Department of Metallurgical and Materials Engineering

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MSE 4941
Advanced Structural Steels
Lecture 6

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Strengthening Mechanisms

The major strengthening mechanisms can be attributed to:

a) Solid solution strengthening

b) Precipitation or dispersion strengthening

c) Dislocation or substructure strengthening

d) Second phase strengthening

e) Grain size

f) Texture strengthening

HSLA Steels

High-strength, low-alloy (HSLA) steels, or micro alloyed steels, are aimed to provide better mechanical properties and/or greater resistance to atmospheric corrosion than conventional carbon steels.

The HSLA steels in sheet or plate form have low carbon content (0.05 to −0.25% C) in order to produce adequate formability and weldability, and they have manganese content up to 2.0%. Small quantities of chromium, nickel, molybdenum, copper, nitrogen, vanadium, niobium, titanium, and zirconium are used in various combinations.

HSLA Steels

The factors that led to the initial development of micro-alloyed steels, at least up to the late 1960s, were:

a) materials cost savings could be obtained directly by the application of micro-alloyed steels;

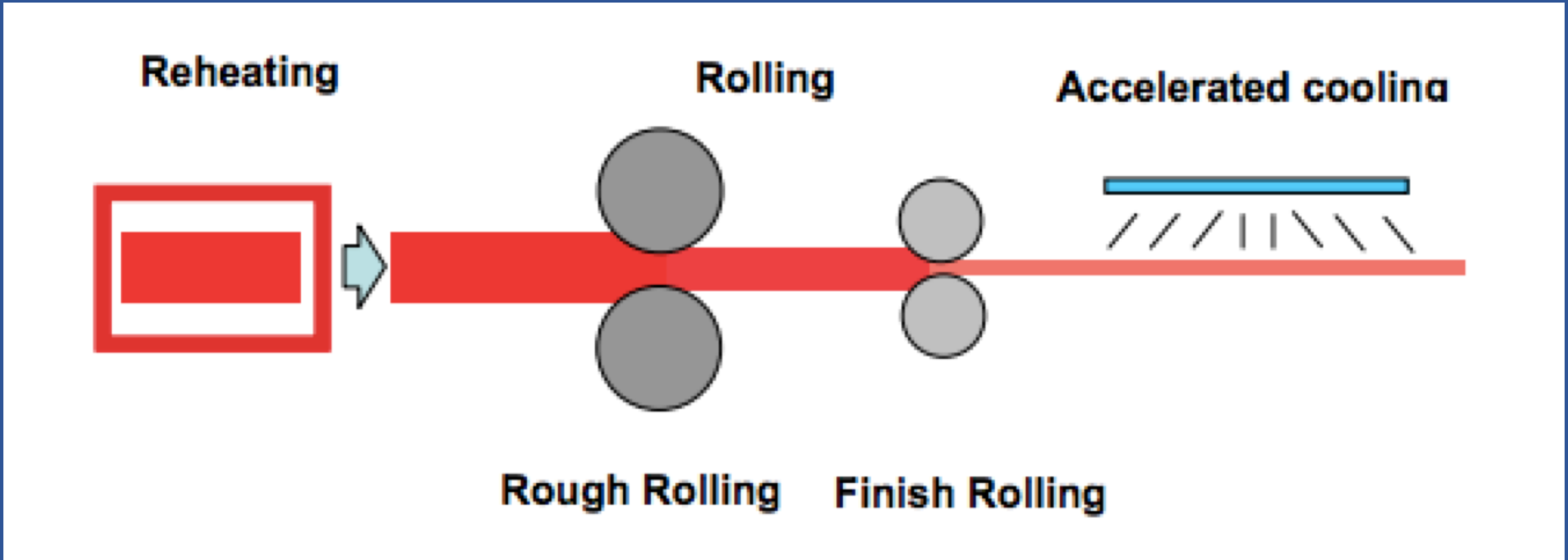
b) in-service benefits could be obtained in the development of lighter goods;

c) the need for a higher strength line-pipe that was easily weldable provided an expanding market for higher-yield-strength steels;

HSLA Steels

d) the extensive use of welding as the principal fabrication method meant that conventional ways of increasing the strength would result in more expensive and much less practicable welding procedures, whilst the new micro-alloyed steels with their generally lower carbon and alloy levels could often be welded using existing procedures;

e) the strength increase could be obtained relatively cheaply, as both niobium and vanadium, are not readily oxidised by steel melt processing.


Reheating
Rolling
Accelerated coolina
Rough Rolling
Finish Rolling

HSLA Steels

Weathering steels, which contain small amounts of alloying elements such as copper and phosphorus for an improvement of the atmospheric corrosion resistance and solid-solution strengthening.

Micro-alloyed ferrite-pearlite steels with very small (generally less than 0.1 %) additions of strong carbide- or carbonitride-forming elements, niobium, vanadium, and/or titanium, for precipitation strengthening, grain refinement, and possibly, transformation temperature control.

As-rolled pearlitic steels, which may include carbonmanganese steels with small additions of other alloying elements to enhance strength, toughness, formability and weldability.

HSLA Steels

Acicular ferrite (low-carbon bainite) steels are lowcarbon (less than 0.05 % C) steels with an excellent combination of high yield strengths (as high as 690 MPa), weldability, formability and good toughness.

Dual-phase steels with a microstructure of martensite inserts dispersed in ferritic matrix and with a good combination of ductility and high tensile strength.

Inclusion-shape-controlled steels with improved ductility and through-thickness toughness due to small additions of calcium, zirconium, titanium or rare-earth elements that change the shape of sulphide inclusions from elongated stringers to small, dispersed, almost spherical globules.

Table 1.1 Statistical summaries of datasets for HSLA steel

Variable	Symbol	Min	Max	Mean	Standard Deviation
Carbon (wt %)	C	0.024	0.077	0.046	0.011
Manganese (wt %)	Mn	0.5	1.72	1.38	0.25
Silicon (wt %)	Si	0.019	0.58	0.405	0.107
Chromium (wt %)	Cr	0	0.85	0.32	0.37
Nickel (wt %)	Ni	0	1.9	0.68	0.65
Molybdenum (wt %)	Mo	0	0.61	0.24	0.25
Titanium (wt %)	Ti	0	0.08	0.02	0.020
Boron (wt %)	B	0	0.0025	0.0013	0.0008
Niobium (wt %)	Nb	0	0.06	0.02	0.02
Copper (wt%)	Cu	0	2.17	1.00	0.70

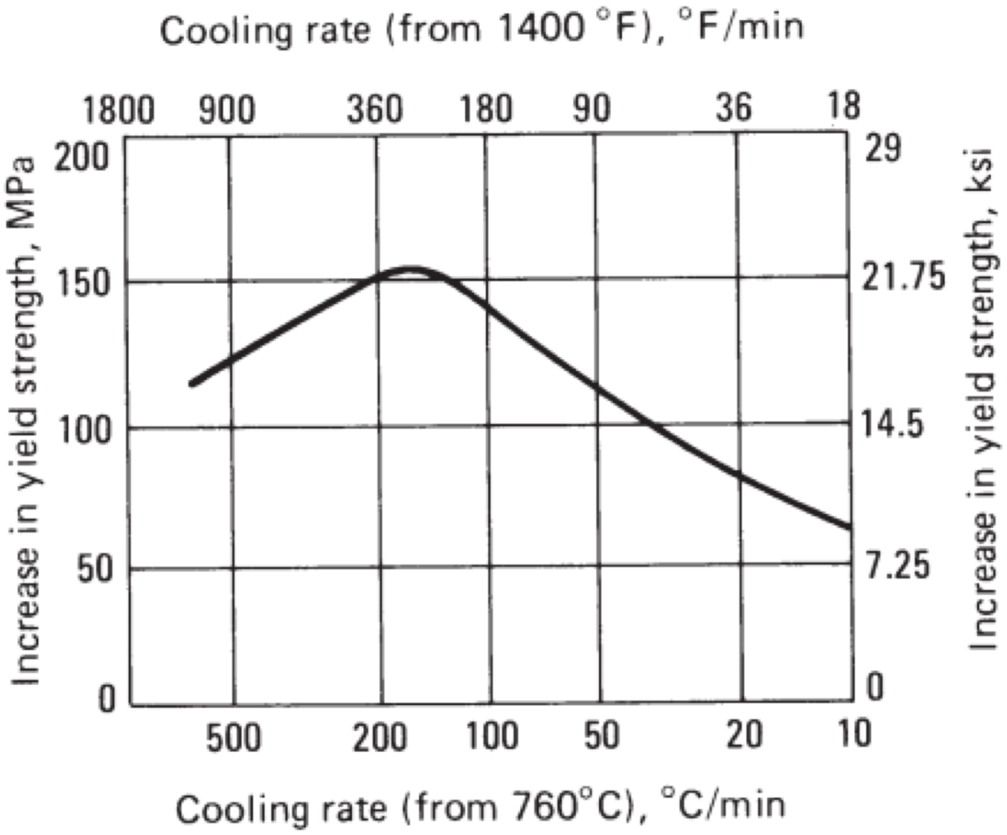


Fig. 1 Effect of cooling rate on the increase in yield strength due to precipitation strengthening in a 0.15% V steel

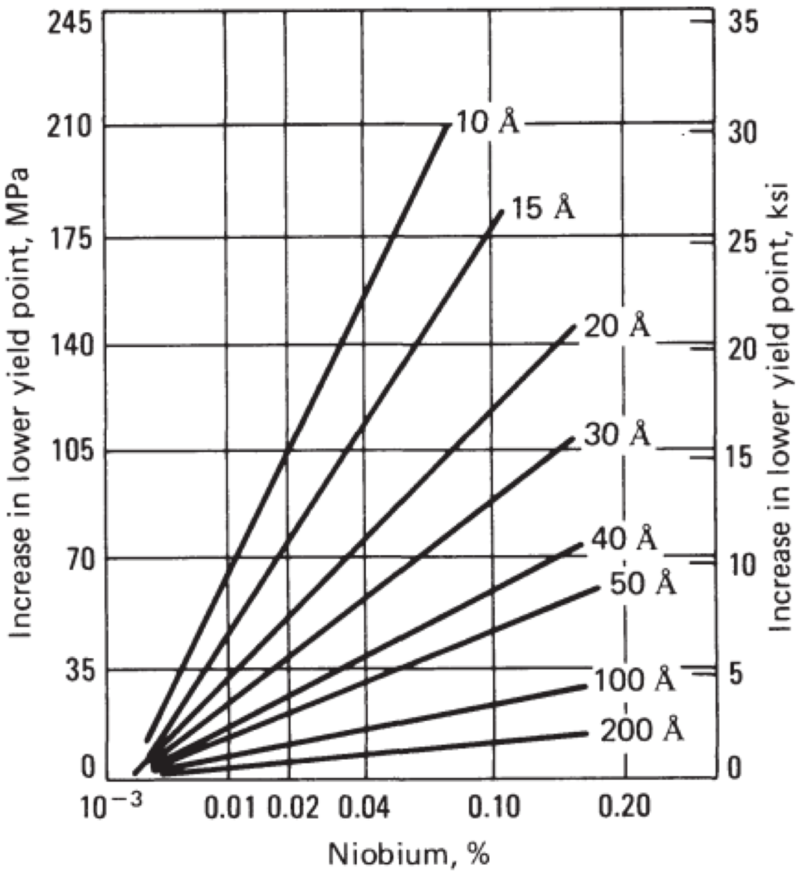


Fig. 2 Effect of niobium carbide on yield strength for various sizes of niobium carbide particles

Dual Phase (DP) Steels

To obtain a homogeneous DP steel microstructure with well-dispersed martensite islands and fine primary recrystallized ferrite, a continuous annealing process is typically applied.

This process includes reheating of the initial cold-rolled ferrite-pearlite or ferrite-bainite microstructure into the range of intercritical annealing (IA) or rapid austenitic annealing, followed by quenching below the martensite start temperature.

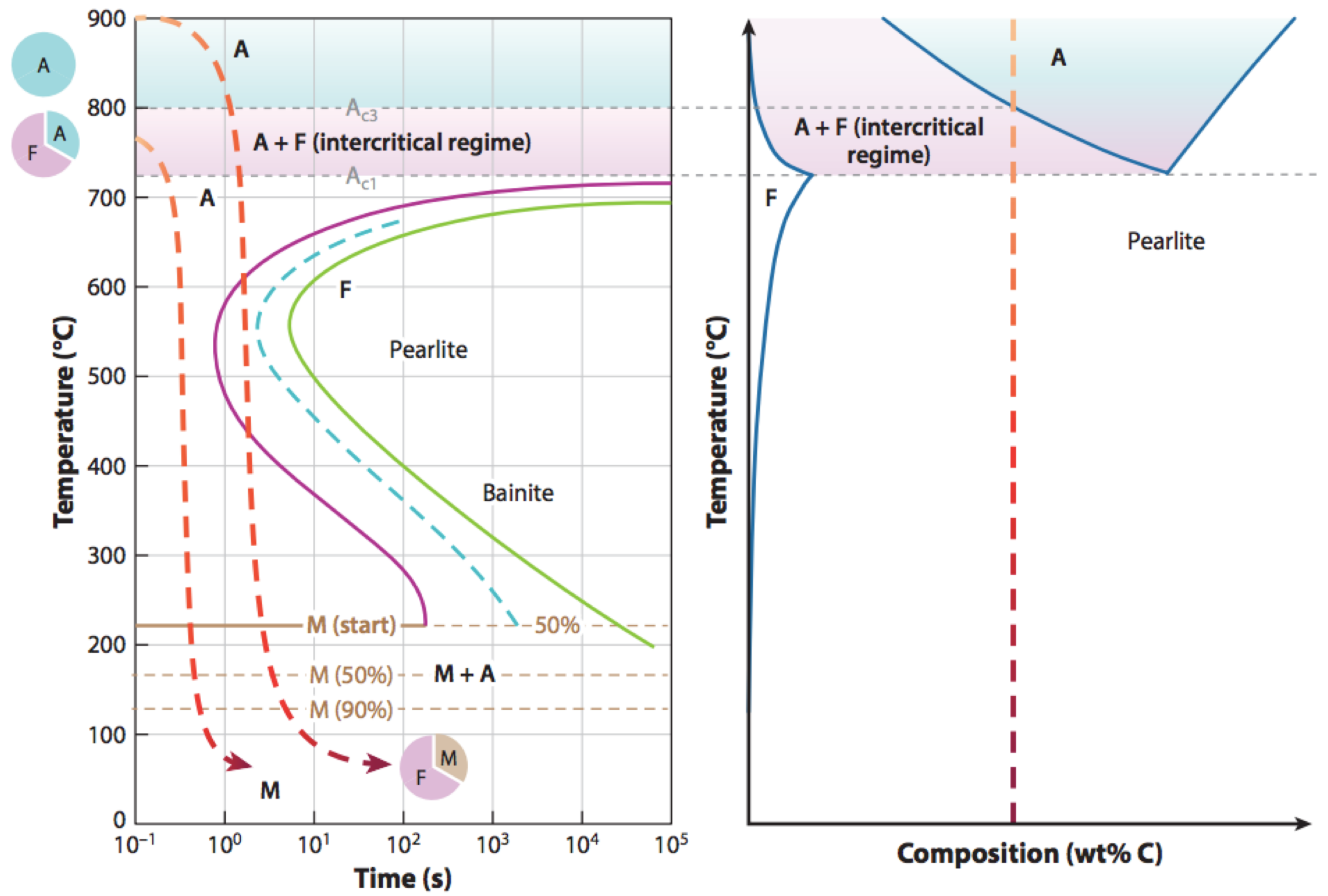
Dual Phase Steels

0.06–0.15-wt% C and 1.5–3% Mn (the former strengthens the martensite, the latter causes solid-solution strengthening in ferrite, and both stabilize the austenite),

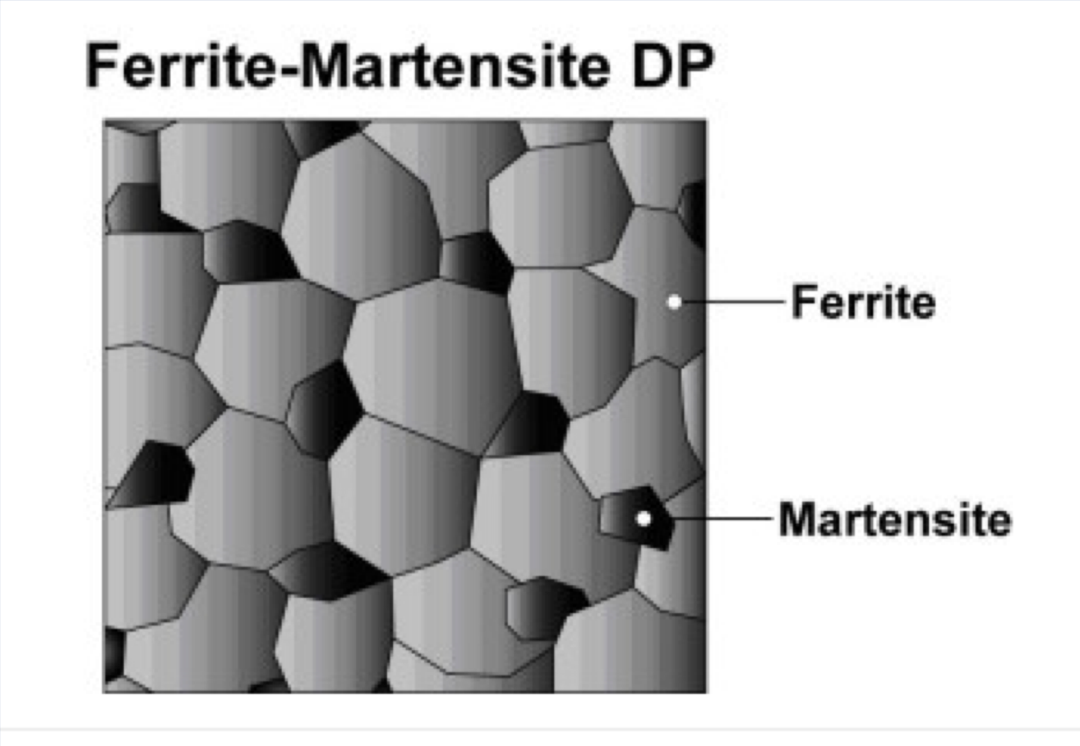
Cr and Mo (to retard pearlite or bainite formation),

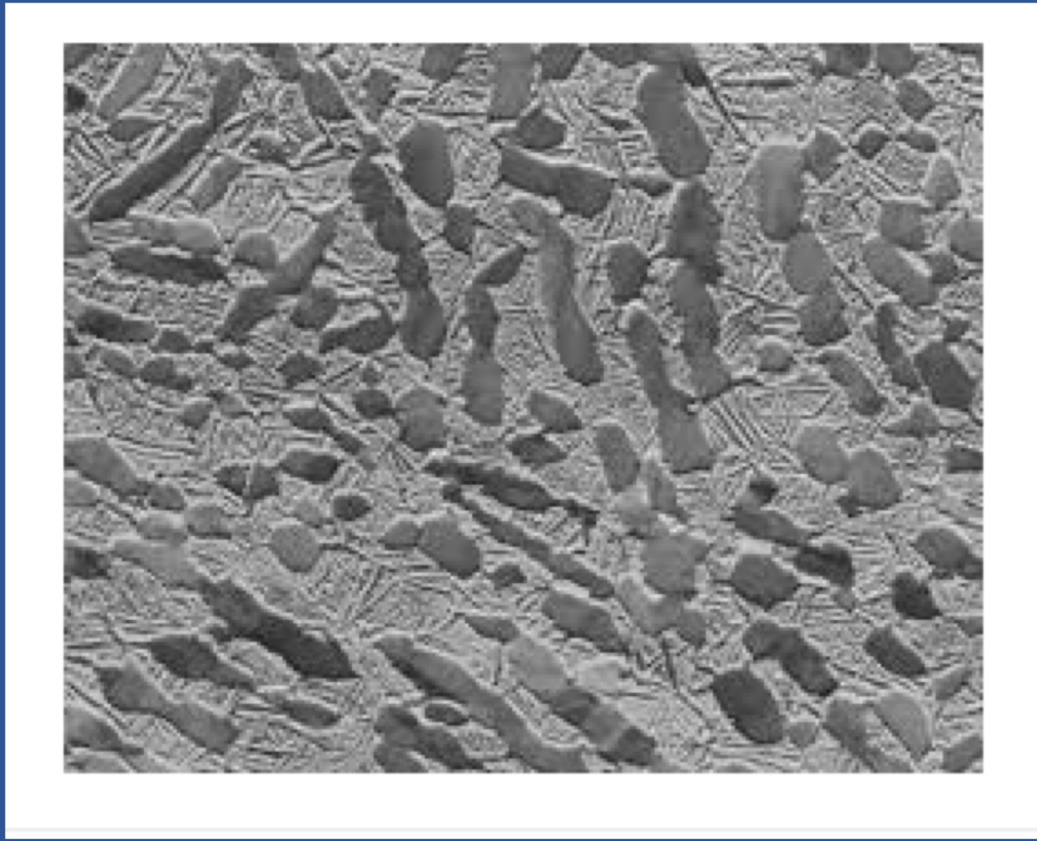
Si (to promote ferrite transformation),

V and Nb (for precipitation strengthening and microstructure refinement).



900
800
700
600
500
400
300
200
100
0
Temperature (°C)
A
F
A
A
A + F (intercritical regime)
A_{c3}
A_{c1}
A
F
Pearlite
Bainite
M (start)
50%
M (50%)
M + A
M (90%)
M
M
F
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
10^{5}
Time (s)
A
A + F (intercritical regime)
F
Pearlite
Temperature (°C)
Composition (wt% C)


Ferrite-Martensite DP
Ferrite
Martensite



Characteristics:

Grade	VDA-Norm	Yield strength $R_{p0,2}$ (MPa)	Tensile strength R_m (MPa)	Elongation A_{80} (%)
HDT550[1]	-	300 – 400	530 – 620	≥ 24[4]
HDT600[1]	HR330Y580T-DP[3]	330 – 470	580 – 670	≥ 24[4]
HCT450X[2]	-	260 – 340	≥ 450	≥ 27[5]
HCT490X[2]	CR290Y490T-DP[3]	290 – 380	≥ 490	≥ 24[5]
HCT590X[2]	CR330Y590T-DP[3]	330 – 430	≥ 590	≥ 20[5]
HCT780X[2]	CR440Y780T-DP[3]	440 – 550	≥ 780	≥ 14[5]
HCT980X[2]	CR590Y980T-DP[3]	590 – 740	≥ 980	≥ 10
HCT980XG[2]	CR700Y980T-DP[3]	700 – 850	≥ 980	≥ 8

DP 300/500	Roof outer, door outer, body side outer, package tray, floor panel
DP 350/600	Floor panel, hood outer, body side outer, cowl, fender, floor reinforcements
DP 500/800	Body side inner, quarter panel inner, rear rails, rear shock reinforcements
DP 600/980	Safety cage components (B-pillar, floor panel tunnel, engine cradle, front sub-frame package tray, shotgun, seat),
DP 700/1000	Roof rails