Contents

Aluminium

- Preparation
- Production and products
- Properties
- Design rules
- Comparison with other materials
- Costs, environmental aspects, economy
- Availability
- Recent developments

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1. Preparation

- **Aluminium:**
  - 8% of earth crust
- **Bauxite:**
  - 50% aluminium oxide
  - 50% other oxides
- **Preparation in three steps:**
  - Extraction of bauxite
  - Preparation of aluminium oxide from bauxite (Bayer process)
  - Reduction of aluminium oxide to aluminium (electrolysis)
- **Electrolysis:**
  - Provides pure aluminium (99,99%)
  - Requires a lot of energy
  - Results in high cost price for primary aluminium
  - What about secondary aluminium?

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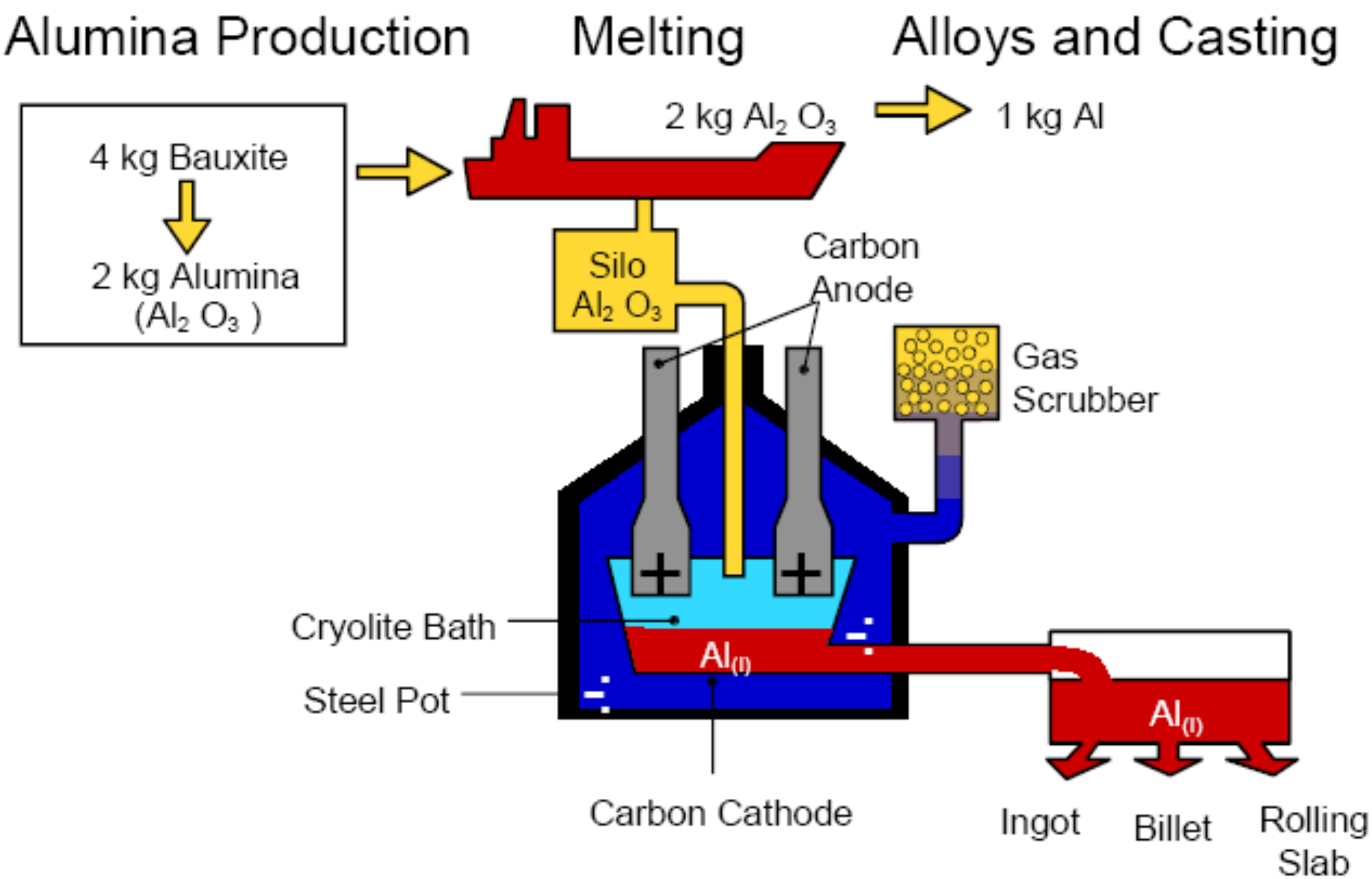
REHABILITATED LANDSCAPE
FLUORIDE
OXYGEN
BAUXITE ORE
4.6 METRIC TONNES
ALUMINA
1.9 METRIC TONNES
ALUMINIUM
1 METRIC TONNE
EARTH'S CRUST
8% ALUMINIUM
RED MUD
2.7 METRIC TONNES



TALAT Training in Aluminium Application Technologies	Aluminium Production from Bauxite	1100.01.01

- **Pure aluminium:**
  - Soft
  - Low strength

- **Improve properties by:**
  - Alloying (Cu, Mg, Mn, Si, Zn)
  - Post-treatment (heat treatment or work hardening)

- **Distinghuish**

  1) Wrought alloys

process :	extrusion (and rolling)
applications :	profiles, bars, hollow sections

  2) Cast alloys

process :	casting
applications :	castings

Codification of aluminium alloys

1XXX	Aluminium of 99% minimum purity
2XXX	Aluminium and copper alloys
3XXX	Aluminium and manganese alloys
4XXX	Aluminium and silicon alloys
5XXX	Aluminium and magnesium alloys
6XXX	Aluminium, Mg and Si alloys
7XXX	Aluminium, Zn and Mg alloys
8XXX	other alloys (eg. aluminium lithium).

Each alloy is described by a four digit number plus a further letter and number indicating the temper or condition.

TALAT	International Nomenclatur for Wrought Aluminium Alloys	1101.02.03

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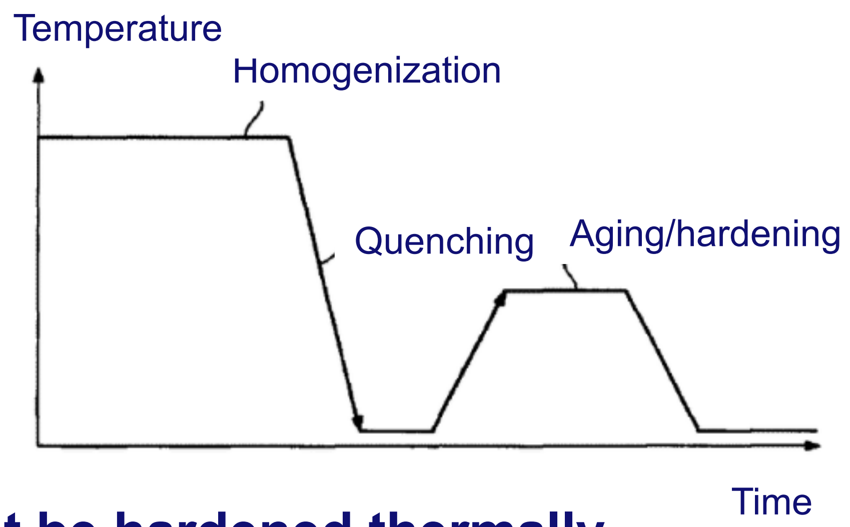
Post-treatment

- **Hardening of wrought alloys**
- **Alloys which can be hardened thermally**

Heat treatment

- Homogenization
- Quenching
- Aging / hardening



- **Alloys which cannot be hardened thermally**

Work hardening (comparable with steel)

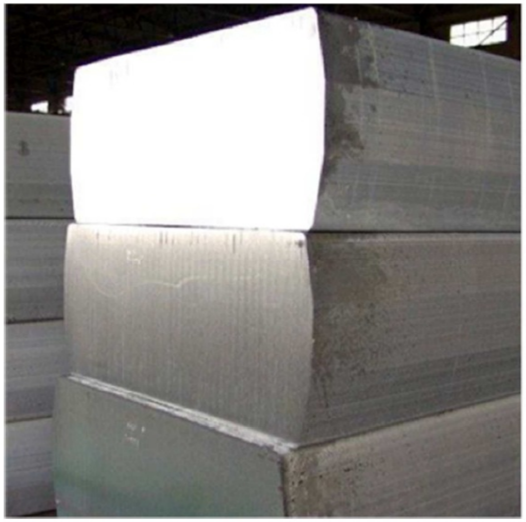
Codification of aluminium alloys

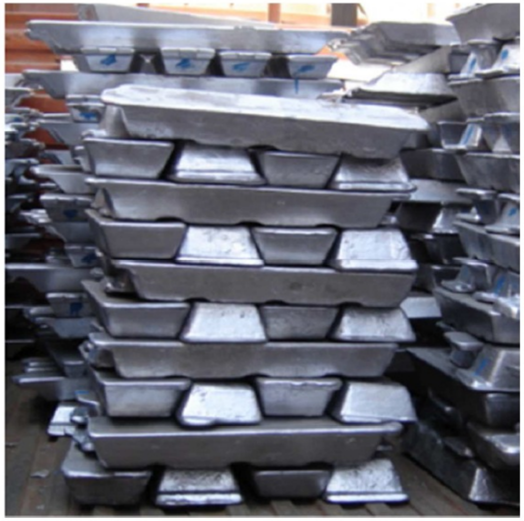
XXXX	-F	as-fabricated	
	-O	annealed	
XXXX	-H1	Work-hardened only	NON-HEAT TREATABLE ALLOYS
	-H2	Work-hardened and partially annealed	
	-H3	Work-hardened and stabilized by low temperature treatment	
	-HX2	Quarter-hard	Degree of cold working
	-HX4	Half-hard	
	-HX6	Three-quarter-hard	
	-HX8	Fully-hard	
XXXX	-T2	Cooled from an elevated temperature and naturally aged	HEAT TREATABLE ALLOYS
	-T4	Solution heat-treated and naturally aged	
	-T5	Cooled from an elevated temperature shaping process and artifically aged	
	-T6	Solution heat treated and artifically aged	
	-T8	Solution heat-treated, cold worked and aged	

TALAT Training in Aluminium Application Technologies | A Selection of Common Temper Designations for Aluminium Alloys | 1501.04.04

2. Production and products

Billets, ingots, castings





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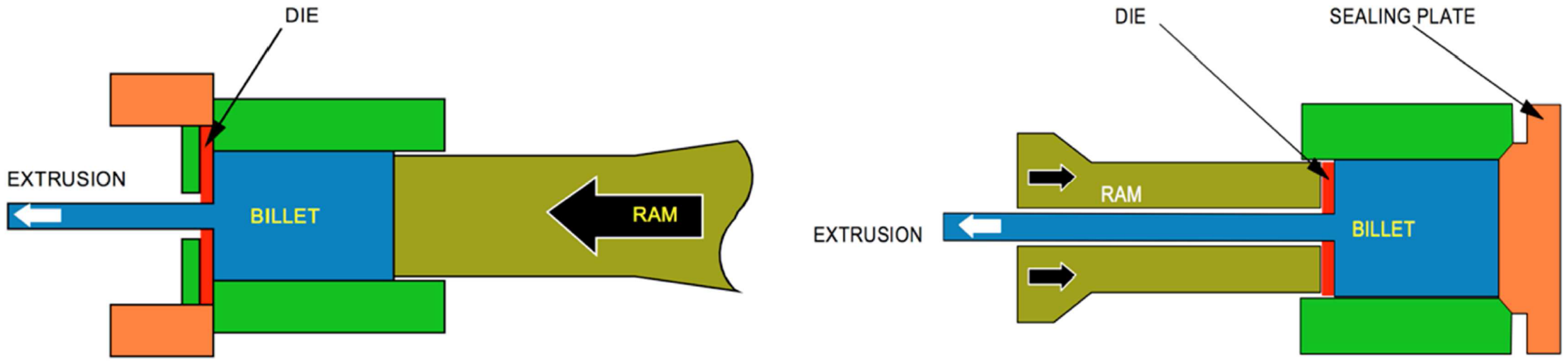
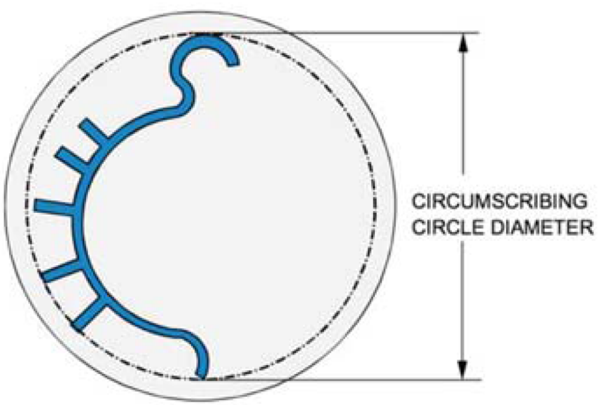
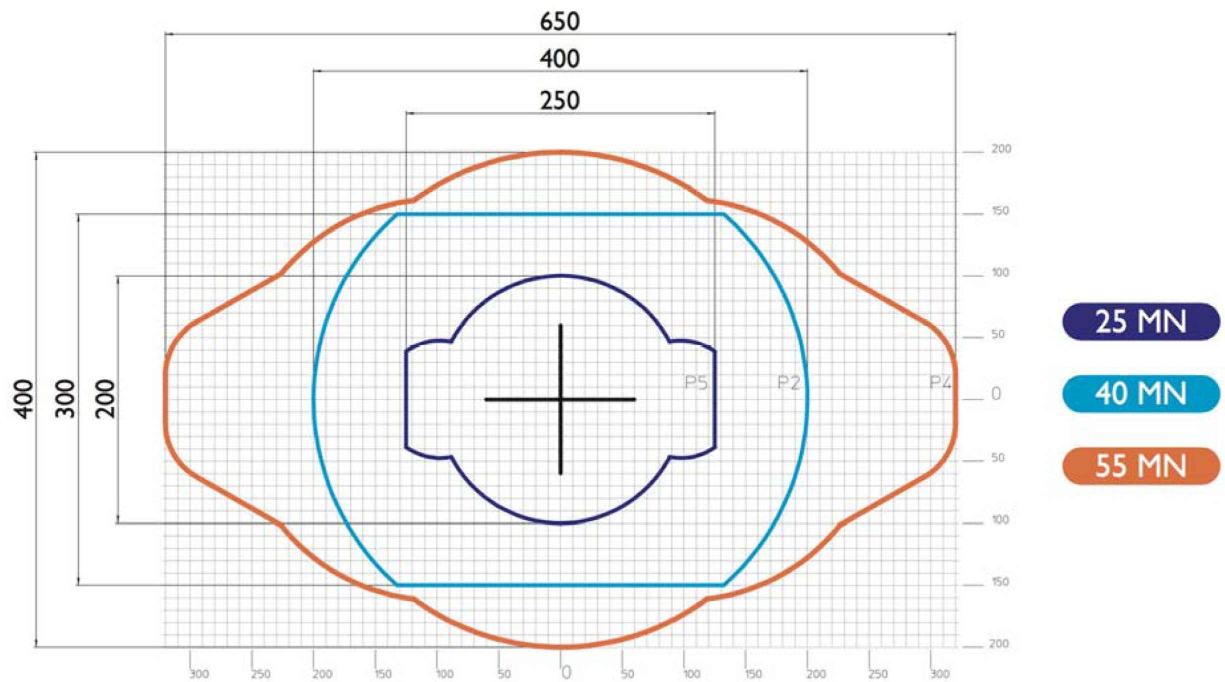
Extrusion proces



Limited press capacity and dimensions





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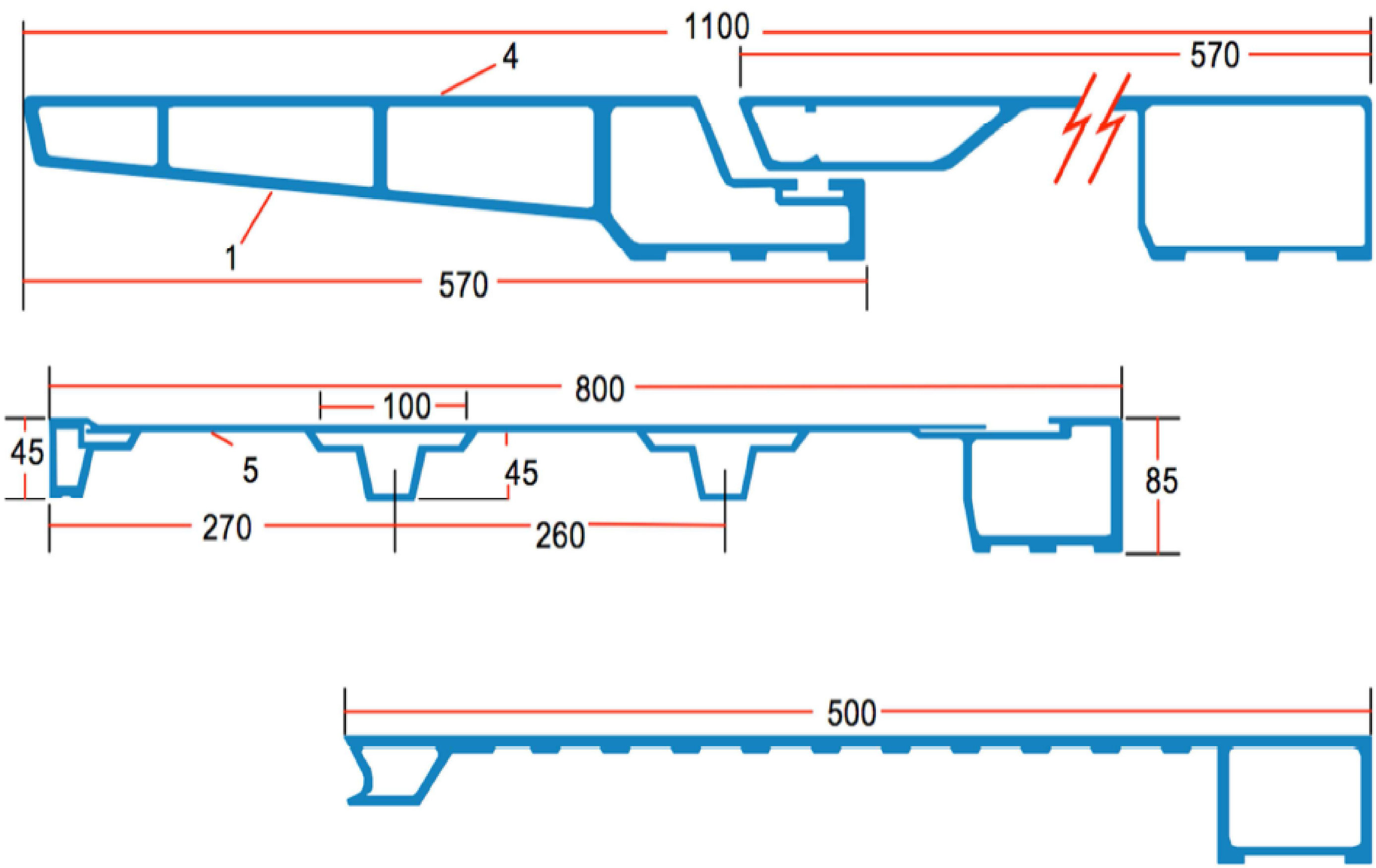
Extrusion products : examples from billets



3. Properties

Favourable properties

- Low density (2700 kg/m^3)
- Good mechanical properties
- Favorable strength to weight ratio
- Good corrosive resistance (tight oxide layer)
- Many design options (extrusion)
- Tough material (applicable for low temperatures)

- Excellent conductor (electricity, heat)
- High reflection (light, heat)
- Non-magnetic
- Non-poisoning

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Unfavourable properties

- Low modulus of elasticity E:

  Problem : deformation or instability may govern above strength

  Solution : adjust cross-section for enough stiffness EI

  Involves : less weight reduction as might be expected

- Low melting point + low strength for elevated temperatures

  Problem : unfavorable under fire conditions (buckling!)

  Solution : proper fire safety design

- Low fatigue strength

  Problem : fatigue failure due to crack growth

  Solution : proper fatigue design

  Involves : less (number and magnitude) stress fluctuations

- Strength reduction due to welding

  Problem : strength reduction in HAZ

  Solution : proper cross-sectional design

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- **Alloy influences:**

  - Strength
  - Strain at rupture
  - Hardness
  - Corrosion resistance
  - Deformation capacity
  - Weldability
  - Machinability
  - Suitability for anodic oxidation

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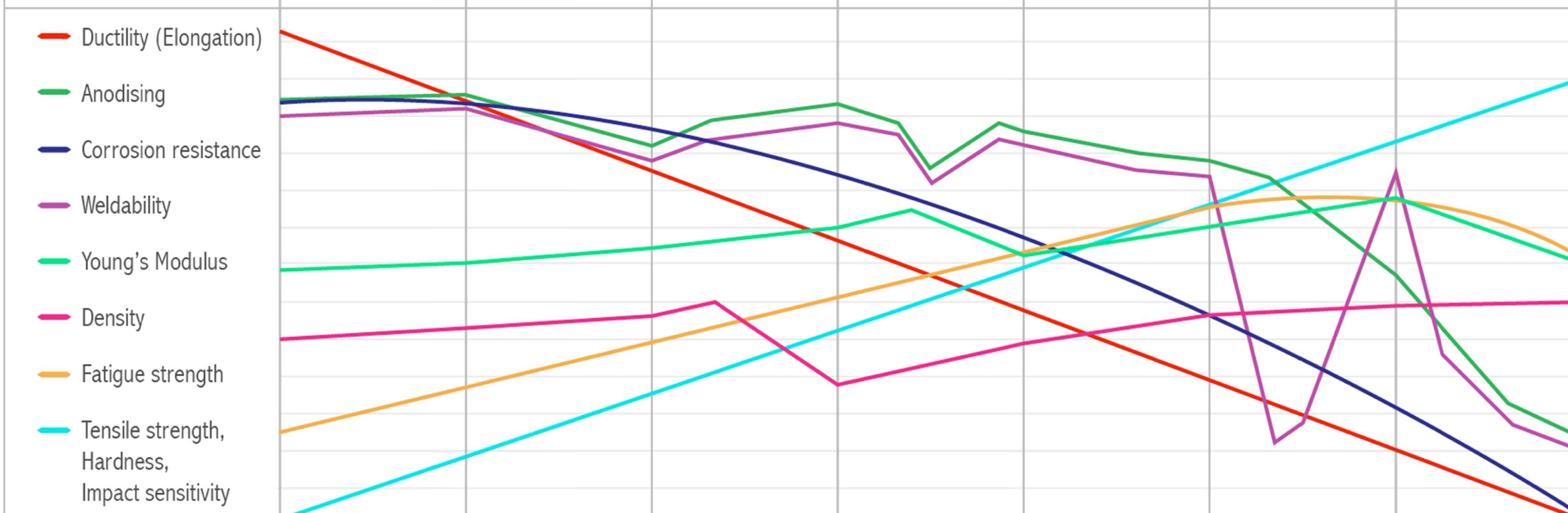
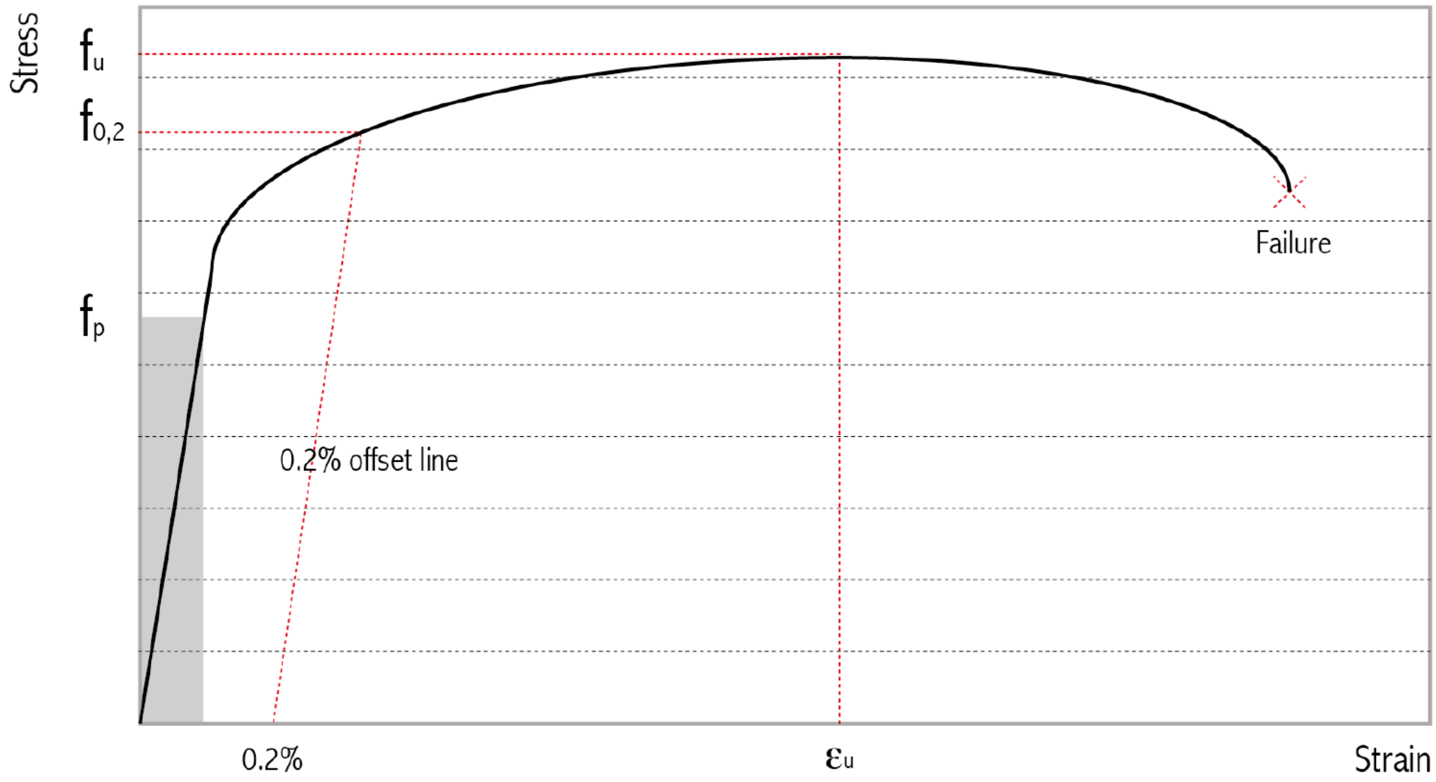
General alloy properties

ALLOY TYPE	1XXX	3XXX	5XXX	6XXX	7XXX	2XXX	7XXX
CHEMICAL CODE	Al	AlMn	AlMg	AlMgSi	AlZnMg	AlCuMgSi	AlZnMgCu



STRENGTH	Soft	Low	Medium	Medium High	High

Stress-strain diagram



f_u = Ultimate (tensile) strength

$f_{0,2}$ = 0.2% proof strength

f_p = Proportionality limit

ε_u = Strain at ultimate strength

ε_f = Strain at failure

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Mechanical properties of some alloys

Alloy EN AW	Product form	Temper*	Dimension t wall thickness or thickness mm	$f_{0,2}$ 0,2% Proof strength N/mm²	f_u Ultimate strength N/mm²	A Minimum elongation %
6106	EP	T6	t ≤ 10	200	250	8
6082	EP, ET, ER/B	T4	t ≤ 25	110	205	14
	EP	T5	t ≤ 5	230	270	8
	EP, ET	T6	t ≤ 5	250	290	8
		T6	5 < t ≤ 15	260	310	10
	ER/B	T6	t ≤ 20	250	295	8
		T6	20 < t ≤ 150	260	310	8
	DT	T6	t ≤ 5	255	310	8
		T6	5 < t ≤ 20	250	310	10
7020	EP, ET, ER/B	T6	t ≤ 15	290	350	10
	EP, ET, ER/B	T6	15 < t < 40	275	350	10
	DT	T6	t ≤ 20	280	350	10

Part of Eurocode 9 – Table 3.2b

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Mechanical properties vary for

- Alloy
- Delivery condition
- Temperature

Example (T between -30°C and +100°C):

- 5754 O → $f_{0.2}$ = 80 N/mm^2, f_t = 210 N/mm^2, ε = 20%
- 5754 H34 → $f_{0.2}$ = 190 N/mm^2, f_t = 260 N/mm^2, ε = 10%
- 6082 T6 → $f_{0.2}$ = 260 N/mm^2, f_t = 310 N/mm^2, ε = 10%

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Mechanical properties vary for
- Alloy
- Delivery condition
- Temperature

- **Aluminium**
  - Low temperature favorable
  - High temperature unfavorable

- **Steel**
  - Low temperature unfavorable
  - High temperature less unfavorable

- Example: alloy 5083

T (°C)	f_t (N/mm²)	$f_{0.2}$ (N/mm²)	ε (%)
-195	405	165	36
-80	295	145	30
-30	290	145	27
100	275	145	36
150	215	130	50
260	115	75	80
370	41	29	130

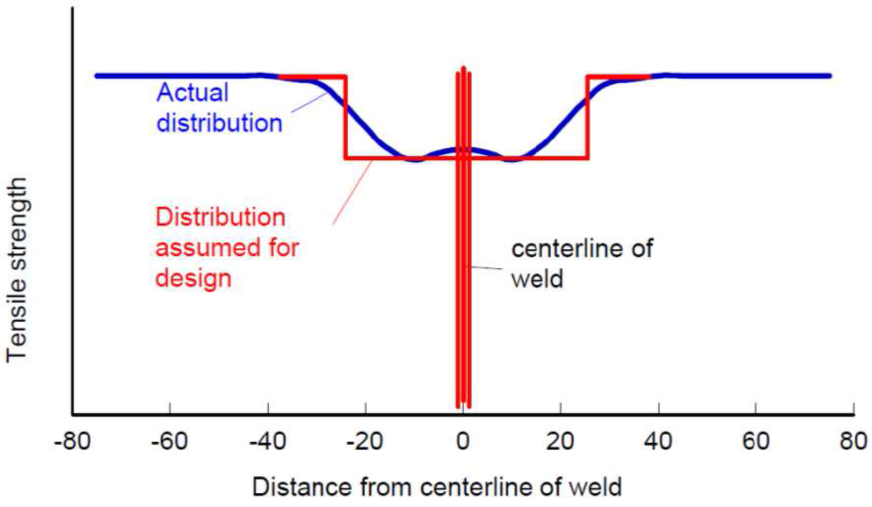
4. Design rules

- Eurocode 9 Part 1.1
- Comparable to Eurocode 3 part 1.1 except for:

  - material factors
  - material properties
  - influence of welding (HAZ)
  - influence of local buckling (class 4 sections)

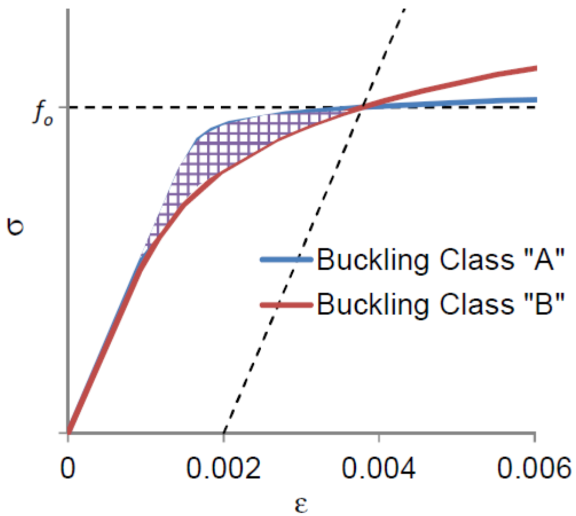
Influence of welding : HAZ

MIG welding		TIG welding	
$0 < t \leq 6$ mm:	$b_{haz} = 20$ mm	$0 < t \leq 6$ mm:	$b_{haz} = 30$ mm
$6 < t \leq 12$ mm:	$b_{haz} = 30$ mm		
$12 < t \leq 25$ mm:	$b_{haz} = 35$ mm		
$t > 25$ mm:	$b_{haz} = 40$ mm		



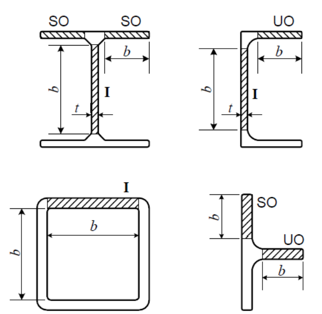
Thickness reduction due to HAZ

Section part	Alloy	$f_{0.2}$ [N/mm^2]	f_t [N/mm^2]	$\rho_{0,HAZ}$	$\rho_{0,HAZ}$	Buckling class
Top flange	5083 O	125	275	1	1	B
Extruded section	6082 T6	250	290	0.5	0.64	A



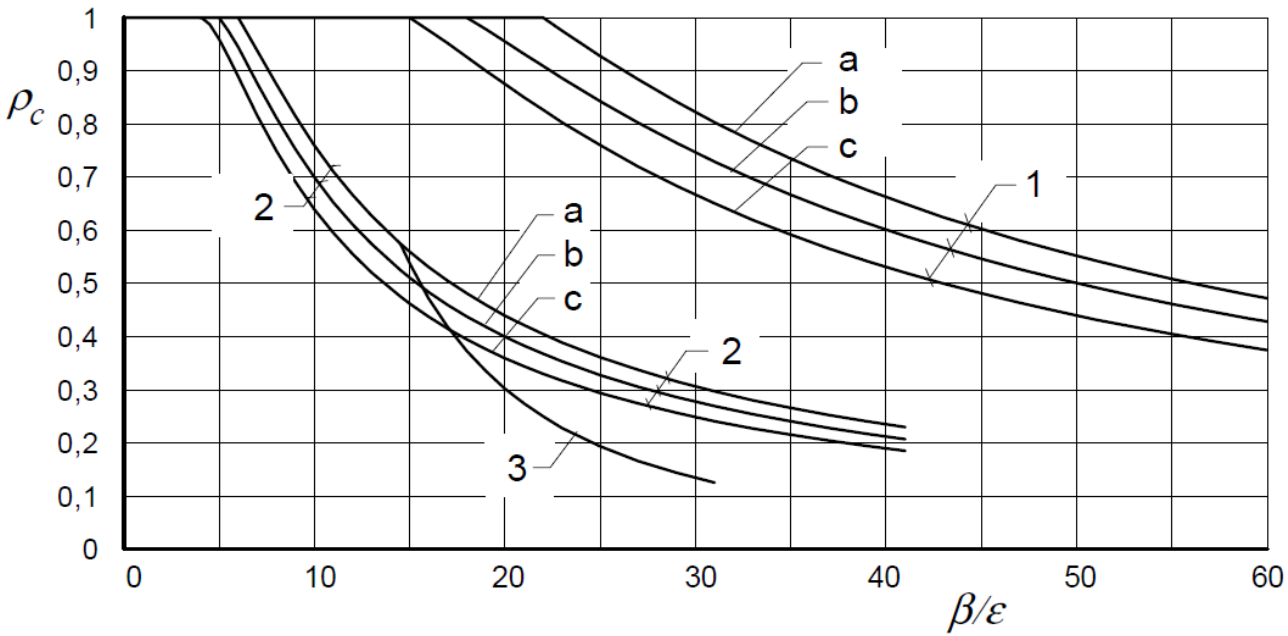
Influence of local buckling

Material classification	Internal			Outstand		
	β_1/ε	β_2/ε	β_3/ε	β_1/ε	β_2/ε	β_3/ε
BC “A”, without welds	11	16	22	3	4.5	6
BC “A”, with welds	9	13	18	2,5	4	5
BC “B”, without welds	13	16.5	18	3,5	4.5	5
BC “B”, with welds	10	13.5	15	3	3.5	4
$\varepsilon = \sqrt{250/f_o}$, f_0 in N/mm^2						



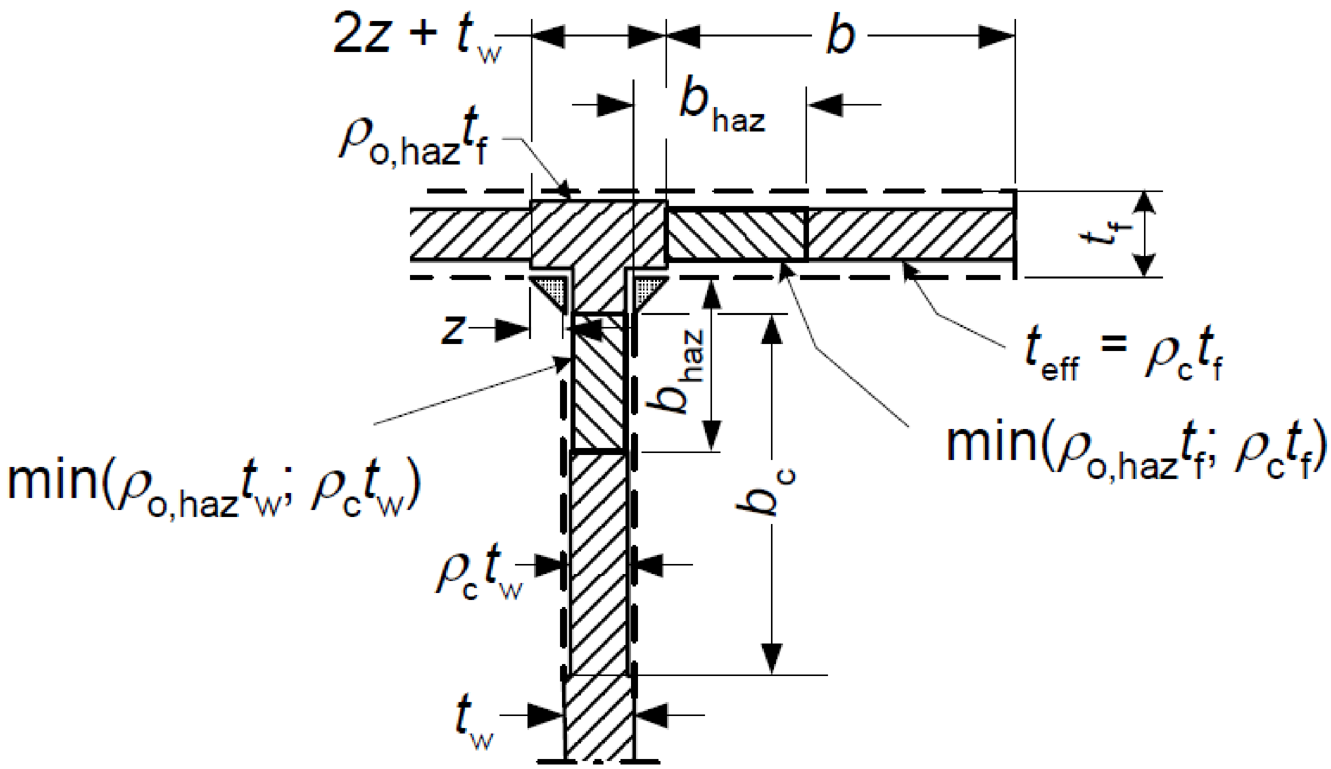
I = internal. SO = symmetrical outstand. UO = unsymmetrical outstand.

Thickness reduction due to local buckling



- Reduction factor is dependant on:
  - Internal/external section part
  - Class A or class B
  - With or without welds

Thickness reduction due to local buckling with or without welding



5. Comparison with other materials

Property		Aluminium	Steel	Reinforced concrete	Timber	Masonry
Weight density (ρ)	kg/m^3	2700	7850	2500	380	1800
Linear thermal expansion coefficient (α)	$^oC^{-1}$	23×10^{-6}	12×10^{-6}	10×10^{-6}	5×10^{-4} *	23×10^{-6}
Modulus of Elasticity (E)	N/mm^2	70000	210000	30000	10000	2500
Shear Modulus (G)	N/mm^2	27000	81000	13000	650	1200
Poisson's ratio (ν)	-	0.30	0.30	0.15	-	0.10

* Parallel to fibre

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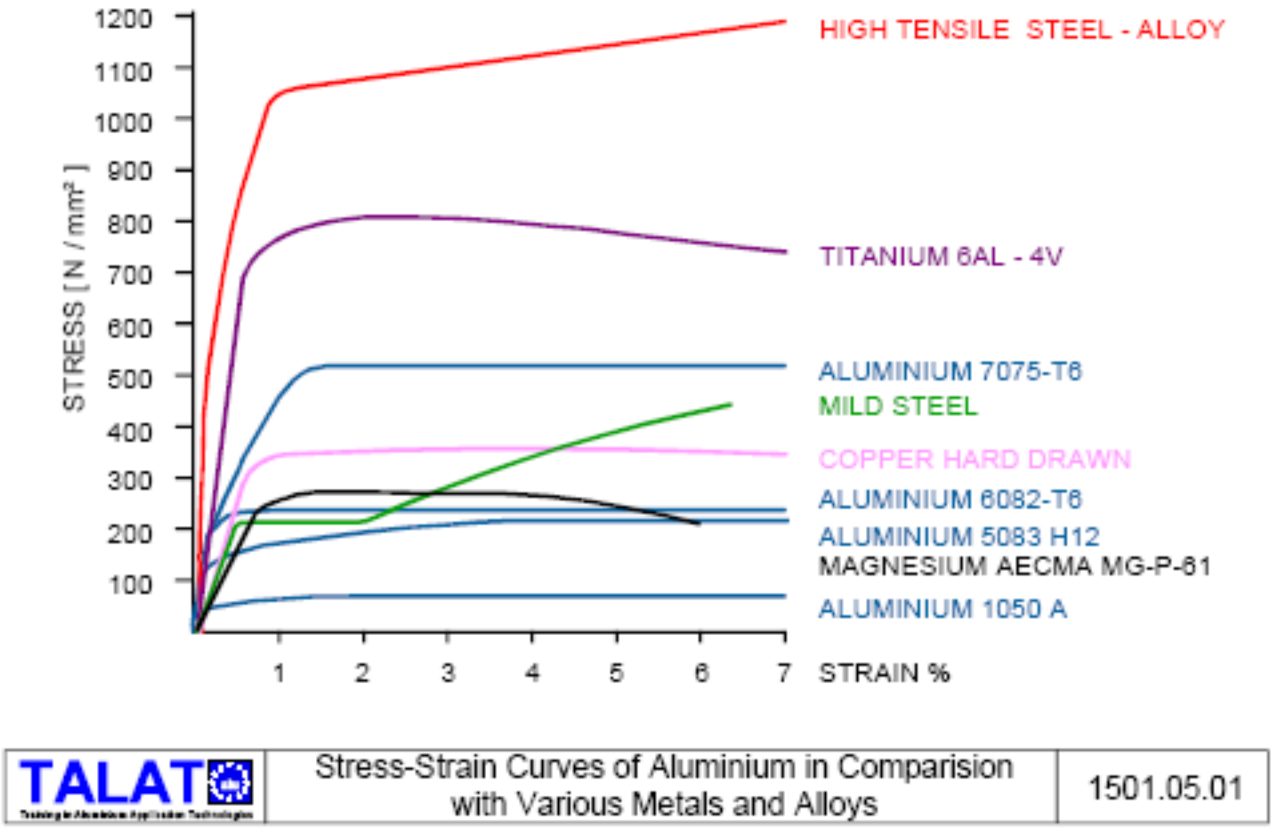
Stress-strain diagrams

- **σ-ε diagram of aluminium and other metals**



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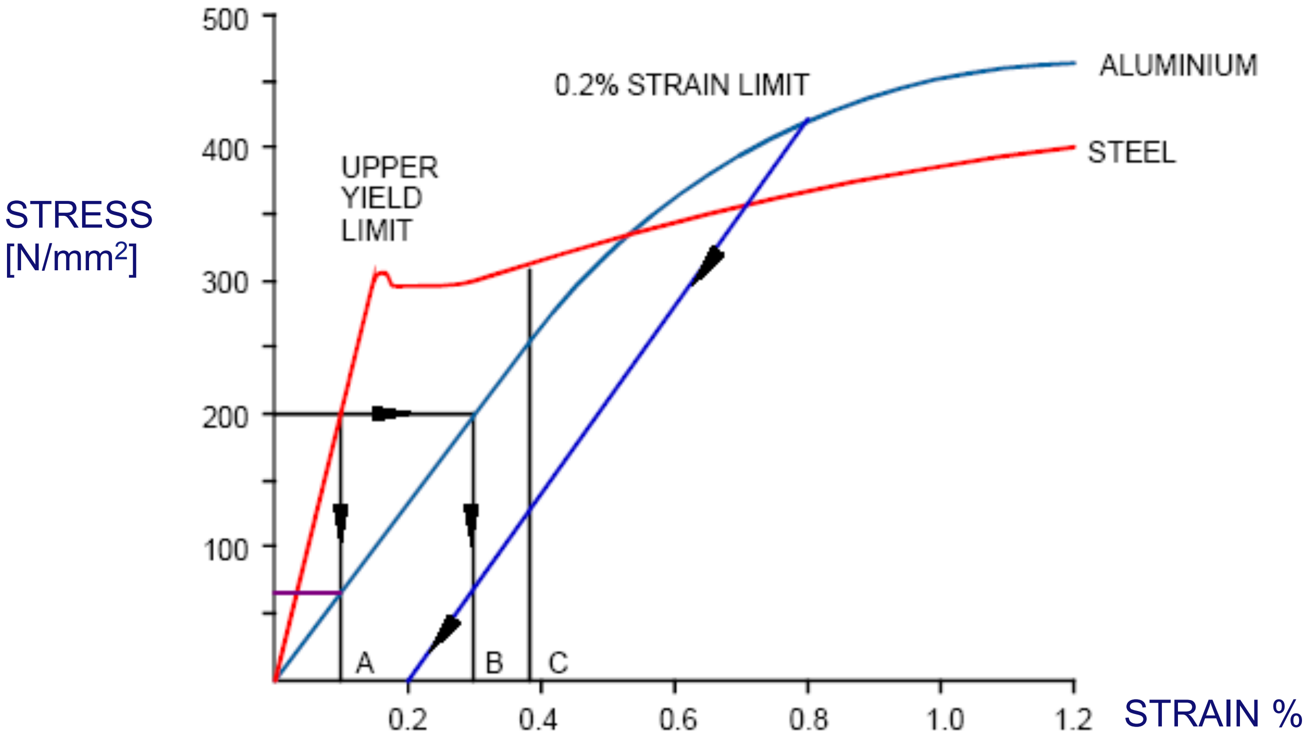
Stress-strain diagrams

- **σ-ε diagram of aluminium and structural steel**



TALAT Training in Aluminium Application Technologies	Plastic Yield Behaviour of Aluminium and Mild Steel	1501.05.03

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Connection methods

Traditional connection methods (comparable with steel):

- Bolting (stainless steel, aluminium)
- Welding (MIG, TIG)

Innovative connection methods:

- Adhesive bonding (epoxy)
- Clicking
- Friction Stir Welding (FSW)

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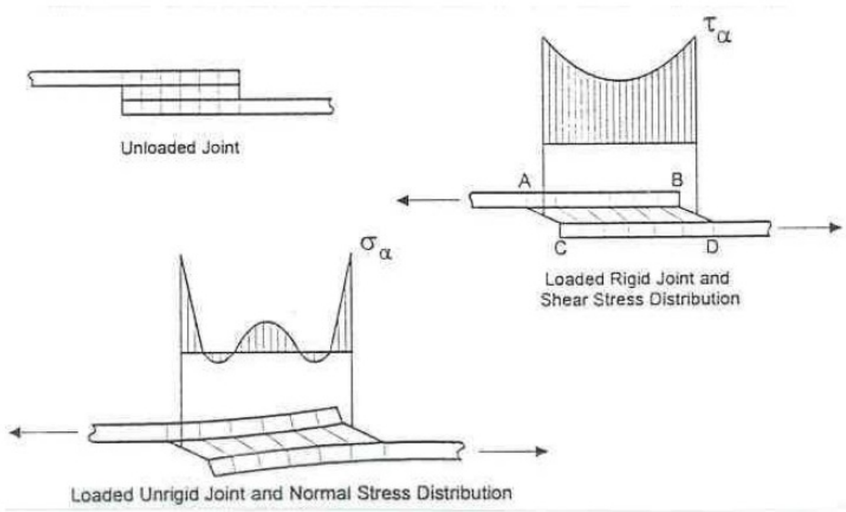
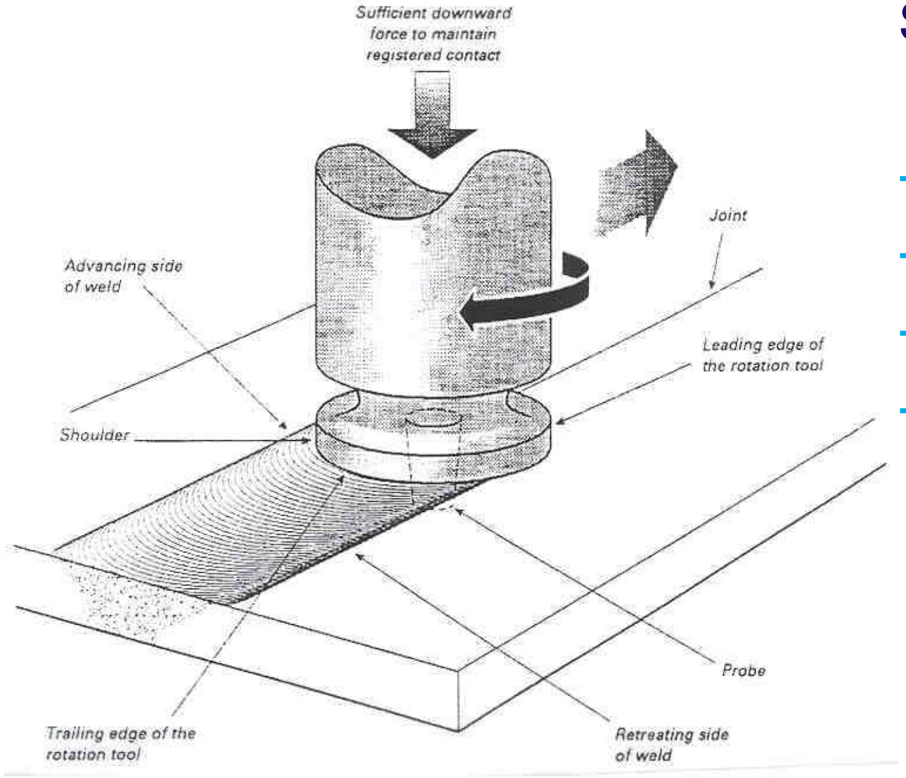
Adhesive bonding



Special aspects adhesive bonding:

- Design shear resistance is low
- Design tensile resistance is negligible
- Large connection dimensions
- Limited design rules available in EC9
- Large material factor (γ_M = 3)
- Preparation under special conditions (temperature, humidity)

FSW



Special aspects FSW:

- Neat design
- No design rules available in EC9
- Applicable for long weld lengths
- High investment

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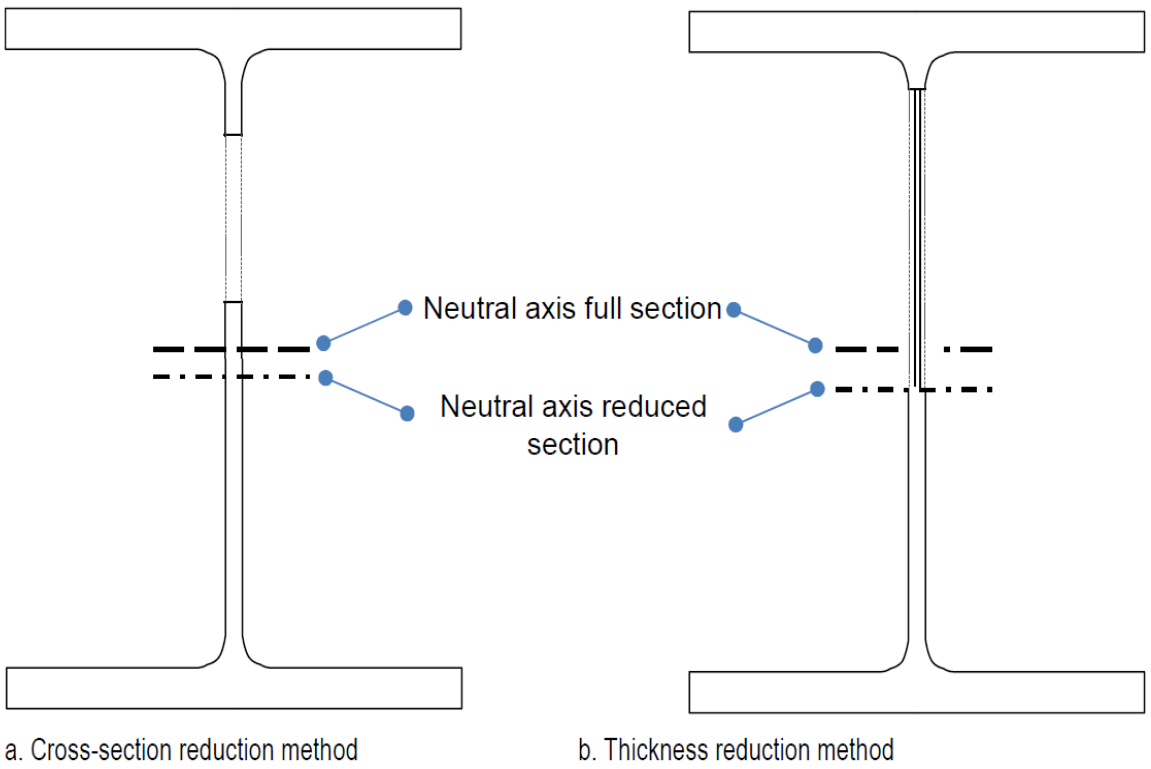
Resistance of class 4 sections

Steel | Aluminium



6. Costs, environmental aspects, economy

Image:

'aluminium is an expensive material'

'aluminium is a low strength material'

Expensive?

- Material costs (euro/kg) are very economy and availability dependant
- Economy shall be based on LCA, including effects due to:
  - Recycling (low material costs, high waste product value)
  - Smart extrusion design (including additional functions)
  - No or low maintenance costs

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Recycling

CHAPTER 2 – PRODUCTION OF ALUMINIUM AND ALUMINIUM ALLOYS

Figure 2.22 – Life cycle of aluminium (illustrations from *[17]*).

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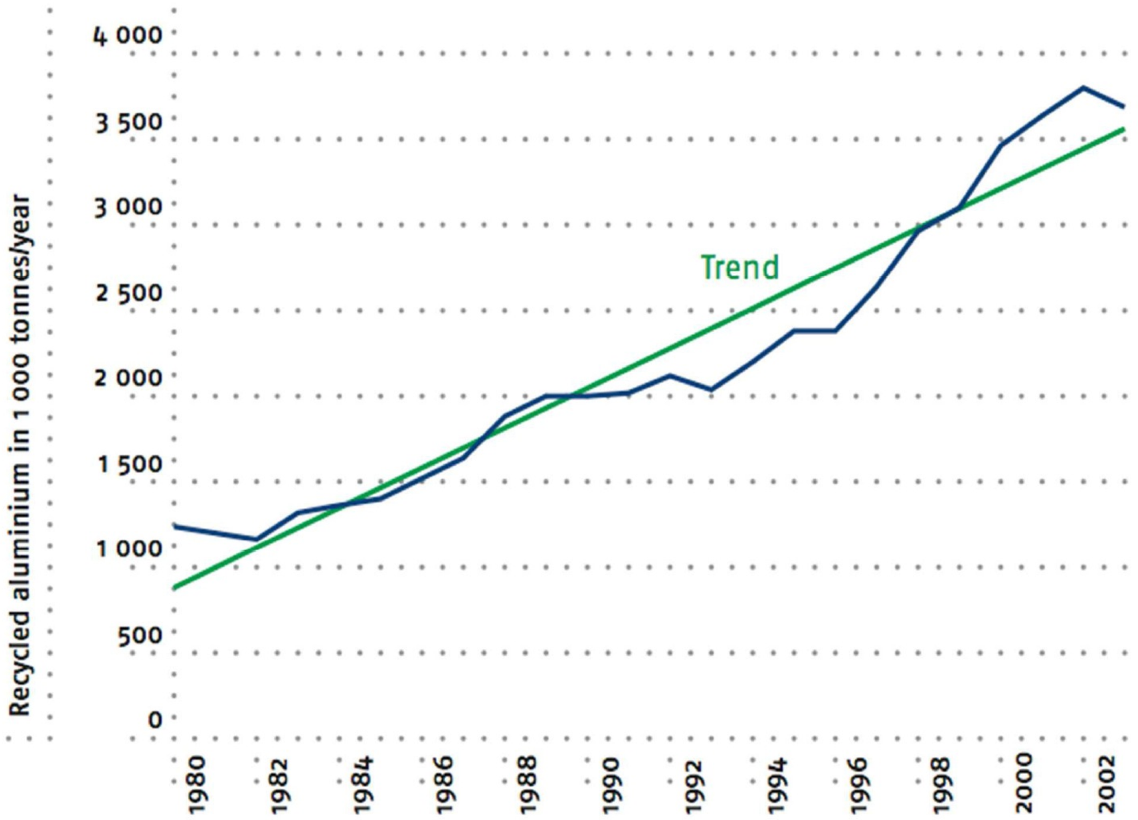
Development of recycled aluminium



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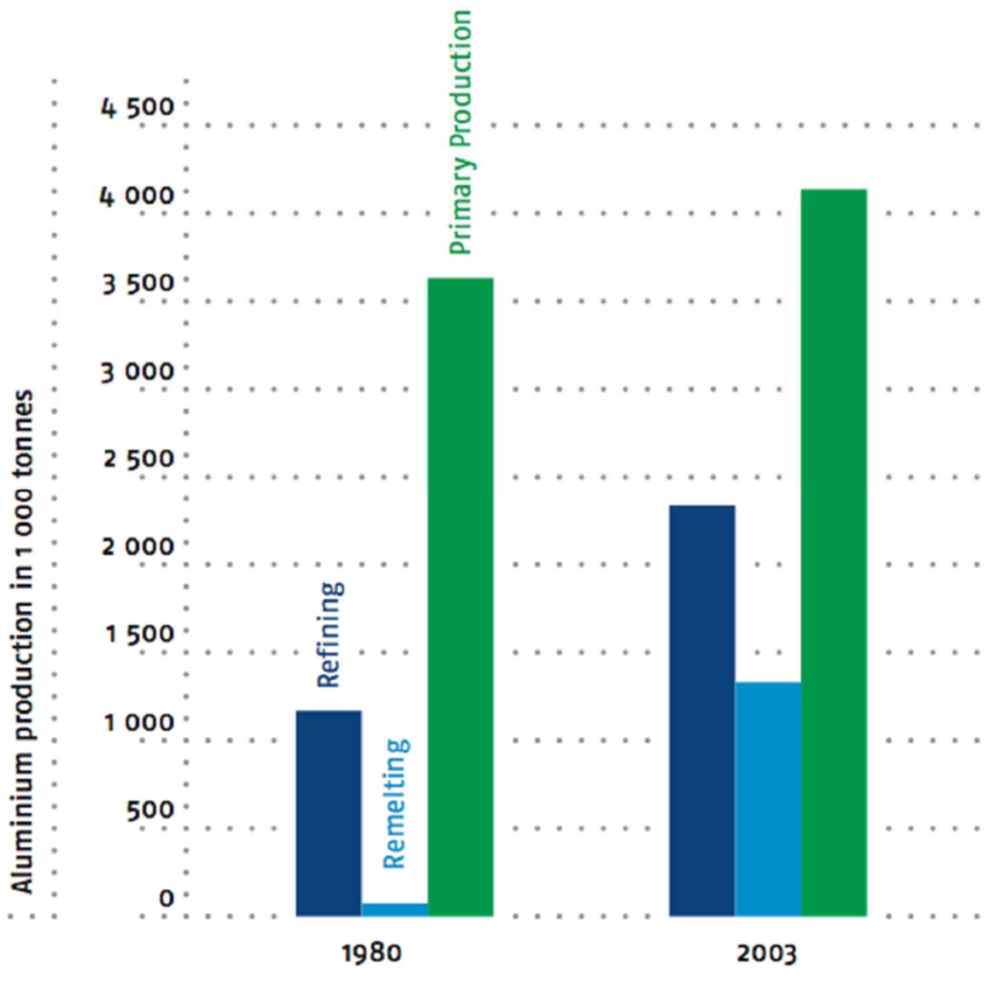
Reuse, remelting and primary production



Smart design

- Aluminium is competitive when there is a need for:
  - Light load-bearing structures
  - Sustainable structures
  - Freedom in design
  - Typical metallic appearance
- Conditions for economic application:
  - Sufficient knowledge
  - Economic design

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Economic design

- Feasibility
  - Manufacturing
  - Transport
  - Assembly

- Durability
  - Maintenance
  - Recycling

- Additional functions
  - Grids
  - Stiffeners
  - Joints

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Smart economic design

Smart design = economic design

- Freedom in shapes
- Slender cross-sections
- Including extra functions

  - Stiffeners
  - Grids
  - Joints

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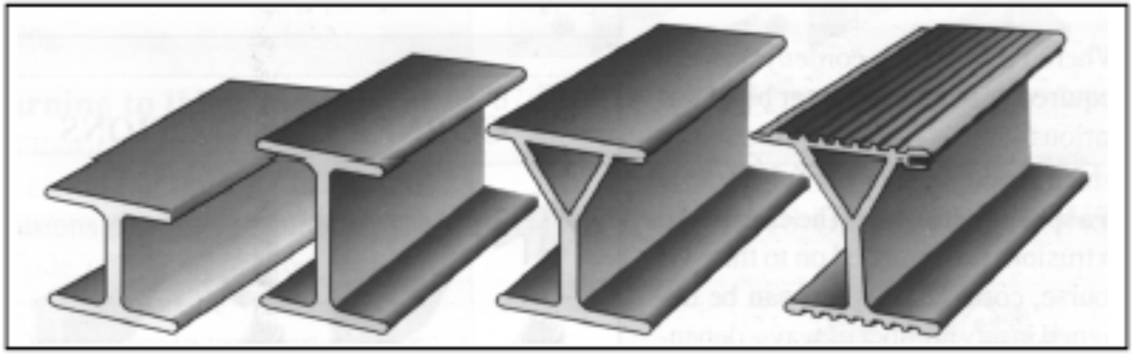
Example 1

Steel- and Aluminium Girders with the same Bending Stiffness



Steel	Aluminium appro. 50% lower weight vs. steel	Aluminium increased torsional stiffness	Aluminium increased torsional stiffness and integrated functions

TALAT	Designing Extrusions with Improved Stiffness	1302.01.11

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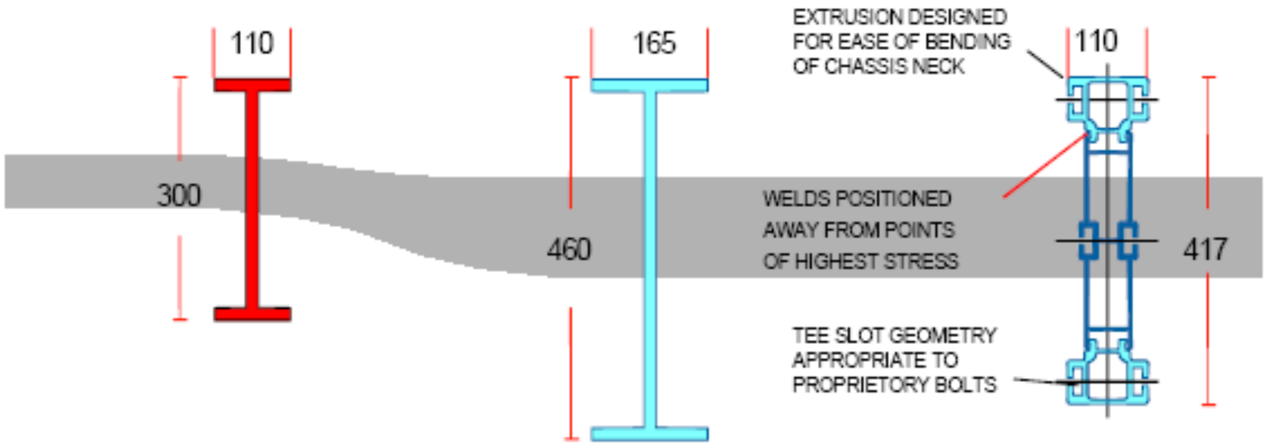
Example 2



	STEEL	ALUMINIUM	ALUMINIUM
WEIGHT kg/m	40	16.9	27
MOMENT of I mm^4	76 X 10^6	225 X 10^6	228 X 10^6
MODULUS Z mm^3	25 X 10^4	49 X 10^4	52 X 10^4
TORSIONAL STIFFNESS FACTOR	1	0.24	27.5
WEIGHT SAVED %		57	32.5

TALAT Training in Aluminium Application Technologies	Stiffness-Weight Relationsship as Design Criteria Example: Trailer Chassis	1501.05.04

7. Availability

On stock:

- simple extrusions (bars, CHS, RHS, SHS, plates)
- available in small amounts
- available in relatively small dimensions
- available in limited amount of alloys

Practice (for special products):

- particular extrusion design suitable for limited/special applications
- extruder is owner of the die
- relative high die costs have to be compensated by proper design

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8. Developments

Summary of important developments

Connections
- FSW properties
- adhesive bonding knowledge

Material knowledge
- weld seams in extruded sections; microstructure and properties
- material behaviour under elevated temperatures (fire)
- optimal extrusion design/techniques dependant on material flow during extrusion

Knowledge on structural phenomena
- cross-sectional stability
- fatigue behaviour of welding details
- behaviour under elevated temperatures

Typical applications

Facades :

- optimization of extrusions due to higher glass weights
- improvement of fire resistance

Renovation of bridges (bridgedecks)

- extension of bridges
- compensation of increase in traffic loads by decrease of deck weight

Applications for corrosive circumstances:

- helidecks / platforms (oil platforms, ships)

Floating temporary road (transportable and demountable elements)