		Polymer concrete	Concrete
bulk density	kg/m^3	**1 900 - 2400**	**2500-2700**
modulus of elasticity	GPa	**10 - 40**	**15 - 40**
tensile strength	MPa	**4 - 25**	**1 - 5**
compressive strength	MPa	**50 - 210**	**6 - 60**
thermal conductivity	W/mK	**1,5 - 2**	**1,28 - 1,54**
thermal elongation	10^6 K^{-1}	**10 - 50**	**9 - 12**
mass sorptivity	%	**0,02 – 1**	**6 - 13**

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