1E5 Advanced design of glass structures

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List of lessons

1) **History, chemical composition, production**
2) Glass as a material for load bearing structures
3) Design of laminated plates
4) Design of glass beams
5) Design of compressed members
6) Hybrid load-bearing members
7) Curved glass members
8) Design of bolted connection
9) Design of glued connection
10) Glass facades
11) Glass roofs
12) Examples of glass structures

Objectives of the lecture

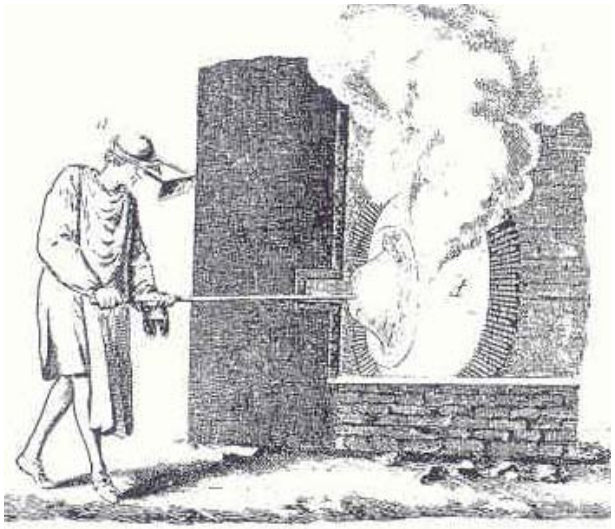
- Introduction to glass structures
- Historical review
- Production - glass products, edge quality
- Material and mechanical properties
- Testing of glass elements

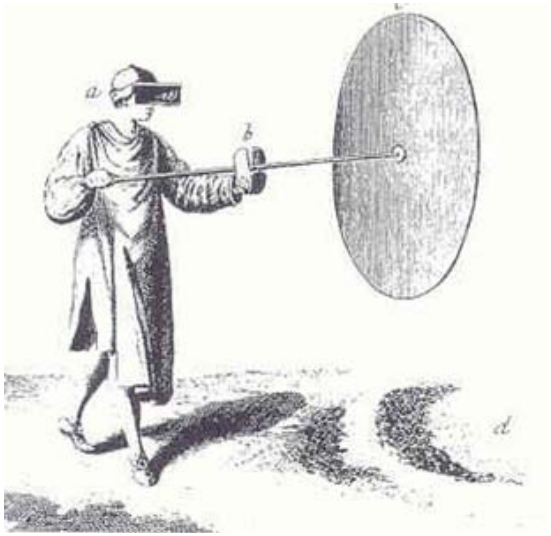
Introduction

- Load bearing elements from glass
- Purpose
- Architectural aspects of new structures
- Design of glass structures

Historical review

- The oldest finds of glass in Egypt – 10 000 BC
- Glass blower's pipe - finding around turn of the era
- Flat glass - crown process, cylindrical process
- 1871 Pilkington – machine for automated production
- Beginning of the 20th century: development of various drawn flat sheet processes
- Mid-20th century: Pilkington developed float glass process





Chemical composition

Glass is isotropic, inorganic, visco-elastic material without lattice structure, solid at room temperature, liquid above transition zone ~580°C.

Typical composition:

- Silica SiO_2 70 – 74%
- Lime CaO 5 – 12%
- soda Na_2O 12 – 16%
- other chemical elements with influence to: spectral transmittance, thermal properties, tensile strength, fracture toughness, colour, etc.

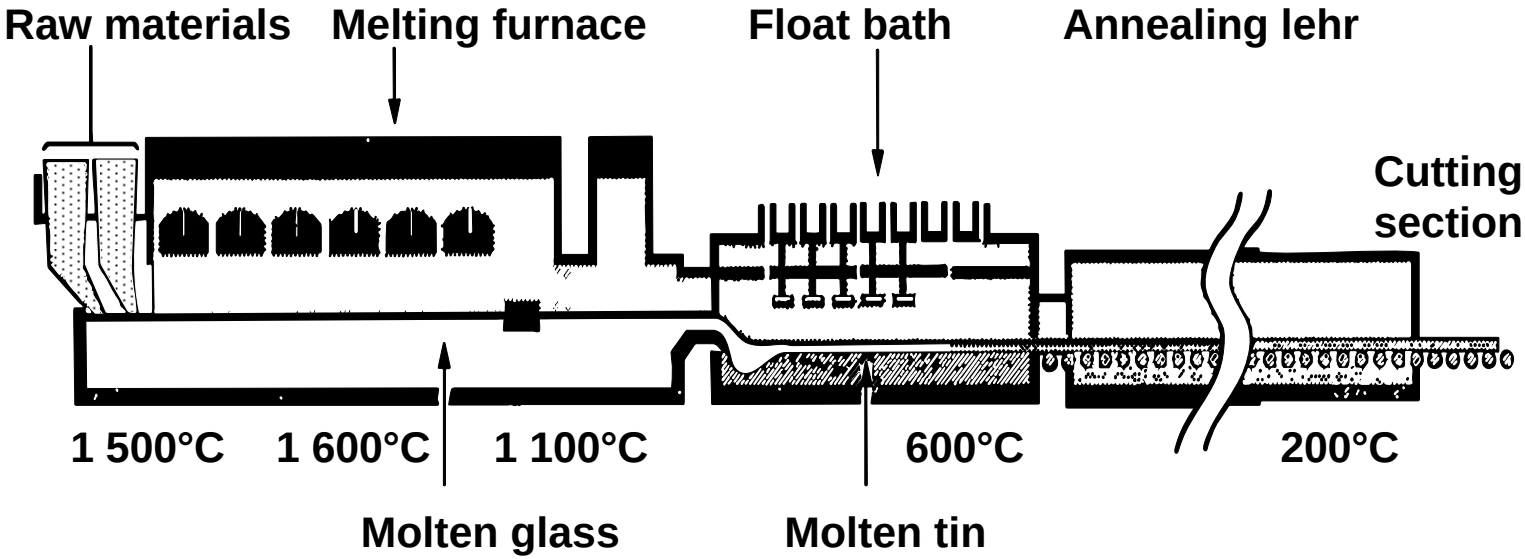
Glass colours produced by the addition of metal oxides

- **green – iron or chromium oxide**
- **red – copper oxide or gold oxide**
- **blue – cobalt oxide**

Production

Float glass process

- silica sand, soda ash, limestone and salt cake with cullet
- controlled heating permits glass to flow
- flat ribbon of uniform thickness, brilliant and flat parallel surfaces



Production

Float glass plant

Float glass ribbon cut to panel size

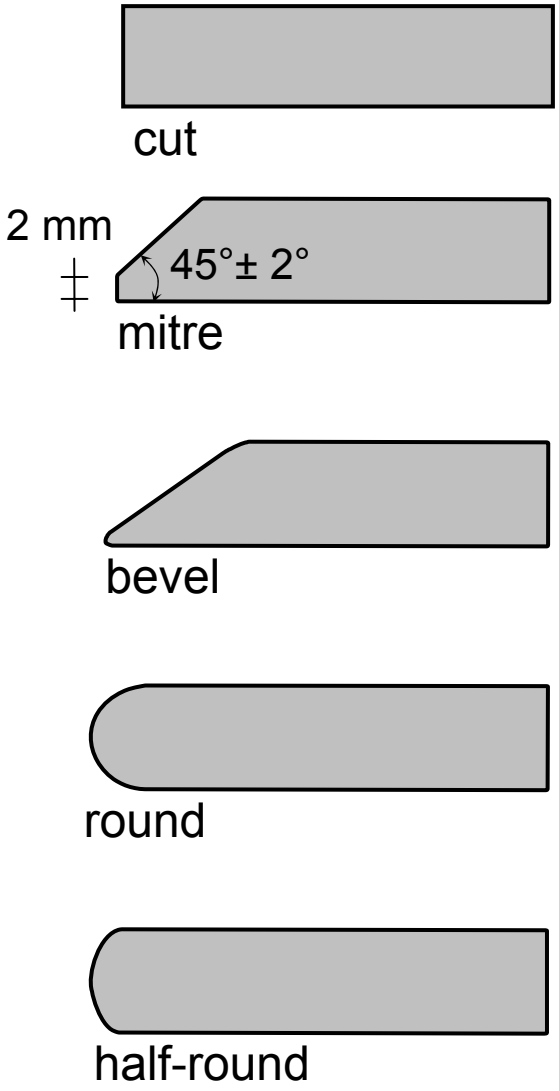
Glass products, edge quality

- **flat glass**
  t = 3, 4, 5, 6, 7, 8, 10, 12, 15, 19, 25 mm, max. size 6,0 x 3,2 m
- **channel glass C, U**
  length up to 6,0 m
- **circular tube**
  thickness from 0,7 to 10,0 mm, diameters d = 3 to 325 mm
- **glass block**
  hollow - (115 x 115 x 80 mm - 300 x 300 x 95 mm)
  solid - (120 x 120 x 40 mm - 200 x 200 x 50 mm)
- **curved glass**
  radius R = 300 mm - ∞
  depend on the thickness, bends in one or two planes

Glass products, edge quality

Edge quality

- **CUT – unfinished sides of glass with sharp edges;**
- **ARRISED – the sharp cut edges have been broken off or bevelled with a grinding tool**
- **GROUND – to required dimensions, with blank spots**
- **FINE GROUND – edge is fully ground over its full surfaces, without blank spots**
- **POLISHED – the fine ground edges are finely polished**



Material and mechanical properties

High durability

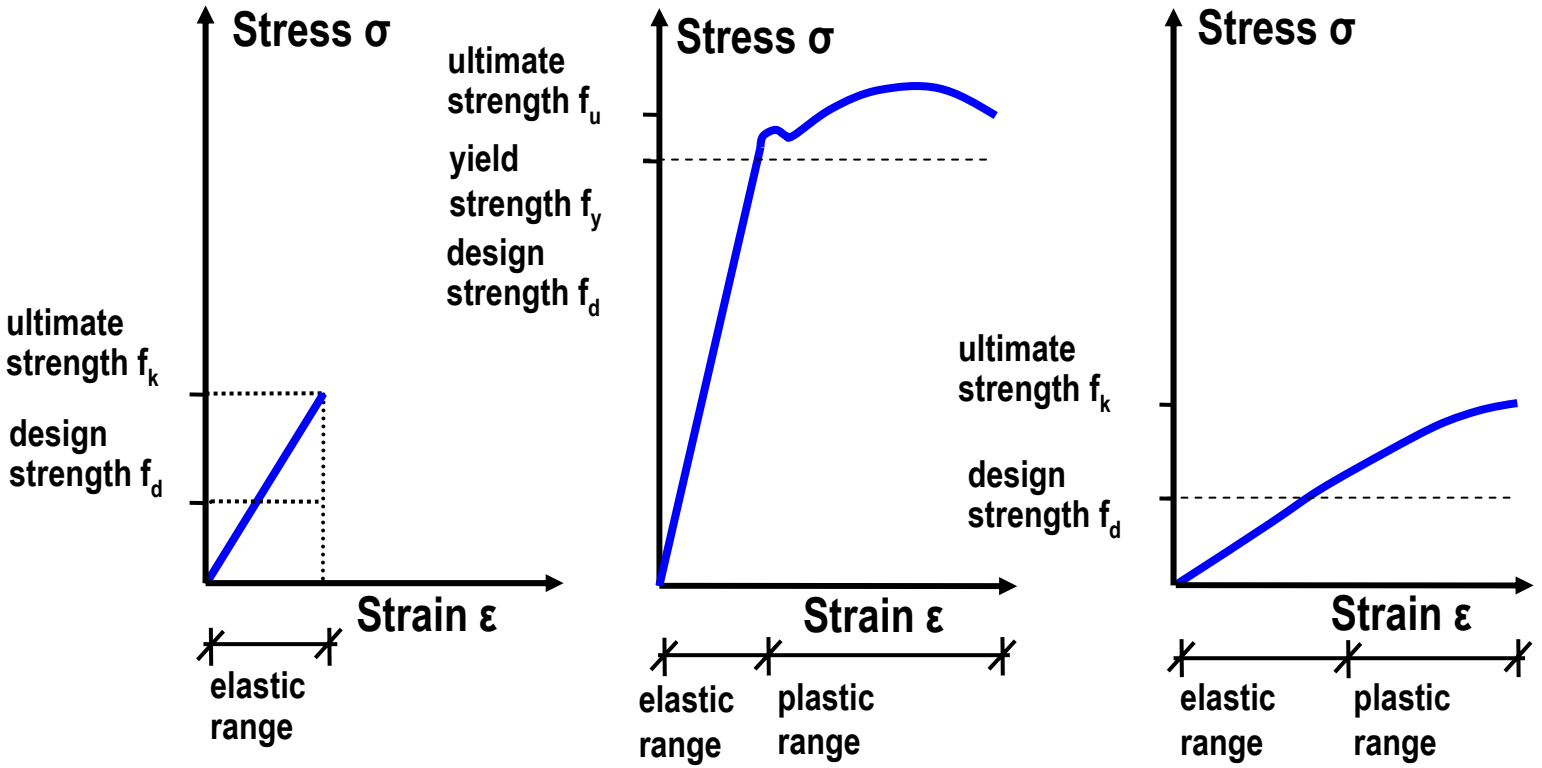
Resistance to:

- water percolation
- corrosion
- salt water
- carbonated water
- strong acids
- organic solvents
- ultra-violet radiation

Material and mechanical properties

Glass property	Value	Unit
Density ρ	2500	kg/m^3
Young's modulus of elasticity E	**70 000**	**MPa**
Shear modulus G	30 000	MPa
Poisson's ratio ν	0,23	-
Coefficient of thermal expansion α_T	7,7 - 8,8 x 10^{-6}	1/K
Thermal conductivity λ	1,0	W/(mK)
Emissivity ε	0,89	-
Compressive strength	**up to 1 000**	**MPa**
Tensile strength	**10 - 100**	**MPa**

Material and mechanical properties



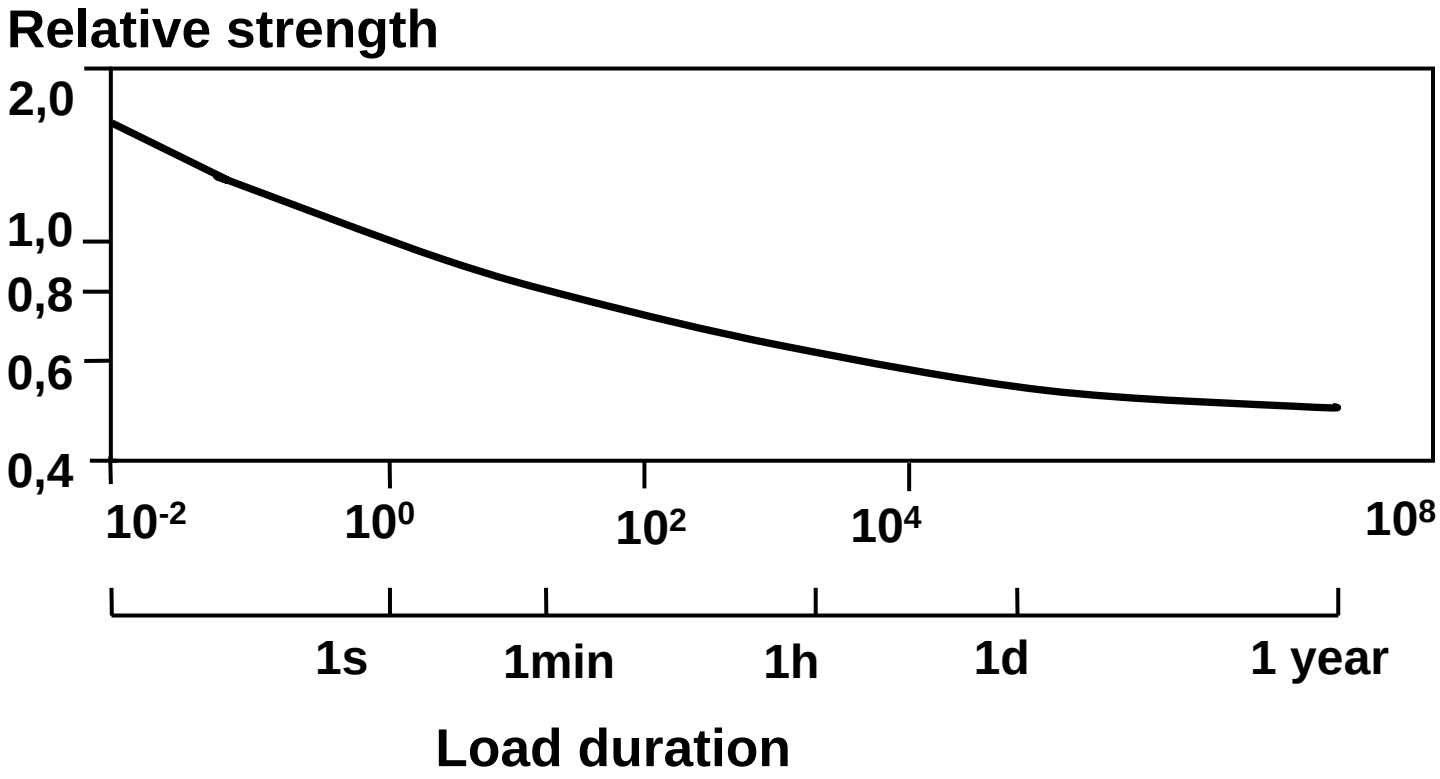
GLASS **STEEL** **TIMBER**

Material and mechanical properties

Strength of glass depends on:

- surface condition and edge quality
- load duration
- environmental condition, especially humidity
- stress distribution on the surface
- size of the stressed area
- damage of glass surface – flaws and cracks

Material and mechanical properties



Relationship between time to failure and applied stress (Sedlacek)

Material and mechanical properties

Relationship between time to failure and applied stress

$$\sigma^n T = constant$$

σ - stress

T - duration of stress

n - constant

environment	**constant *n***
water at 25°C – recommended for design purposes	16,0
air with 50% relative humidity at 25°C	18,1
air with 10% relative humidity at 25°C	27,0
vacuum	70,0
melting snow at 2°C	16,0

Material and mechanical properties

FRACTURE MECHANICS – growth of crack (Griffith's theory)

Critical combination of stress and crack length for fast fracture is a material constant

$$\sigma\sqrt{(\pi a)} = \sqrt{(EG_c)}$$

a - half of the crack length,

E - Young's modulus of elasticity

G_c - toughness of the glass [kJ/m^2], (critical elastic energy release rate)

- critical length of crack x critical stress
- crack grows slowly when stress $\sigma < \sigma_{cr}$ until critical length

Material and mechanical properties

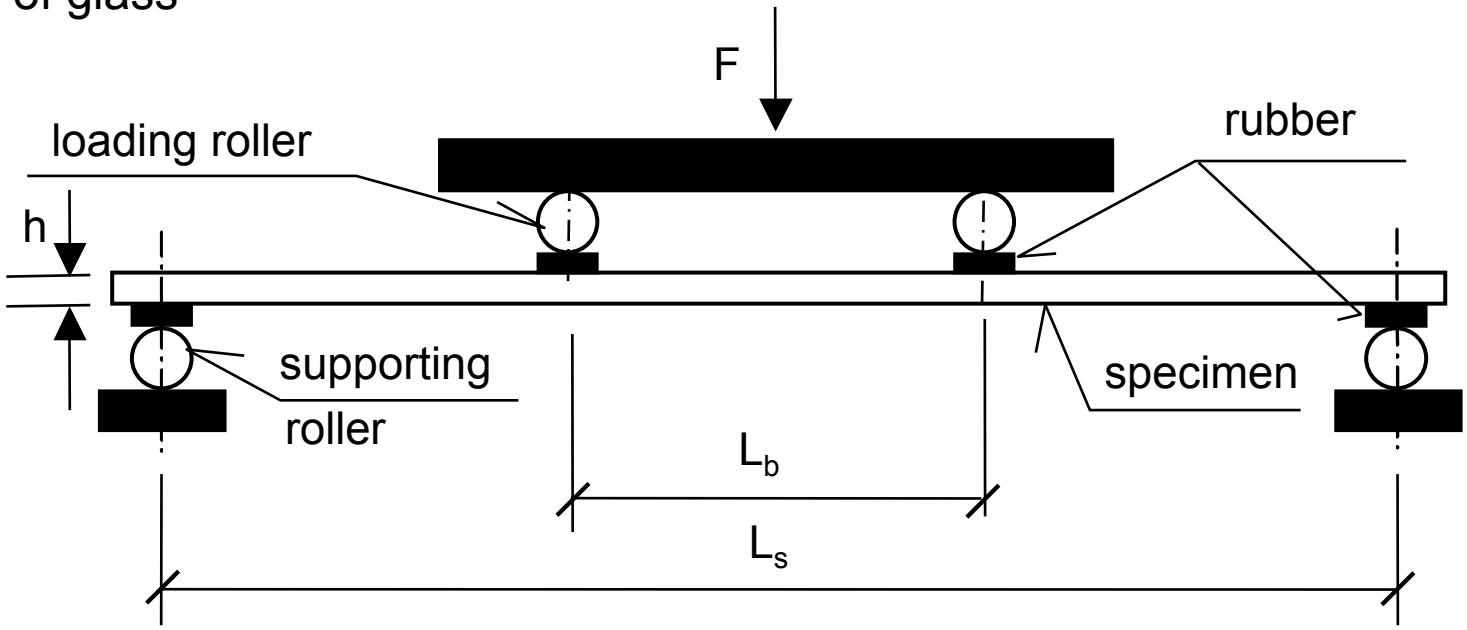
Irregularities and defects in glass

- manufacturing – in material (vents, sulphate scab, inclusions)
- mechanical processing – sawing, cutting, drilling, edge and surface grinding
- environment – cleaning (new micro cracks and scratches are generated)
- glass has ability to reverse damage in unstressed state (i.e. heal the micro cracks)

Testing of glass elements

Four point bending tests of glass

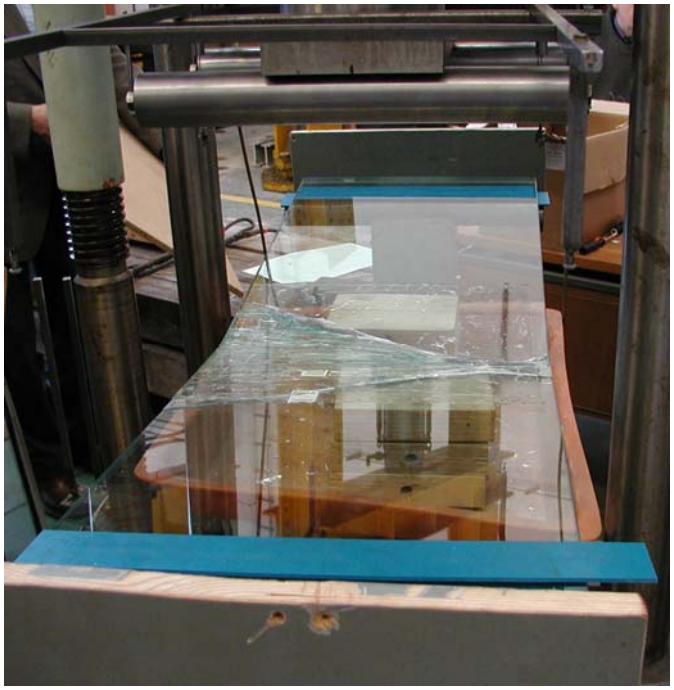
EN 1288-3 Glass in Buildings – Determination of the bending strength of glass



- length of the test specimen: L = 1 100 mm
- width of the test specimen: B = 360 mm
- fluent increase of the load with speed 2 MPa/s till the failure

Testing of glass elements

Four point bending test of glass



- Test set-up
- Typical failure of float glass

Testing of glass elements

Impact test - EN 12600

- **impact resistance of glass – to resist dynamic human impact**
- **50kg pendulum, dropping height, glass breakage**

Thank you
for your kind attention