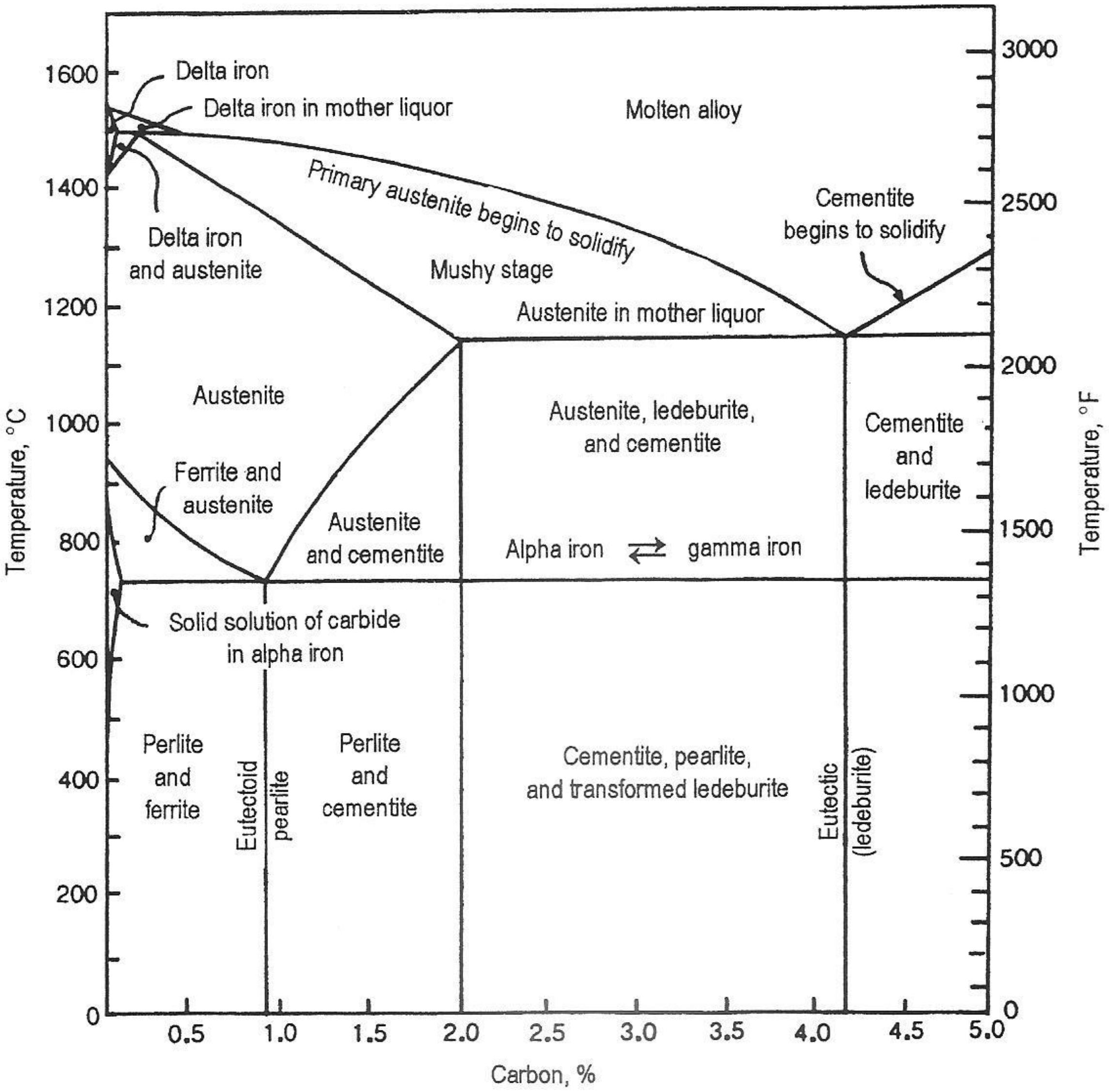
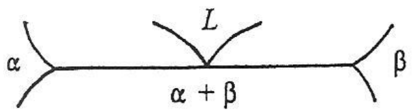
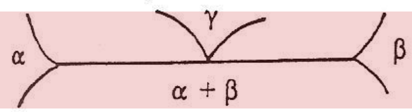
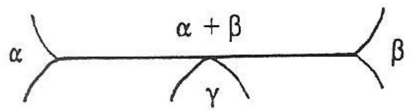
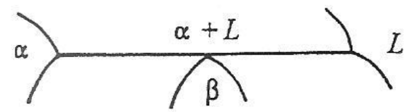
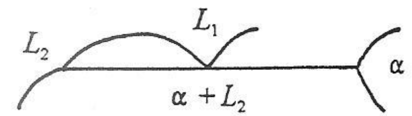
4. Thermo-mechanical processing of car body steels and aluminium alloys for beverage cans

Iron-cementite phase diagram

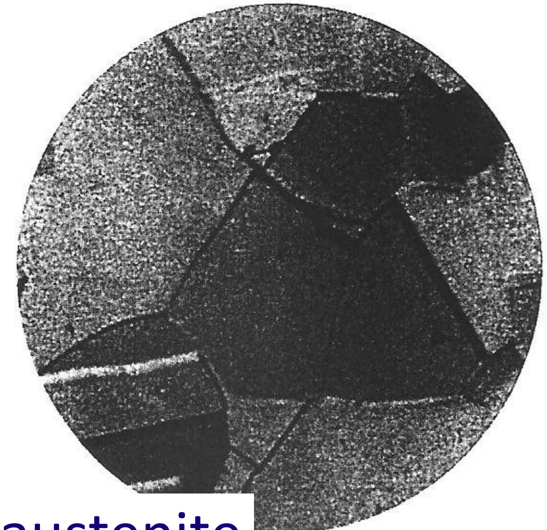


Types of multiphase reactions in metals

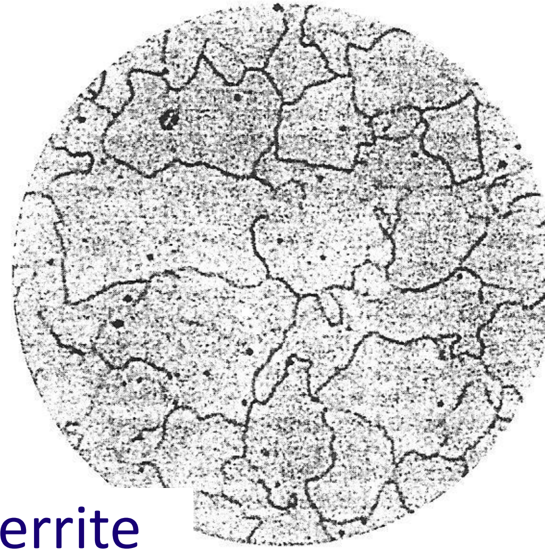
Reaction	Equation	Phase Diagram
Eutectic	$L \rightarrow \alpha + \beta$	
Eutectoid	$\gamma \rightarrow \alpha + \beta$	
Peritectoid	$\alpha + \beta \rightarrow \gamma$	
Peritectic	$\alpha + L \rightarrow \beta$	
Monotectic	$L_1 \rightarrow L_2 + \alpha$	

Types of three-phase reactions in metals

Microstructure of:

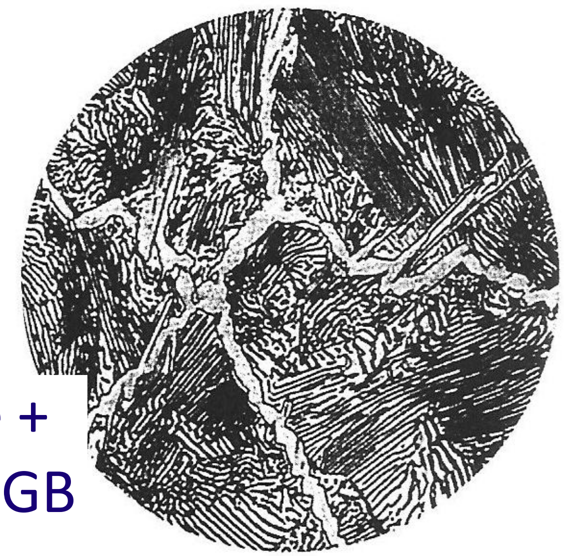


austenite

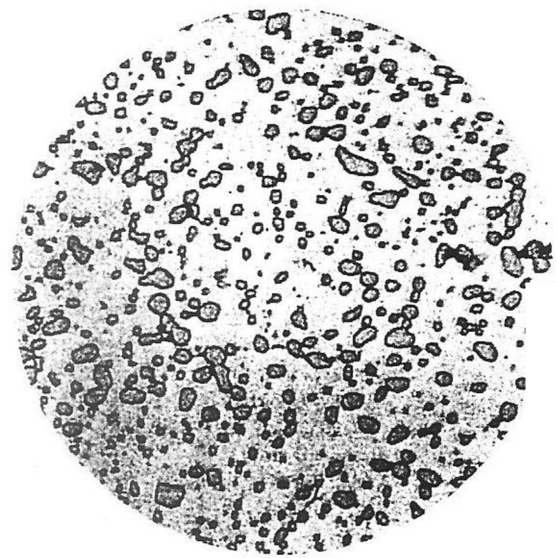


ferrite

Graphite or graphitic carbon in low carbon steel



Perlite + Fe_3C in GB



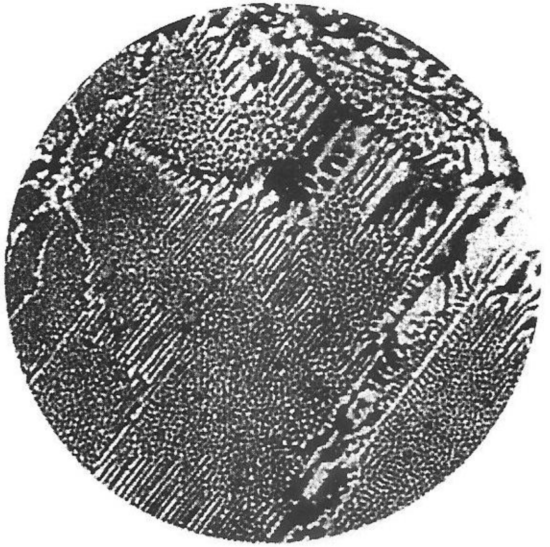
Spheroidized Fe_3C in a matrix of ferrite

Eutectoid *vs.* eutectic transformation

ferrite + Fe_3C

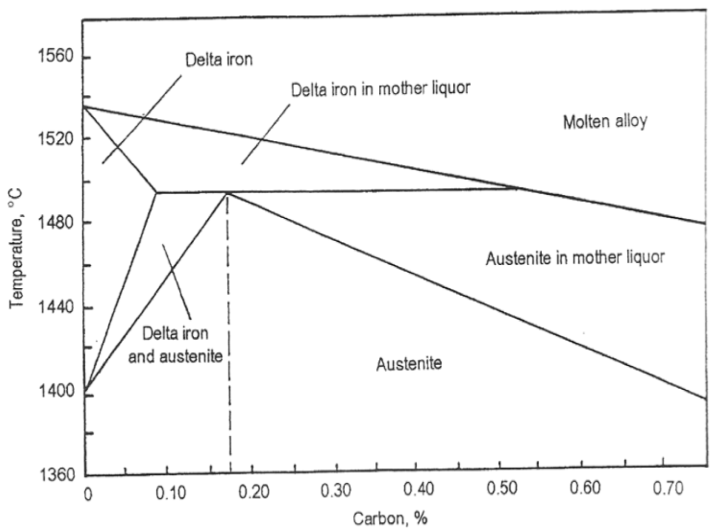
Perlite

Austenite + Fe_3C

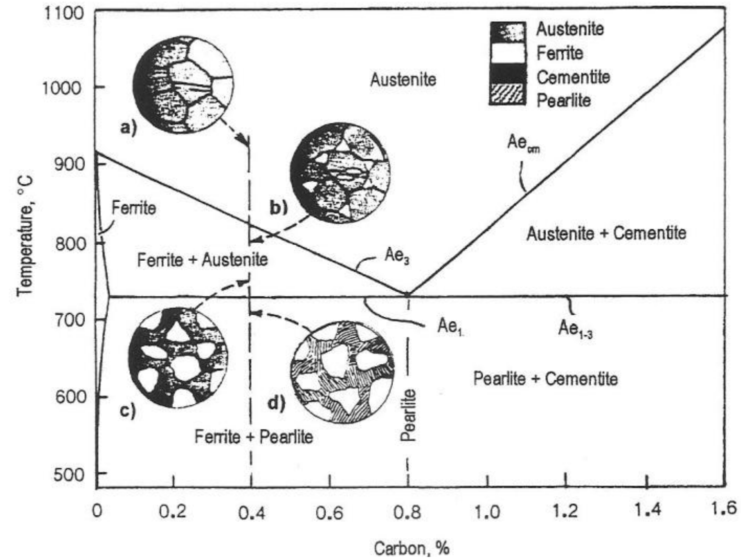


ledebutite

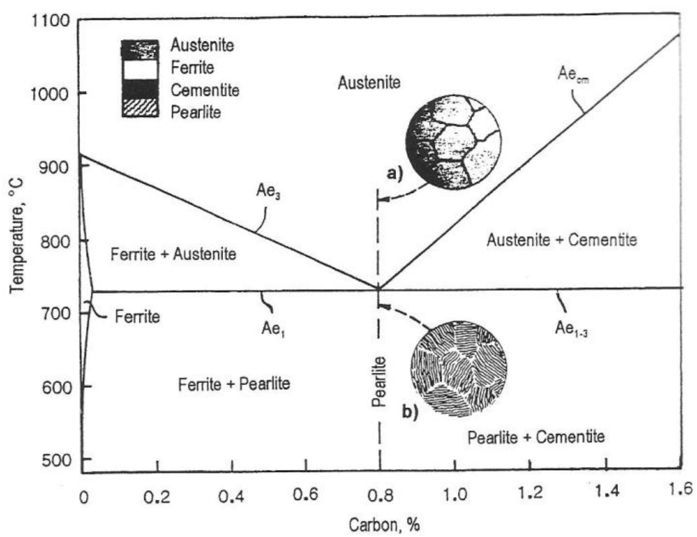
Multiphase reactions in steels



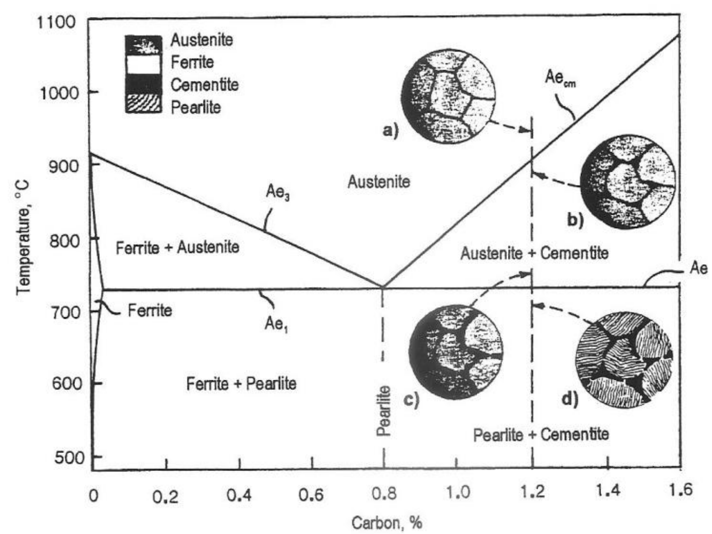
Phases in peritectic steels



Phases in hypoeutectoid steels

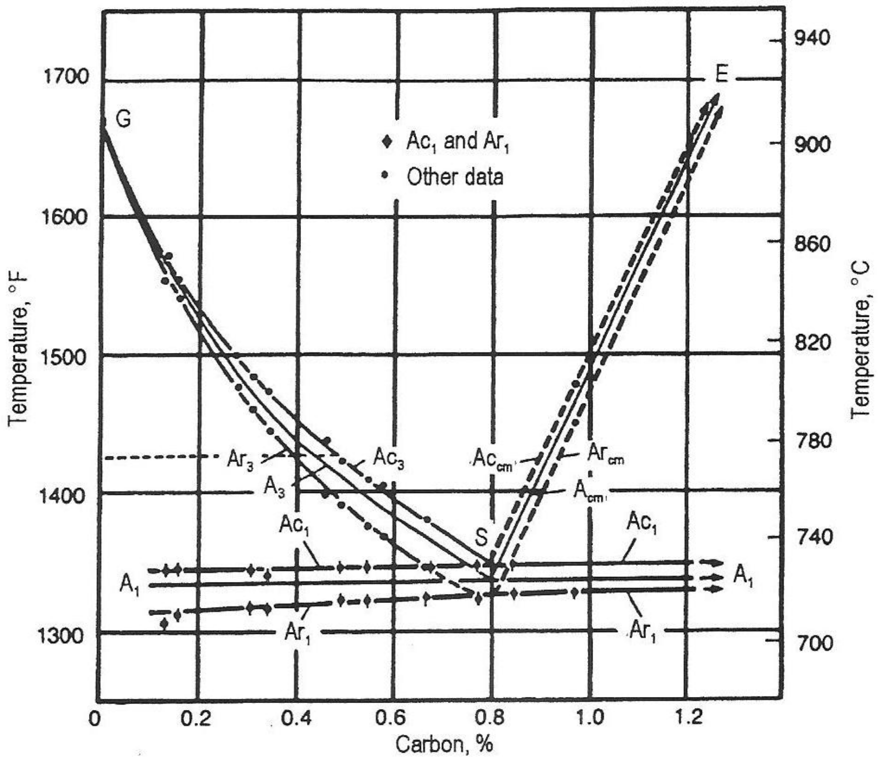


Phases in eutectoid steels



Phases in hypereutectoid steels

Phase transformation hysteresis



Phase transformations do not occur at the same temperature in heating as in cooling.

- In heating, the Ac temperatures are somewhat higher than equilibrium temperatures Ae.
- On cooling the Ar temperatures are lower than equilibrium temperatures Ae
- The difference in temperature between the Ac and the Ar can vary in some cases as much as 24C.

Austenite transform to perlite when it is cooled slowly below the A*r* critical temperature.

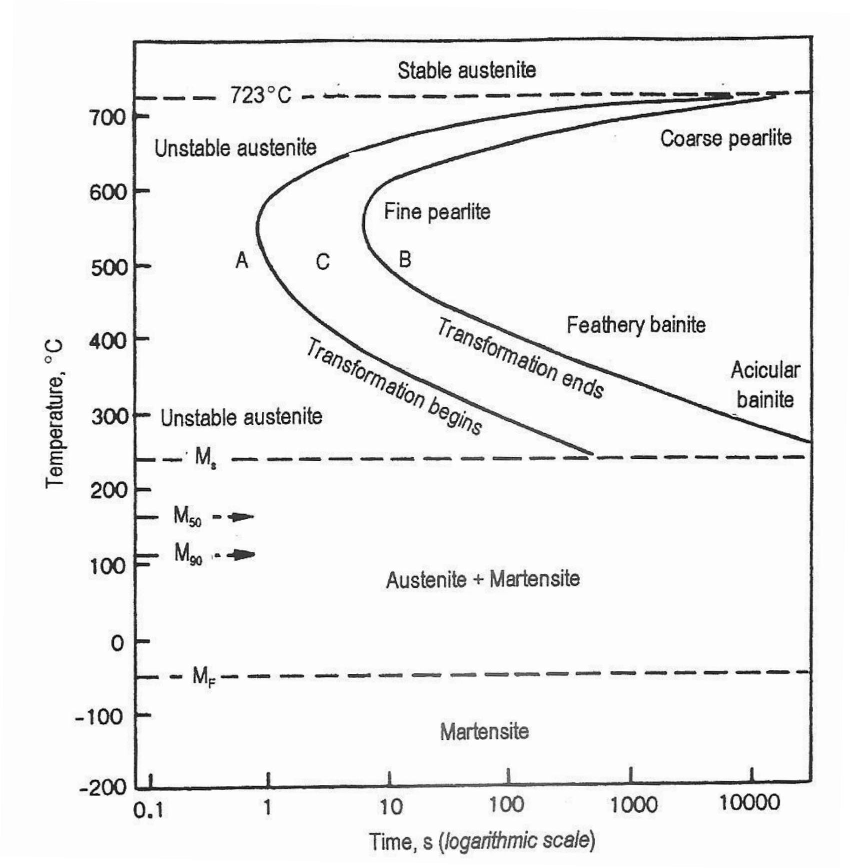
When austenite is more rapidly cooled, however, this transformation is retarded.

As the cooling rate is increased, the transformation temperature is lowered which results in the formation of the micro-constituents that are shown in table w

Constituents	Temperature Range
Pearlite	705 to 535°C (1300 to 1000°F)
Bainite	535 to 230°C (1000 to 450°F)
Martensite	Below 230°C (450°F)

Constituents formed during supercooling of austenite

Time-Temperature-Transformation

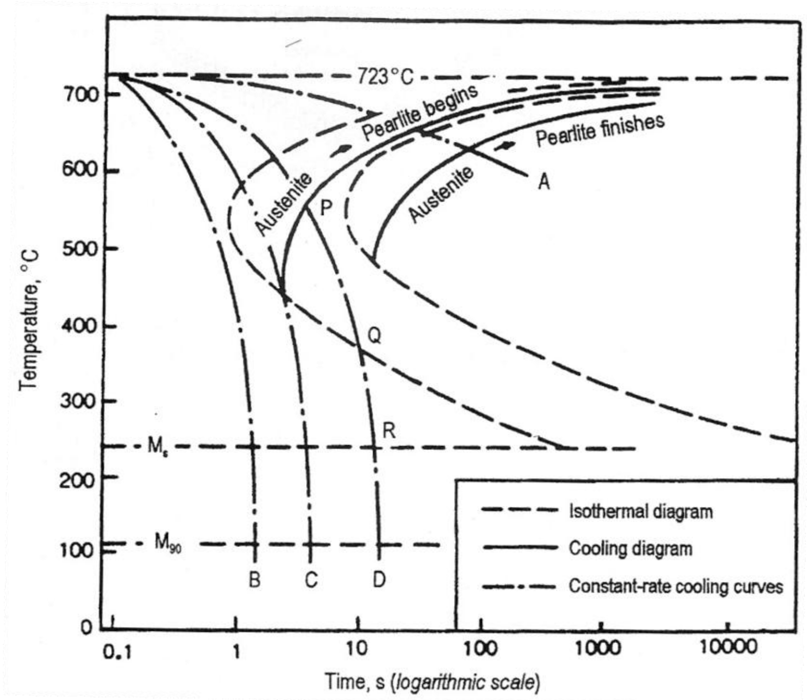


Isothermal Transformation Diagram

Cooling rates:

A-5ºC, B-400º,D-50ºC

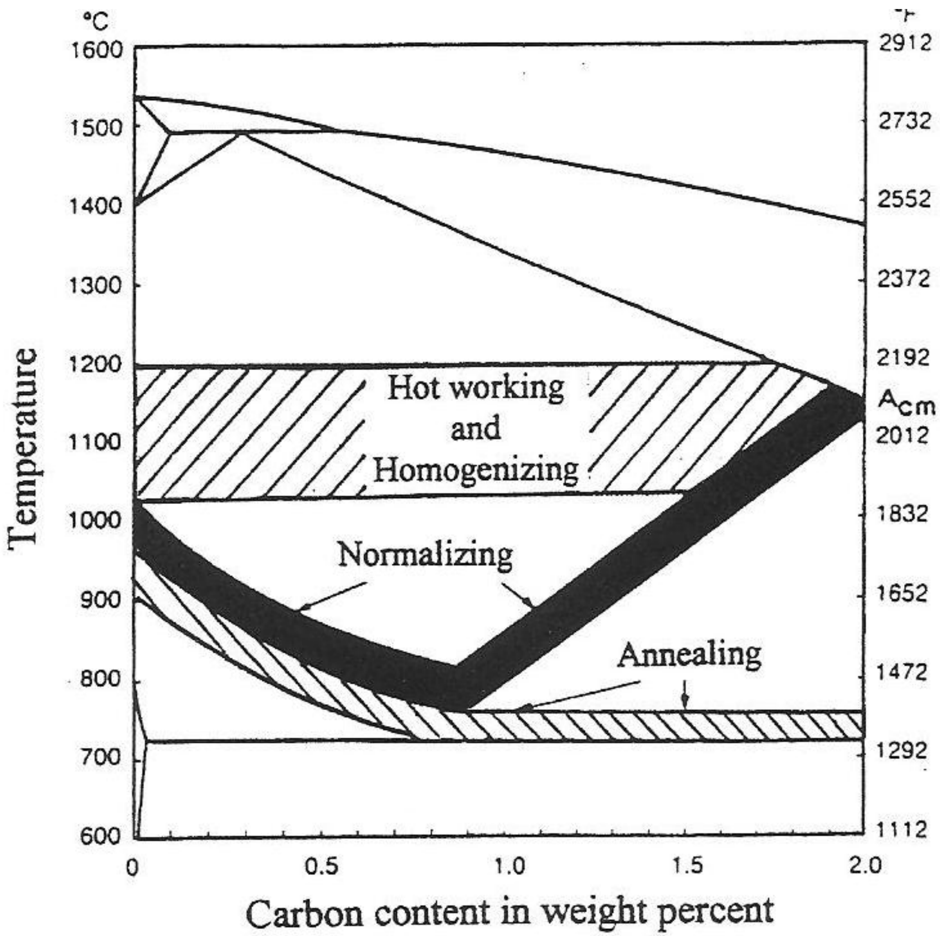
C-critical cooling rate, i.e. minimal cooling rate that must be maitained to obtain a completely martensitic microstructure



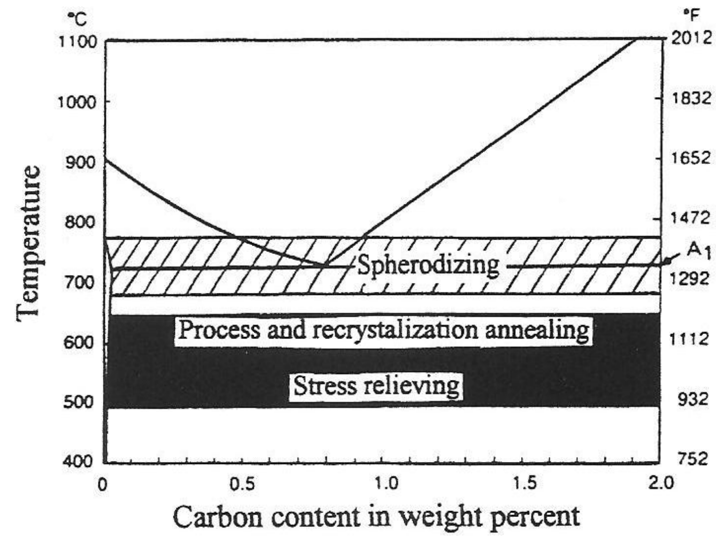
Continuous-cooling Transformation Diagrams

Types of heat treatment

Portion of the Fe-C diagrams showing temperature ranges for:



full annealing, normalizing, hot working and homogenizing



Process & recrystallization annealling stress relieving and spheroidizing

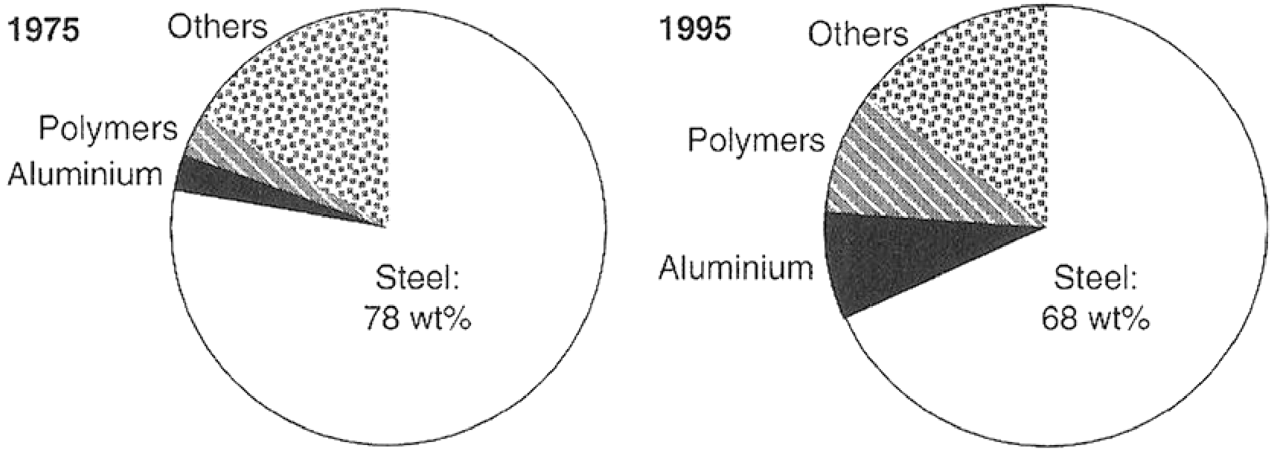
Heat Treatment Process	Microstructure
Full annealing	Ferrite and pearlite
Isothermal annealing	Ferrite and pearlite
Normalizing	Ferrite and pearlite
Spheroidizing	Ferrite and carbide
Quenching and tempering	Tempered martensite
Martempering	Tempered martensite
Austempering	Bainite
Dual-phase	Ferrite and martensite

Microstructures produced by major heat treatment process

Thermo-Mechanical Processing of Steels

Steel for car body applications

Steel for car body applications



Weight fraction of different materials in standard passenger car

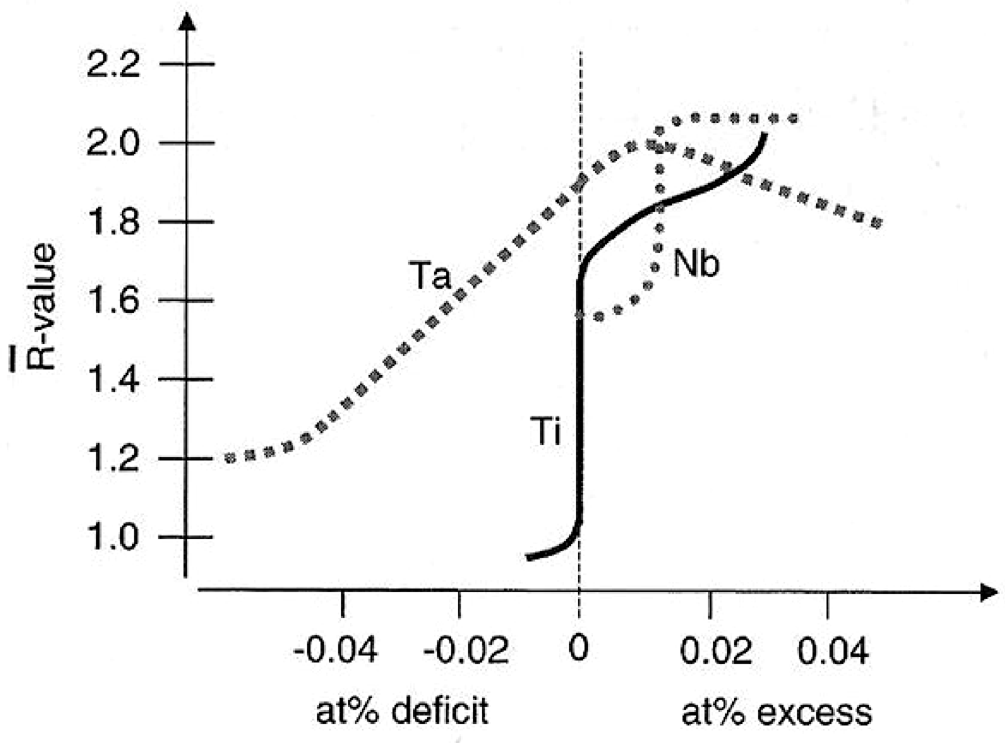
Factors that decides about formability of sheets:

- The langford coefficient ($\bar{R}$) – deep drawibility
- The planar anisotropy (ΔR) – earing
- The strain hardening coefficient (n) – resistance to strain localization

Texture control (anisotropy and good drawibility) is crucial

Steel for car body applications

Interstitial-free steels



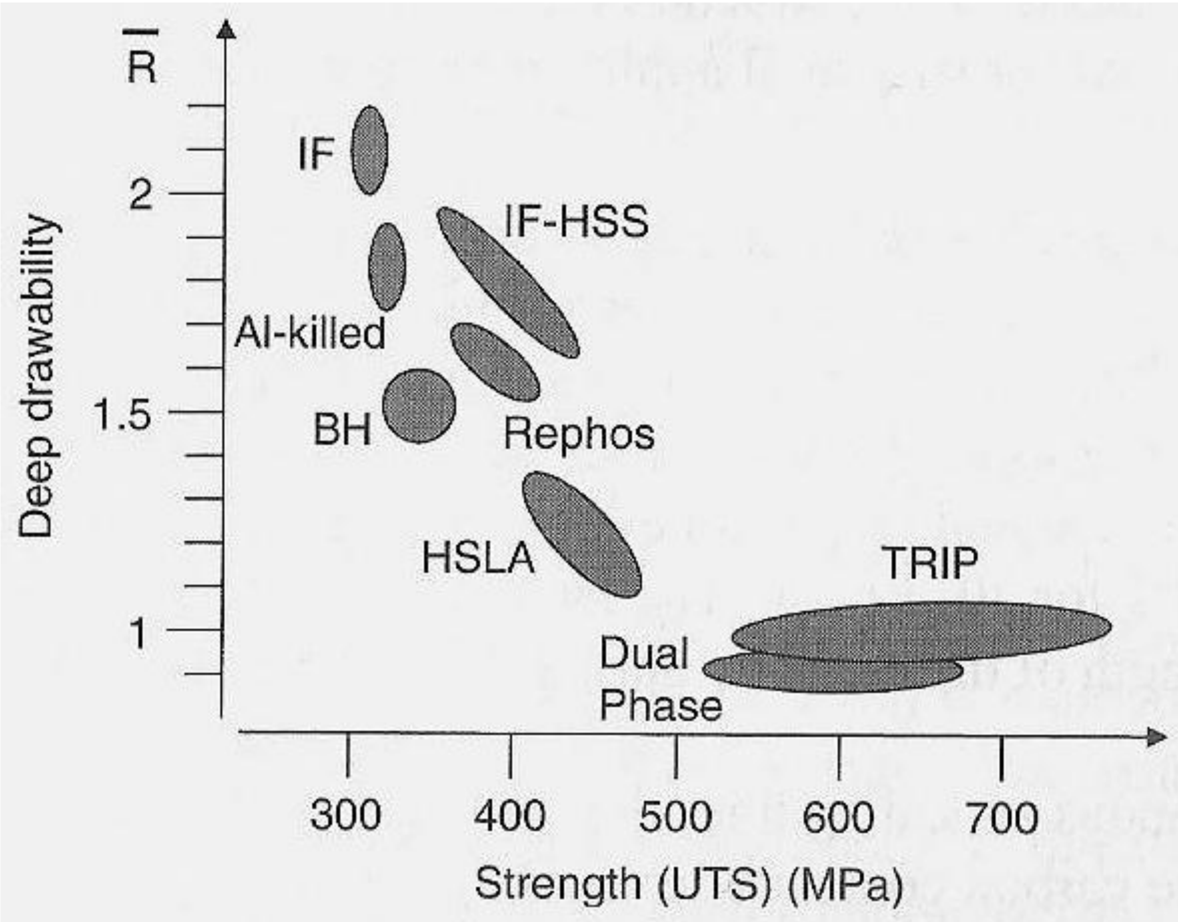
The larger the $\bar{R}$ value the better deep drawibility

The problem with these steels is to obtain a fine grain size after hot rolling

The influence of Ti, Ta, Nb content on $\bar{R}$-value (normal anisotropy coefficient). The graph shows the deficit excess in at% of the alloying elements relative to the C+N content

Steel for car body applications

low carbon steels



IF-interstitial-free steels

Strenght increase:

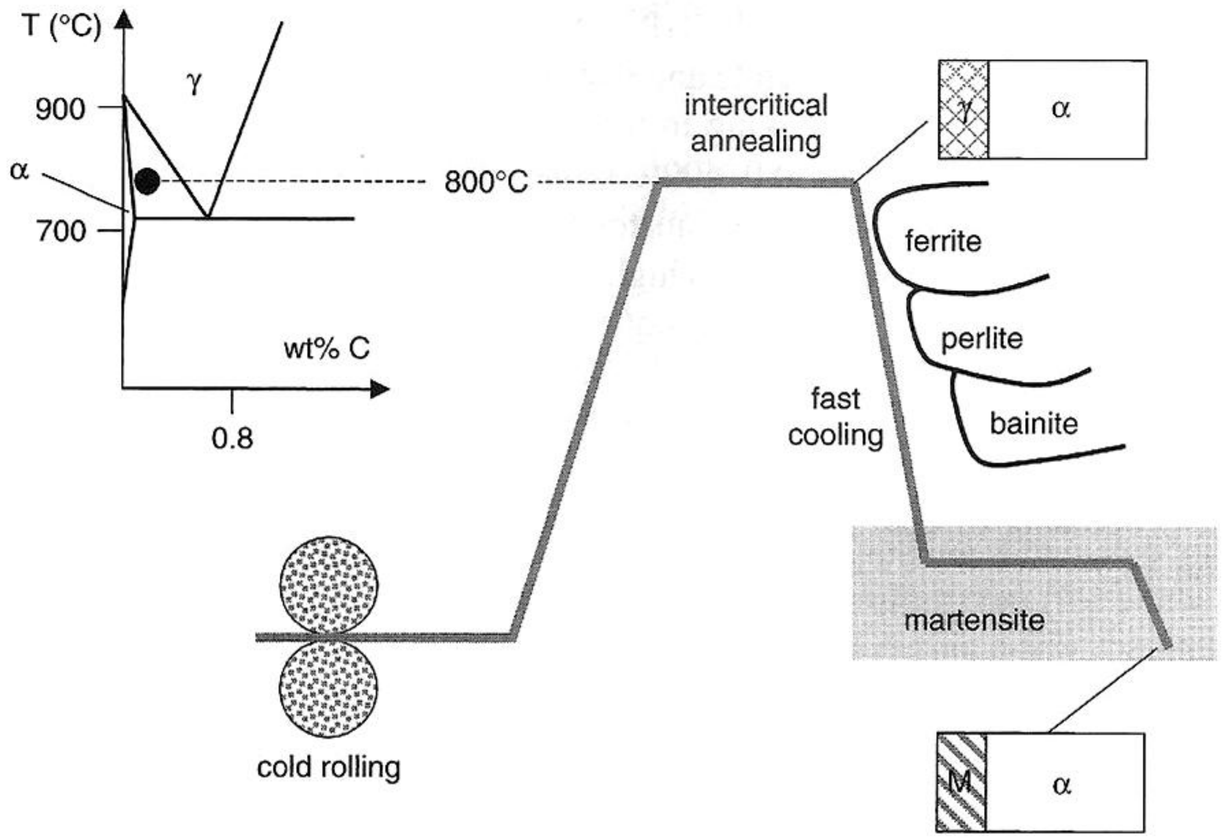
IF-HSS – IF high strenght steels (+ Nb, Ta & Ti)
BH – bake hardening steels
Rephos – rephosphorised steels (P-0.04-0.08%)
HSLA-high-strenght low-alloy steels (+ Nb & Ti)
DP-**D**ual **P**hase (ferrite + 10-20% martensite)
TRIP-**TR**ansformation-**I**nduced **P**lasticity ferrite, bainite & retained austenite).

Deep drawibility as a function of the ultimate tensile strenghth (UTS) for several steel grades used in car body applications

Steel for car body applications - low carbon steels

Composition and properties of typical **dual phase steel**

Composition in wt%	0.1 C	0.2 Si	0.7 Mn	0.05 P	0.04 Al	0.005 N
Properties	UTS: 600 MPa	YS: 350 MPa		$\bar{R}$: 0.9	El: 27%	



Ferrite + 10-20% austenite

Ferrite + 10-20% martensite

Processing of dual phase (DP) steel by cold rolling and two-step annealing treatment

Steel for car body applications - low carbon steels

Composition and properties of typical **TRIP steels**

Steel	C	Si	Al	Mn	P	S	N	Reference
1.5 Si	0.11	1.50	0.04	1.53	0.008	0.006	0.0035	Girault *et al*. [2001]
0.8 Si	0.12	0.78	0.04	1.51	0.010	0.006	0.0035	Girault *et al*. [2001]
Si–Al	0.115	0.49	0.38	1.51	0.003	0.009	0.030	Jacques *et al*. [2001]
1.5 Al	0.110	0.06	1.50	1.55	0.012	0.007	0.017	Jacques *et al*. [2001]

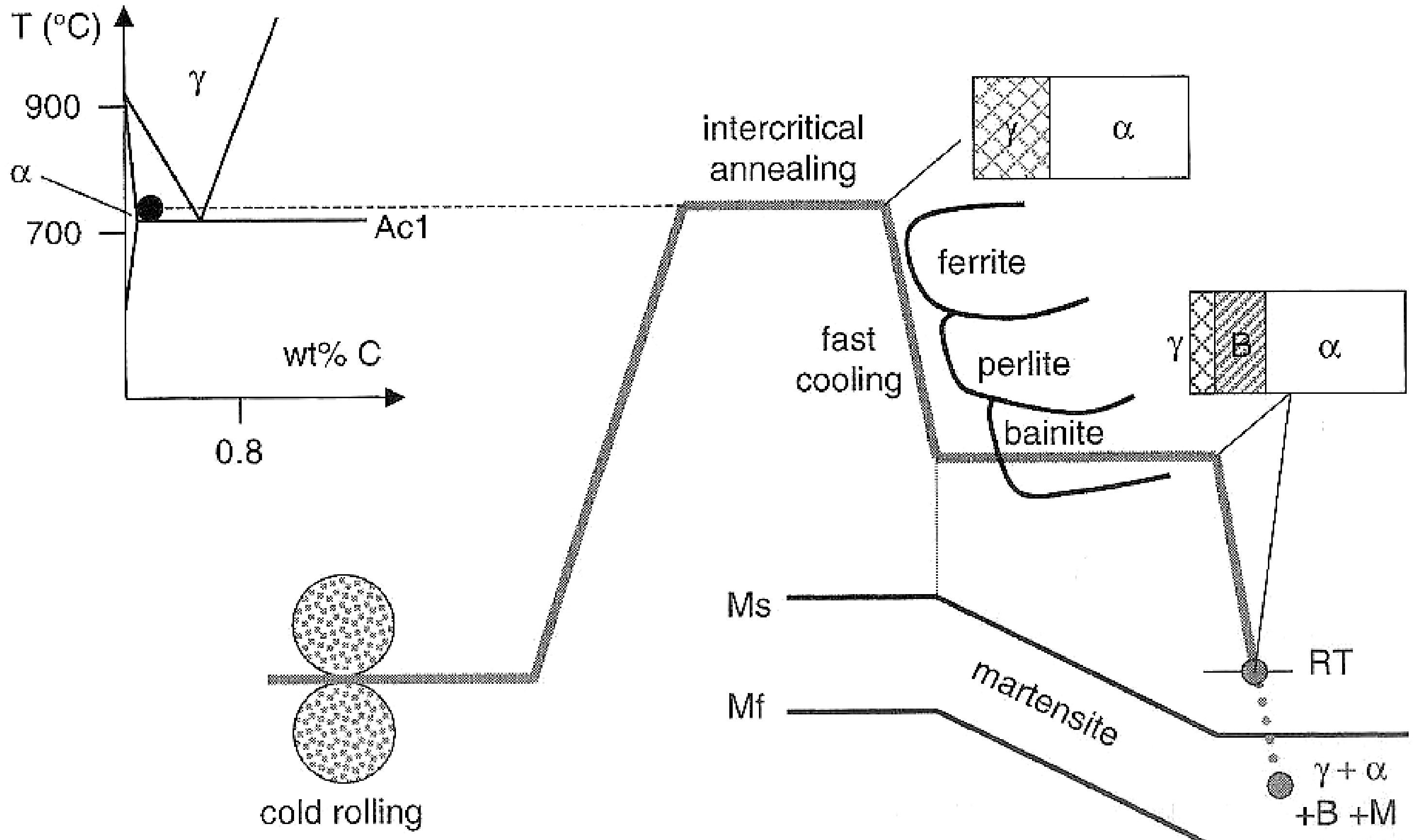
TRIP steels can be considered as a further development of dual phase grades.

Starting structure – mixture of ferrite and austenite (high temperature annealing -1st) → fast cooling

Final structure – austenite, ferrite, bainite (formed during low temperature annealing - 2nd) and martensite (formed during further rapid cooling to room temp.)

Steel for car body applications - low carbon steels (~0.1%C)

TRIP steel – cold rolling route



Processing scheme and structural evolution during the two-step heat treatment of TRIP steel

Steel for car body applications - low carbon steels (~0.1%C)

TRIP steel

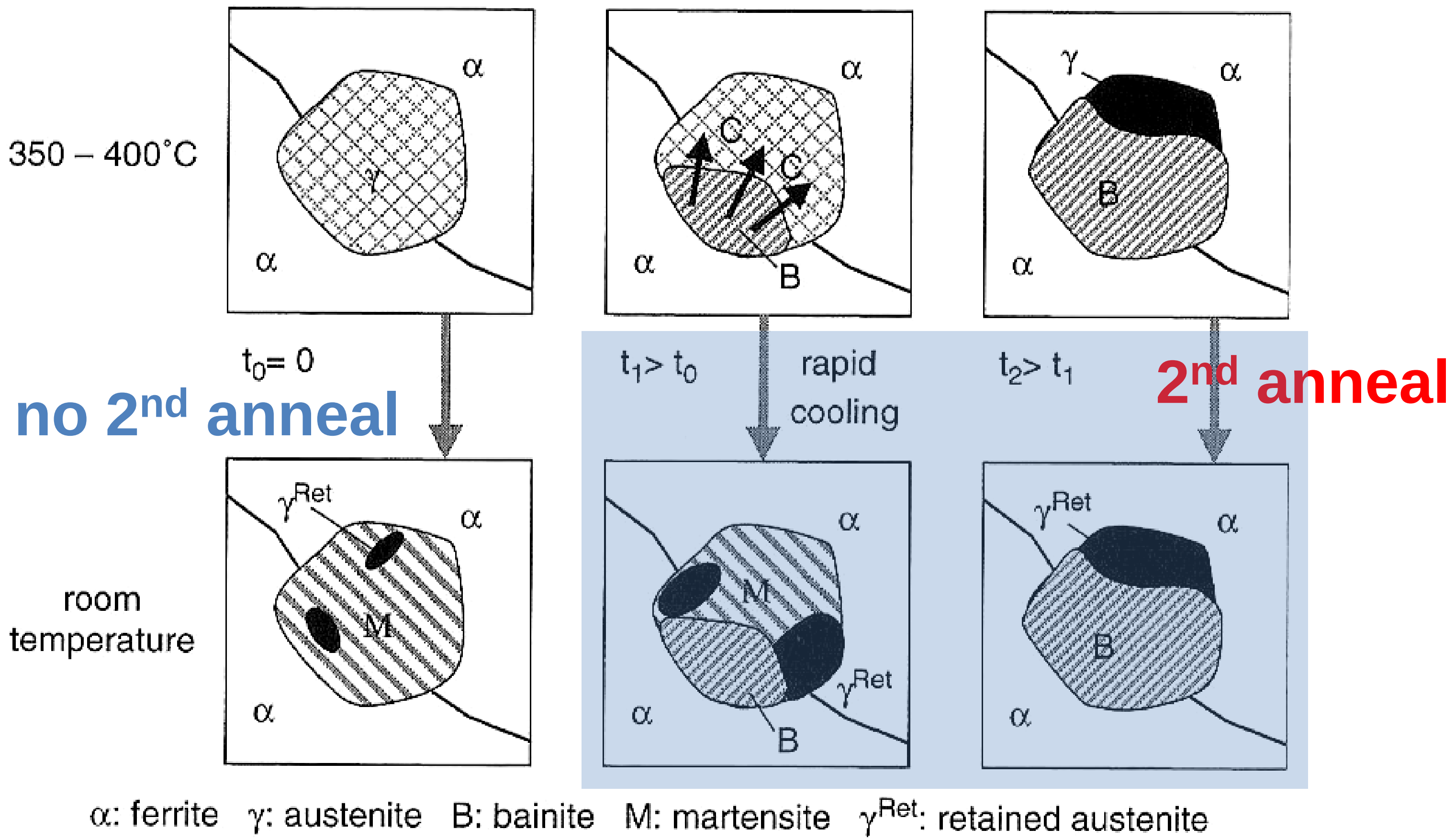
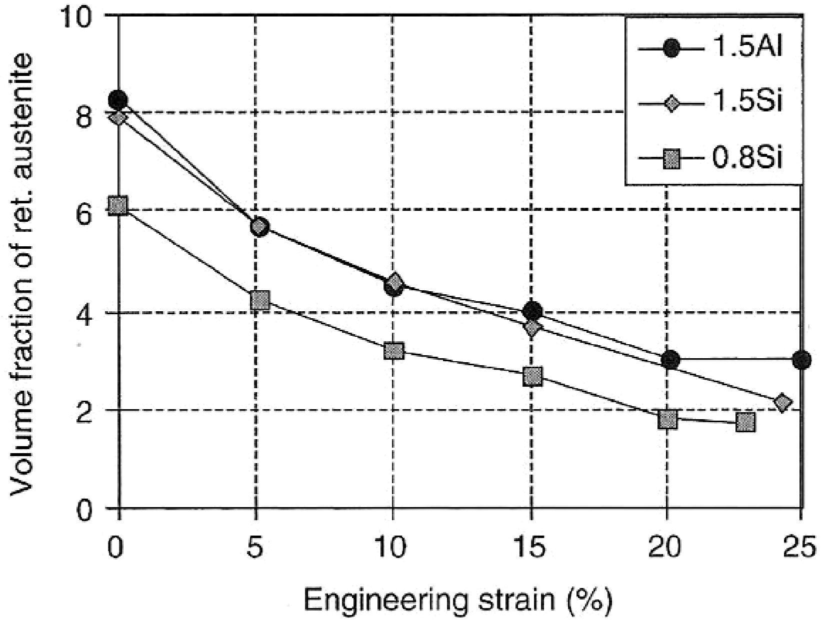


Illustration of the structural changes in TRIP steel during the second isothermal treatment (above) and transformation products after rapid cooling

Steel for car body applications - low carbon steels (~0.1%C)

TRIP steel – hot rolling route

- Hot rolling in the austenite region or in the intercritical (α+γ) region and cooled (quench finish temperature ~400ºC),
- During annealing in the bainite region the residual austenite will partially transform into bainite, and the rejected carbon stabilize retaining austenite,
- After further cooling some austenite will be retained at RT



'Consumption' of retained austenite during a uniaxial tensile test

Steel for car body applications - low carbon steels (~0.1%C)

TRIP steel

Compilation of mechanical properties of some selected TRIP steels

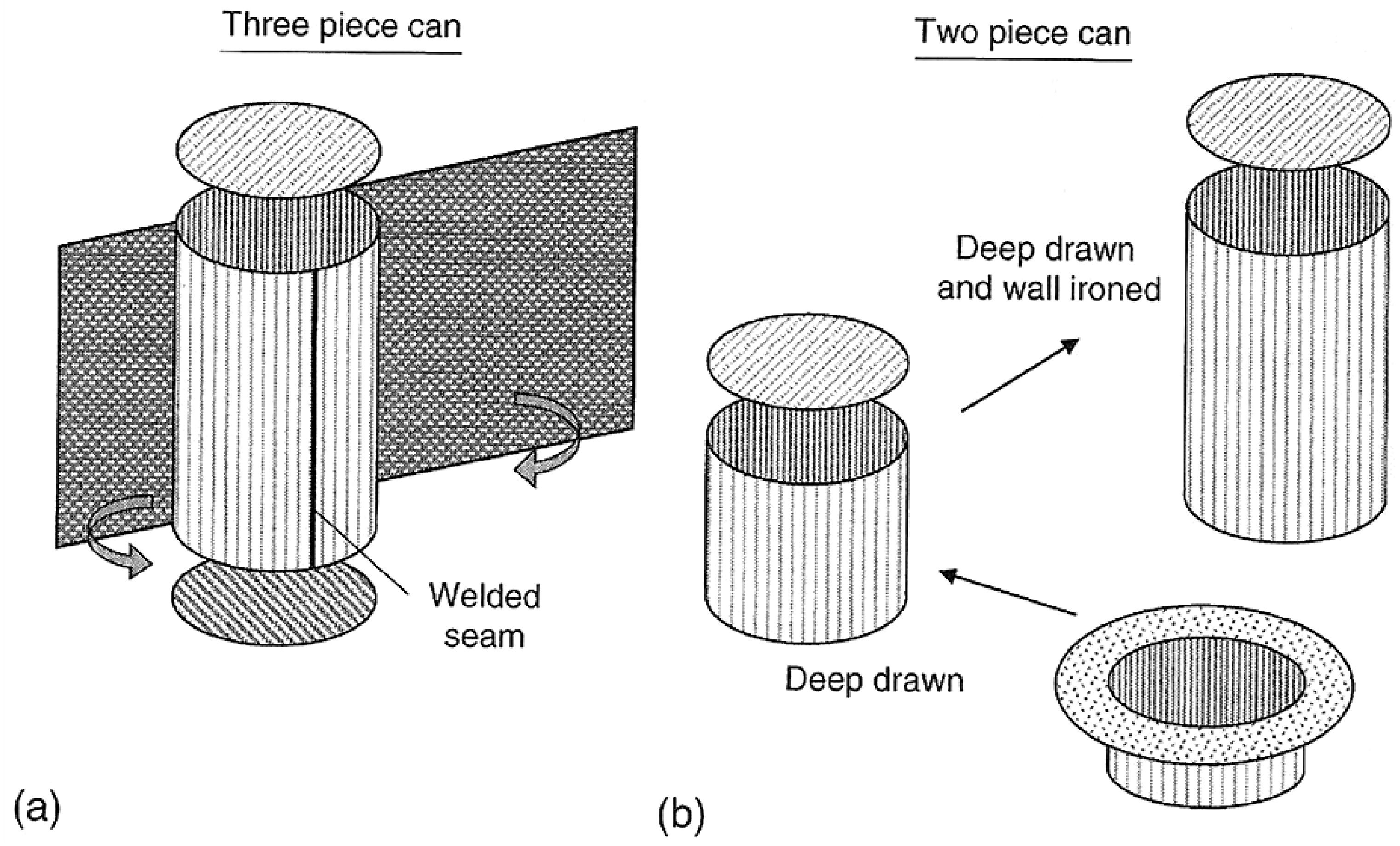
Type	C (wt%)	Si (wt%)	Mn (wt%)	YS (MPa)	UTS (MPa)	ε_{total} (%)	Lüders strain	n (5–15%)	$\bar{R}$	LDR	UTS × ε_{total}
IF	0.006		0.12	133	298	51	0	0.24	2.1	2.34	1.5×10^4
Dual phase	0.10	0.2	0.7	350	600	27	0	0.18	0.9		1.6×10^4
TRIP 0.8 Si	0.12	0.78	1.51	374	635	29	1.1	0.25	1.14	2.20	1.8×10^4
TRIP 1.2 Si	0.11	1.18	1.55	339	614	35	Yes	0.244	0.86		2.2×10^4
TRIP 1.5 Si	0.11	1.50	1.534	452	698	31	1.5	0.24	1.0	2.24	2.2×10^4
TRIP 1.9 Si	0.14	1.94	1.66	530	890	32	Yes				2.6×10^4

Thermo-Mechanical Processing of Aluminium Alloys

Aluminium beverage cans

Aluminium beverage cans

AA3xxx

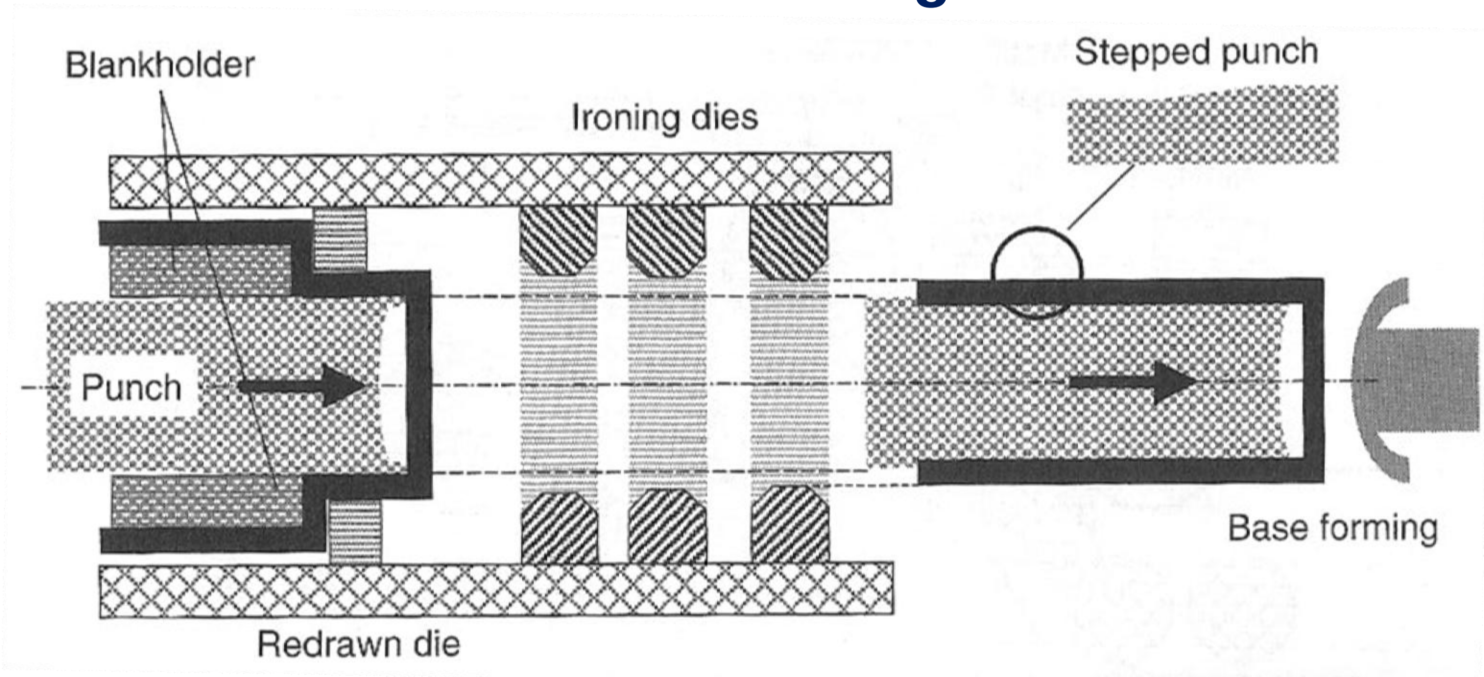


(a) A ‘three-piece’ container with welded seam, (b) ‘two-piece’ container, deep drawn or deep wall ironed

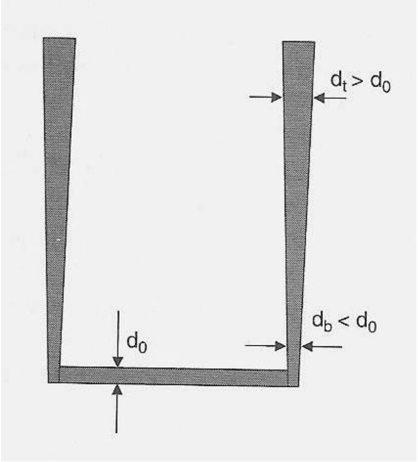
Aluminium beverage cans

- The draw and wall-ironed cup is made of an AA3xxx alloy, in most cases AA3104 (~1%wt.Mn and ~1%wt.Mg,
- The lid – AA5xxx alloy, e.g. AA5182 (4-5%wt. Mg and 0.3-0.4 %wt.Mn
- The pull ring is fabricated from another high-Mg AA5xxx alloy.

Aluminium beverage cans



Scheme of the second deep-drawing pass, the three-wall ironing passes and the formation of a dome-shaped bottom in the 'bodymaker' press.



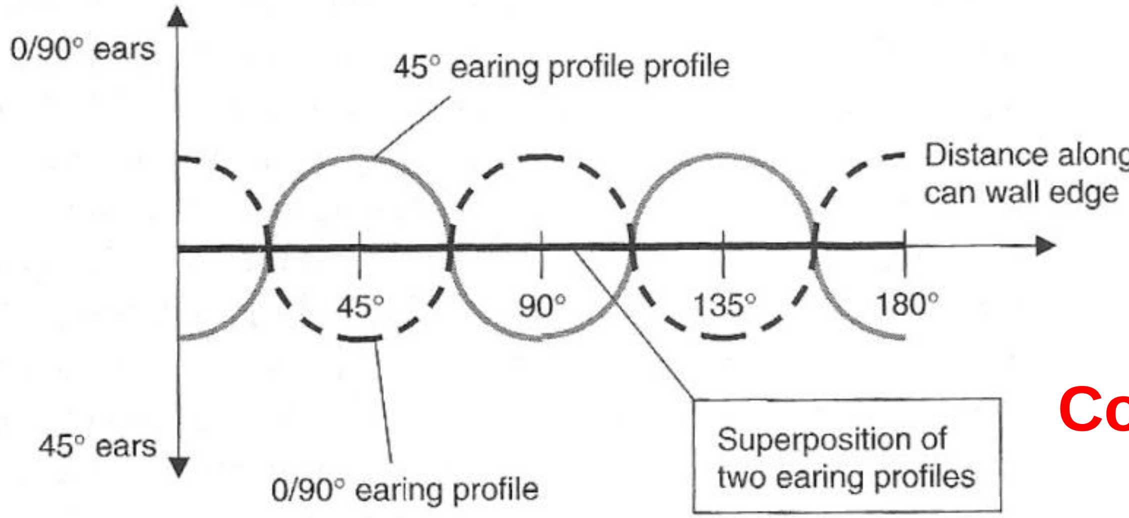
Schematic showing the variation in the wall thickness along the height of the cup. The thickness of the bottom (d_o) is closed to original sheet thickness.

Aluminium beverage cans

Influence of some texture components on earing

Texture component	Name	Earing
{100}<001>	Cube	4 ears; 0/90/180/270°
{110}<001>	Goss	2 ears; 0/180°
{110}<112>	Brass	4 ears; 45/135/225/315°
{112}<111>	Copper	4 ears; 45/135/225/315°
{123}<412>	R or S	4 ears; 45/135/225/315°

cube



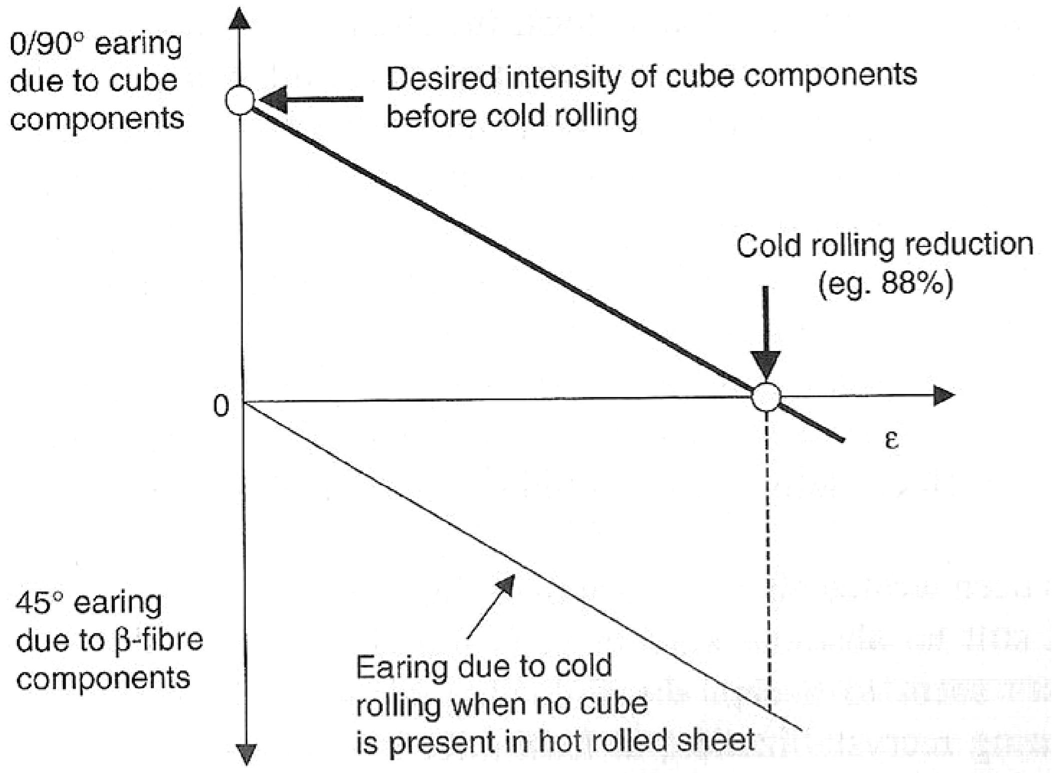
Components of the β-fibre

Illustration of how 45º and 0/90º ears can compensate each other

Aluminium beverage cans

Composition of an AA5182 alloy

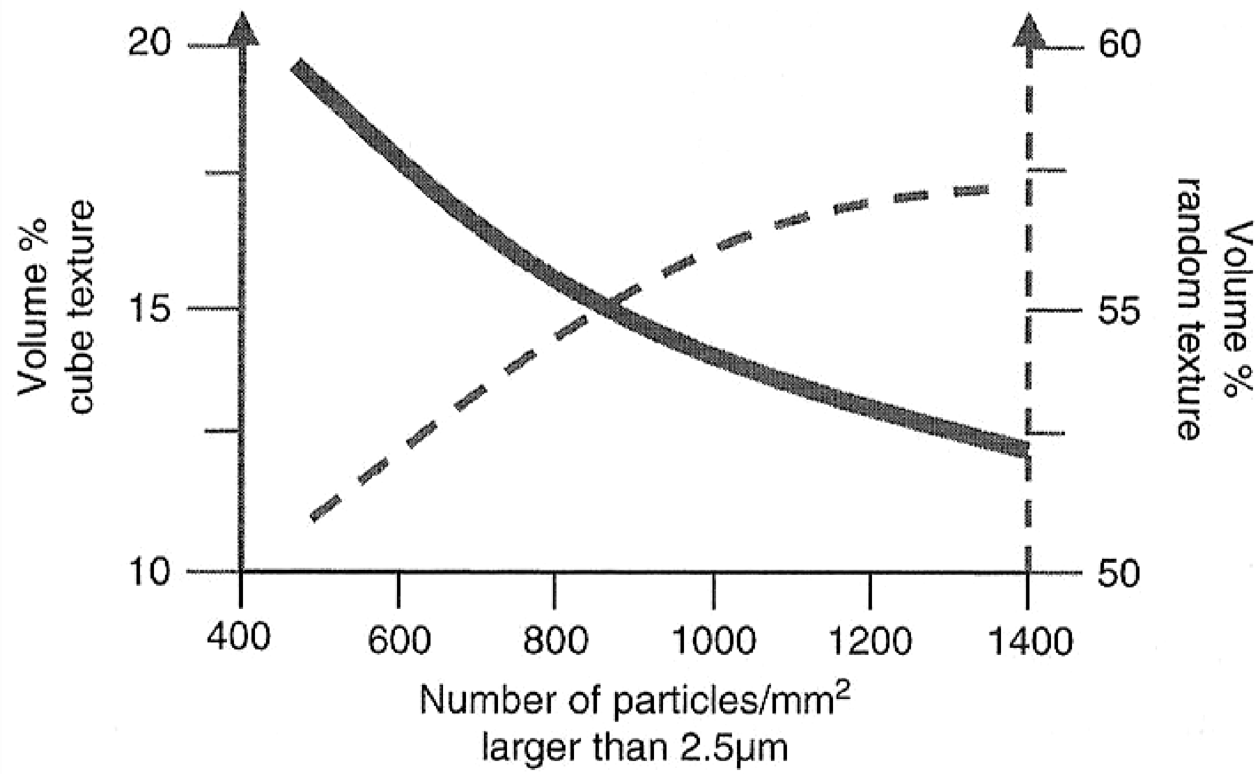
Wt%	Mg	Mn	Fe	Si	Cu	Zn
AA5182	4–5	0.2–0.5	0.20	0.20	0.15	0.25



The 0/90º ears are gradually compensated by the 45º ears as a function of increasing cold rolling

Aluminium beverage cans

Influence of large particles (>2.5 µm) on the texture after hot rolling and recrystallization

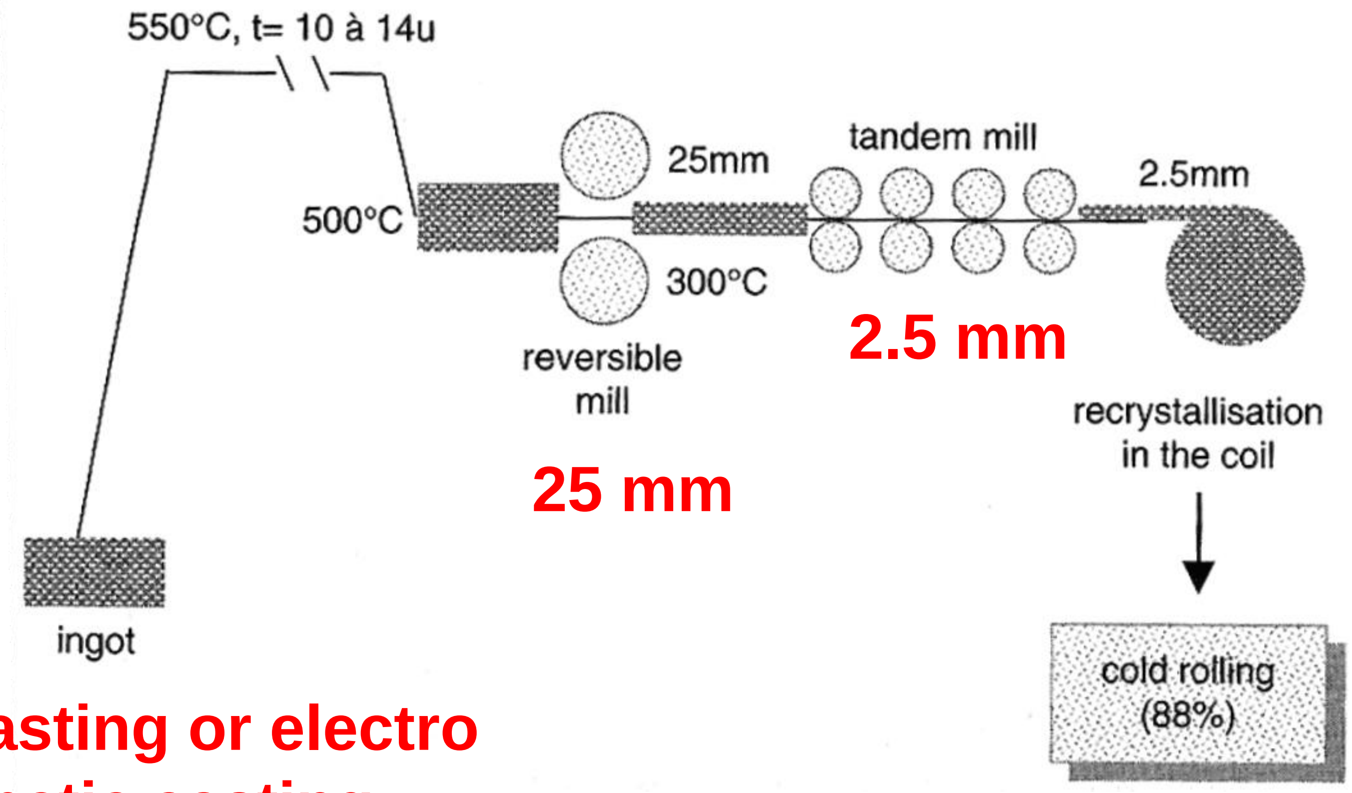


Weaker cube texture due to PSN and smaller grain size

Very large particles can promote fracture during can forming operations

Aluminium beverage cans

homogenization



2.5 mm

25 mm

~0.3 mm

Direct casting or electro magnetic casting (750mm x 180mm)

Typical production scheme for can body sheet