Government College of Engineering and Research, Avasari(Khurd)

Department: Mechanical Engineering

Learning Resource Material (LRM)

Name of the course: Engineering Metallurgy **Course Code:** 202048

Name of the faculty: J. M. Arackal **Class:** SE(Mech)

SYLLABUS(Unit 5)

Unit V: Engineering Alloy Steels & designation (4 Hrs) Classification of alloy steels & Effect of alloying elements, examples of alloy steels, stainless steels, sensitization & weld decay of stainless steel, tool steels, heat treatment of high speed steel, special purpose steels with applications, super alloys. Heat affected zone. Designation (for plane & alloy steels) : IS, AISI, SAE, DIN etc.

Lecture Plan format:

Name of the course: Engineering Metallurgy **Course Code** 202048

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Unit No	Lecture No.	Topics to be covered	Text/Reference Book/ Web Reference
		UNIT 5: **Engineering Alloy Steels & designation**	
5	1	Classification of alloy steels & Effect of alloying elements, examples of alloy steels, stainless steels	1
5	2	Sensitization & weld decay of stainless steel, tool steels, heat treatment of high speed steel, special purpose steels with applications	1
5	3	super alloys. Heat affected zone	1
5	4	Designation (for plane & alloy steels) : IS, AISI, SAE, DIN etc.	1

List of Text Books /Reference Books/ Web Reference

1- *Material Science & Metallurgy For Engineers", Dr. V.D. Kodgire & S. V. Kodgire , Everest Publication.*

2- *Introduction to Physical Metallurgy, Avner, S.H., Tata McGraw-Hill*

Unit V – Engineering Alloy steel & designation

various criteria.

i) Amount of Carbon.
ii) Amount of alloying elements & carbon.
iii) Amount of deoxidation.
iv) Grain coarsening
v) Method of manufacturing.
vi) Depth of hardening
vii) Form & use.

1) On the basis of Carbon.

Eutectoid steel.

Hypoeutectoid steels. | Hypereutectoid steels.

0.008	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2.2
Low Carbon steels		Medium carbon steel		High Carbon steel.						

Plain CS.

Low Carbon steel	0.008 to 0.3 % C
Medium Carbon steel	0.3 to 0.6 % C.
High Carbon steel	0.6 to 2 % C.

A) Low CS – Soft, ductile, malleable, machinable weldable & non-hardened by Heat Treatment.
Good for cold working process (purpose).
rolling, galvanizing, tinning or press work.
Used for wires, nails, rivets, screws, panels, welding rods, ship plates, boiler plates & tubes, fan blades, gears, valves, camshafts, crankshafts, connecting rods, railway axles, fish plates, cross heads, tubes for bicycle & automobiles.

Steels with 0.15 to 0.3 % C are widely used as structural steels. & used in building bars, grills, beams angles, channels etc.

Mild steel is well known in this group &. its requirements as per IS specifications. (IS-226).

	(IS-226)	for structural Steel
C	< 0.23 %.	
YS	– 26 Kg/mm² (min).	– 42.5 kg/mm².
Sulphur	< 0.055 %.	
Phosphorous	< 0.055 %.	
UTS	– 42-56 kg/mm².	42.5 Kg/mm² (minimum)
Elongation	– 23 %.	14.5.

Its used as rolled & air cooled condition (MS)

Microstructure has 25 %. pearlite & remaining ferrite. (MS).

B) Medium Carbon Steels:

Intermediate properties to Low & High. Carbon steels.

They require high cooling rate for hardening & hardness produced after hardening is not so high., they are called shallow hardening type.

They are difficult to cold work &. hence hot work. They are called Machinery steels.

Used for bolts, axles, lock washers, large forging dies, springs, wires, wheel. spokes, hammers, rods, turbine rotors, crank pins, Cylinder liners, railway rails & tyres.

:) High Carbon steels:

Hard, wear resistant, brittle, difficult to machine & to weld, can be hardened by Heat treatment.

Cant be cold worked, & hence hot worked, they are als called tool steels.

used for forging dies, punches, hammers, springs, clips, clutch discs, car bumpers, chisels, vice jaws, shear blades, drills, leaf spring, music wires, knives, razor blades, balls & races of ball bearings. mandrels, cutters, files, wire drawing dies, reamers & metal cutting saws.

On the basis of Alloying Elements & Carbon.

Carbon Content	Total content of alloying element
Low (< 0.3 %)	Low (< 10 %)
Medium (0.3 – 0.6 %).	High (> 10 %)

On the basis of deoxidation

A) Rimmed Steels

A molten steel contains large number of dissolved oxygen & other gases, the solubility of these gases is more in liquid state than in solid state. so during solidification the dissolve gases along with CO tries to go out & gets entrapped.

So the rim of the i's of less carbon. The gases form blow holes; these are removed by machining.
$2C + O_2 \rightarrow 2CO$ (these gases can punture the thin solidified layer).
L so they can't be continously cast.
These steel rapidly coarsen during heating in the austenitic region & hence are not much suitable for forging and carburizing process. [Low CS containing less than 0.15% C are produced in sheet form in rimmed condition].

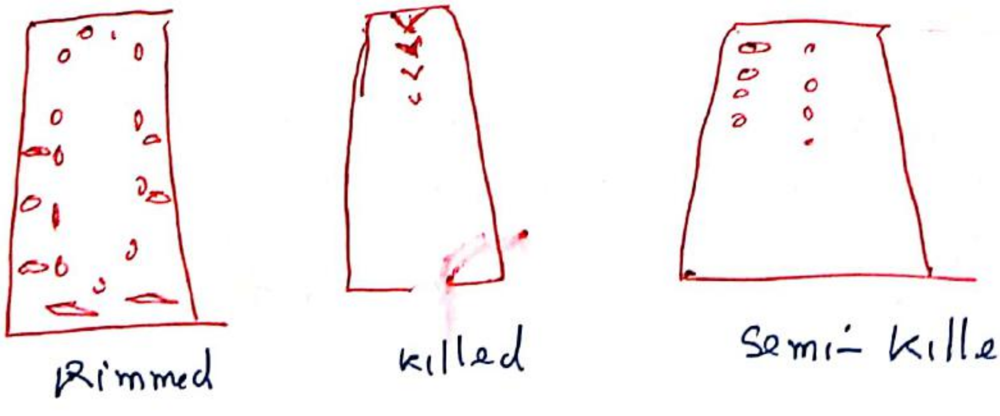
B) Killed steel: Dissolved gases removed by (oxygen) strong deoxidising agents like Al, Si or Mn. In the form of ferro-silicon or ferro-manganese master alloys.

In such steel dissolved oxygen decreases but inclusion increases.

These steels are used for components which have to be forged, carburized or heat treated.

c) Semi-killed steels:

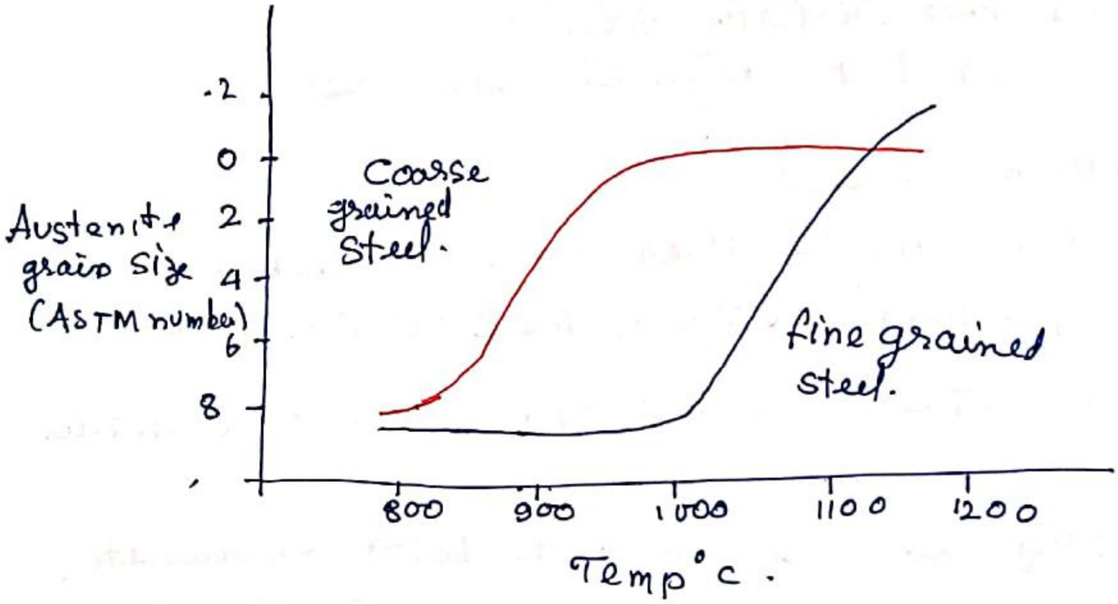
Part of dissolve oxygen is removed, they show intermediate grain coarsening characteristics of rimmed & killed steels. [0.15 to 0.25% C are made as semi-killed steels].



iv) On the basis of grain coarsening characteristics

A) Coarse grained steels.

B) fine grained steels.



V) on the basis of method of Manufacture:

A) Basic open hearth.
B) Electric furnace.
c) Basic oxygen process.
D) Acid open hearth.
E) Acid Bessemer.

vi) on the basis of depth of hardening

Its obtained / based on hardenability. Non-hardenable steels contains less carbon.

A) Non hardenable steels.
B) Shallow hardening steels.
c) Deep hardening steels.

(ii)

VII) on the basis of form & use.

A) Boiler steels : Less than 0.25 % C.

B) Case hardening steels : Less than 0.2 % C.
Suitable for case hardening purpose.

C) Corrosion & heat resisting steels.
Stainless steel & high Chromium steels.

D) Deep drawing steels :
High formidability, used for automobiles bodies, stoves refrigerator etc. [below 0.1 % C].

E) Electric steels : C less than 0.05 %, contain Si.

F) Free Cutting steel : used for nuts, bolts screws etc. (easily machined). They Contain S, P, Se, Te & Pb.

G) Machinery steels : used for automotive & machinery parts, the Carbon content is between 0.3 to 0.55 %.

H) structural steels : Construction of ships, cars, building bridges etc, they contain 0.15 to 0.3 % C.

I) Tool steels : used as tools for machining or cutting of metals & contain more than 0.6 % Carbon.

Specification of Steels

1) Indian standard Designation system

In 1974. the stand was revised to two parts.

Part 1 —. Designation of steel based on letter symbols.

Part 2 — Designation of steel based on numerals.

Designation on basis of mechanical properties.

Fe — Minimum tensile strength (N/mm²)

FeE — Minimum yield strength (N/mm²)

St — Minimum tensile strength (kg/mm²).

StE — Minimum yield strength (kg/mm²)

Its followed by special characteristics covering method of deoxidation, steel quality, degree of purity, surface condition, weldability, heat treatment & low & high temperature properties.

Fe410K — killed steel with minimum TS of 410N/mm².

St 42 — steel with minimum TS of 42 kg/mm²

Fe E 270 — Steel with minimum yield strength of 270 N/mm²

Designation of steels on the basis of chemical composition consist of a numerical figure. indicating 100 times the average % of Carbon content. Letter C is used for plain Carbon & T for tool steels, these letters are followed by a figure indicating 10 times the average percent of Manganese content.

C 20 → 0.2 % C (steel).

C 40 → 0.4 % C (steel).

25C5 → 0.25 % of C with 0.5 % of Mn.

80 T 11 → 0.8 % of C with 1.1 % of manganese.

Symbols 'S', 'Se', 'Te', 'Pb' or P are used to indicate free cutting steels. followed by a figure indicating 100 times the percent content of the respective element.

Alloy steels are designated in symbolic form on the basis of their alloy content along with Carbon Content (100 times %).

The index numbers are rounded off, decimal digit being underlined by a bar,

→ Cr % of 1.60 is represented as Cr 1<u>6</u>

– If Cr content in between 12 & 18 %. is represented as Cr 15.

15 Ni 13 Cr 1 Mo 12 — Steel with average composition 0.15 % C, Ni – 1.3 %, Cr – 1 %, Mo – 0.12 %.

35 S 18 — C – 0.35 %, S – 0.18 %.

35 Mn 1 S 18 — C – 0.35 %, Mn – 1 %, S – 0.18 %.

20 Mn Cr 1 — C – 0.2 %, Manganese – 1 %, Chromium 1 %.

20 Mn 2 — Carbon 0.2 %, Manganese – 2 %.

95 Cr 5 Mo 1 — Carbon 0.95 %, Chromium 5 %, Molybdenum 1 %.

20 Ni 55 Cr 50 Mo 20 — Carbon – 0.20 %, Nickel – 0.55, Chromium 0.50, Molybdneum – 0.20.

T 85 Cr 5 Mo 1 V 30.

Tool steel
C – 0.85, Cr – 5 %, Mo – 1 %, V – 0.3 %.

11) American Iron & Steel Institute (AISI) & Society of Automotive Engineers (SAE).

The method consist of designating the steel with four or five numerical digits. The first from left, indicates the type of steel as follows.

1 - Carbon steels
2 - Nickel steels.
3 - Ni - Cr steels.
4 - Molybdenum steels.
5 - Chromium steels
6 - Cr - V steels.
7 - Tungsten steels.
8 - Ni - Cr - Mo steels (low).
9 - Si - Mn steels.

The second number indicate the approximate percentage of predominant percentage of the alloy (predominant). The last two or three digits divided by 100 usually indicate average percent of carbon in the steel.

2440 -

- 40 → $\frac{40}{100} = 0.4\ \%\ C.$
- 4 → 4% of Nickel
- 2 → Nickel steel

9260 -

- 60 → $\frac{60}{100} = 0.6\ \%\ C.$
- 2 → 2% of Silicon
- 9 → Si - Mn Steels.

1040 -

- 40 → $\frac{40}{100} = 0.4\ \%\ C.$
- 1 → carbon steels

In addition AISI specification may include aletter prefix to Indicate the manufacturing process of that steel as below:

A - Basic open hearth alloy steel.

B - Acid bessemer carbon steel.

C - Basic open hearth carbon steel.

D - Acid open heart carbon steel.

E - Electric furnace steel.

(iii) British Standard Designation System-

Its known as En series (Emergeny number) It has no correlation with composition or even mechanical properties.

En 01 → C-0.7 to/0.15 . Mn-0.8 to/.2 other S-0.2/0.3 P-0.07 Si-0.10

Engineering Alloy steels.

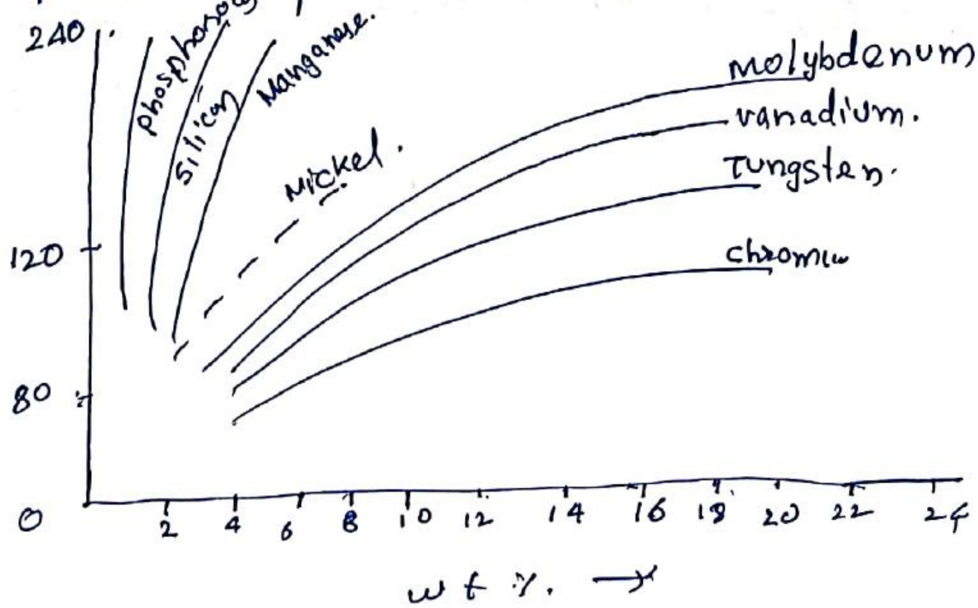
Alloy steels are more superior than Plain CS. due to the following reasons.

i) More strength, hardness, toughness etc
ii) Better resistance to wear & abrasion.
iii) Less tendency to warping & cracking.
iv) High hardenability
v) Uniform properties.
vi) High resistance to tempering.
vii) Less tendency of decarburization.
viii) High corrosion & oxidation resistance.

Effect of Alloying Elements

i) Solid solution strengthening / hardening:

Most of alloying elements. form solid solution when added to steel, they increase the strength & hardness of steels.



ii) Formation of Carbides.

Some of the alloying elements combines with Carbon & form respective Carbides. They increase resistance to tempering at high temperature. Carbides of chromium & vanadium carb. have maximum hardness (High speed steels & High alloy tool steels.)

eg: Ti, Zr, V, Nb, Mo, Cr, Mn ...

iii) Formation of intermediate compounds

FeCr ~~(Sig~~ Sig (Sigma phase in high chromium alloys) & Fe_3W_2 (in tool steels).

eg: Nickel, Si, Al, Zr, V, Ti, W, Cr.

These phases increase brittleness & hence its undesirable.

iv) Formation of Inclusions: They may combine with oxygen & form oxides when added to steel.

eg: Si, Al, Mn, Cr, V, Ti.

v) Shifting of critical temperature & eutectoid Carbon:

Austenite stabilizers like Ni & Mn lowers the eutectoid temperature.

Ferrite stabilizers like Ti & Mo raise the eutectoid temperature.

vi) Lowering of Critical cooling rate:

Elements like Mn, Cr & Ni are most effective in increasing the hardenability. they shift the IT diagram to the right.

vii) Changes in volume during transformation.

Classification of Alloying Elements.

i) Carbide forming elements: They form carbides.
eg: Ti, Zr, V, Nb, W, Mo, Cr, Mn.

ii) Neutral elements: Cobalt is the only element in this category which neither forms carbides nor causes graphitization.

iii) Graphitizing Elements: They decompose the carbides into graphite.
Si, Ni, Cu & Al.

with respect to temperature interval (effects) they are classified in two groups.

i) Austenite stabilizer: Raise A_4 temperature & lower A_3 temperature, they are called Austenitic steels.
eg: Ni, Mn, Cu, C, N.

ii) Ferrite Stabilizers: Lowes A_4 & raise A_3, they are called ferritic steels.
eg: Cr, W, Mo, V, Si, Al, B, Zr, Nb
P, Ti ...

Properties & uses of Alloying Elements

i) Sulphur: Sulphur combines with Iron & forms FeS which is hard & brittle, it has low melting point & hence is the last to freeze in solidification so it appears at grain boundaries.

During hot working of steels, this phase liquifies at working temperature, making the working difficult without cracking (hot short).

The problems are reduced by restricting the amount of sulphur to a maximum of 0.05% & addition of manganese.

MnS has higher melting point than FeS, so brittleness reduces along with hot shortness. Sulphur increases machinability (Mn is also added).

ii) Phosphorous: Most powerful solid solution strengthener. so tensile strength & Hardness is increased. If added in excess, it forms Fe_3P, which is hard & brittle, so its restricted to 0.05%. In general phosphorous improve machinability.

Phosphorous reduces the solubility of Carbon in ferrite, leading to formation of banded structure, which is undesirable.

iii) Silicon: Its also a solid solution strengthener. Its a strong deoxidiser. Silicon is purposefully added in spring steels, chisels, punches & automobile valves to increase their toughness.

Silicon is a strong graphitizer. Higher amount is not added because cementite decomposes to ferrite & graphite

iv) Manganese.

It increases hardenability of steel but with a liability of quench cracks. Temper. embrittlement observed if more than 0.6% C. So its kept below 0.5%.

It improves machinability, so free. cutting steels have Mn maximum upto 1.6 %.

Higher amount of Manganese (12 to 14) is added with 1 to 1.2% C which is extremely tough, wear resistant & non magnetic. steel called Hadfied steel.

used in frogs & switches in railroad track work, jaw plates for stone crushes, dredge bucks & power shovel teeth.

v) Nickel.. Its also solid solution strengthener. It increases tensile strength & toughness without decreasing ductility

Its austenite stabilizes. Nickel also increases corrosion & oxidation resistance if added in excess of 5 %.

It increases impact resistance of steels at low temperature.

Nickel reduces coefficient of thermal expansion

Invar → 36% Ni, 0.2% C & 0.5% Mn.

Elinvar → 36% Ni, 12% Cr. & W.

It reduces carbon content of eutectoid & the eutectoid. temperature.

These steels find applications as large forgings castings & structural components which can not be conviniently quenched, its also used for locomotive boilers, railway axles & bridge structures.

vi) Chromium:

1) Increases hardenability
2) It forms carbides & increases hardness & wear resistance of steels.
3) It decreases eutectoid carbon hence more carbides are formed.
4) It increases corrosion & oxidation resistance.

It has certain disadvantage.

1) It makes steel susceptible to temper embrittlement.
2) They are liable to form surface markings (chrome lines).

small amount of chromium is present in bolt, springs, gears, races & balls of antifriction bearings, structural steels etc. & large amount is present in tool & die steels, stainless steel & heat resisting steels

vii) Tungsten:

- Increases hardenability
- forms carbides & increases wear resistance & abrasion resistance
- Carbides also increase resistance to tempering (even at 600°C).
- Refines grain size.
- Reduces decarburization

VIII) Molybdenum:

- Similar to tungsten, but its resistance to grain coarsening & decarburization is less as compared to tungsten.
- Molybdenum reduces or eliminates temper embrittlement.
- About 0.5% is added.

IX) Vanadium:

- similar to tungsten / molybdenum.
- Resistance to grain coarsening is excellent.
- Carbides of vanadium are extremely hard, hence secondary hardening occurs during tempering & offers resistance to tempering.

  Its important alloying addition in tool & die steels.

  Rc - 65 to 66 (1% V)

  - 70 to 72 (5% V).
- Improves the fatigue & creep resistance. So its used for leaf & coil springs, heavy duty axles, gears, pinions, valves etc.
- Its a strong deoxidiser. Vanadium killed steels are inherently fine grained & maintain fine grain size upto a high temperature

x) Titanium:

Its a strong carbide former. It effectively inhibits grain coarsening & als acts as grain refine. Its added to stainless steel to prevent precipitation of chromium carbide

xi) Cobalt: It not a carbide formers, it its the only element which reduces hardenability of steel.

It increases resistance to tempering. at elevated temperature.

Its used in sintered (cemented) carbide tips tools

Its also used for manufacture of stellites (Co-chromium alloys. for wear resistant).

xii) Aluminium

A powerful deoxidiser, used for killing of steels; it grain refiner & inhibitors.

Its important alloy added for nitriding

xiii) Boron

It improves hardenability of medium CS.

It also improves machinability, boron is diffused into surface of a steel for obtaining high. surface hardness. wear resistance & corrosion resistance.

Its used for control rods in nuclear reactor

Typical examples of Alloy steels

i) **Free cutting steels:**

These steels can be machined or cut with faster speed (high machinability)

Chip formation & breaking is the sign of good machinability

Low CS are soft & produces continous ribbon, machinability of Low CS is improved by adding Manganese & Phosphorous (0.6 to 1.2%) Manganese is generally added 5 to 8 times the amount of sulphur.

High CS are hard & difficult to machine, so Lead is added, it improves machinability without much affecting normal temperature ductility, toughness & other properties of steel.

ii) High strength Low Alloy (HSLA) steels.

They are low CS; they have good ductility malleability, toughness & weldability. they have small (< 0.5%) addition of Ti, V, Nb & Al. Superior mechanical properties of these steels are due to ultra fine grain size - widely used in Automotive industry

iii) Maraging steels:

Air hardened by martensitic transformation They are Low CS containing 18-25% Ni 3 to 5% Mo, 3 to 8% Co & 0.2 to 1.6% Ti & small amount of Al. They are used for special applications such as rocket casing, air frame & engine components, low temperature structural parts, pressure vessels, injection moulds 1/. & dies.

iv) Dual phase steels:

Microstructure consists of fine ferrite & pool of martensite (Dual phase).

Low CS with or without alloying element. They are heated just above A_1 temperature & rapid cooling to room temperature.

They have less yield strength. ~~ratio to~~ tensile strength ratio

No Luders bands are formed during pressing. & hence they are widely used for bumpers, wheels, discs, door panels and al other automotive parts.

v) High temperature alloys (super alloys).

They have high strength, high hardness & wear resistance, high creep resistance & high oxidation resistance at elevated temperature. They can be iron base alloys, nickel base alloys, cobalt base alloys or refractory metals & alloys.

Iron base alloys contain W, Mo, V & Cr as alloying element

Nickel base alloys may contain Mo, Cr & Co [Inconels, Hastealloys, Nimonics & waspaloy]

Cobalt base alloys may contain Mo, Cr, & Ni, Stellites are used for gas turbine & milling cutters

Refractory metals such as W, Mo, Cr & Co & their alloys can be used at high temperature because of their high recrystallization temperature.

VI) Creep Resisting Steels:

These alloys are mainly used for high temperature applications. They have high ~~strength~~, creep resistance.

W, Mo, V, Cr, Ti, Nb & Co are added to obtain creep resistance.

These elements are strong carbide formers, so they increase the resistance to softening & tempering of steels at elevated temperature.

Oxidation resistance of these steels is increased by addition of Cr, Si & Al.

VII) Low Expansion Steels:

Assignment

1. State the designation of Steel on the basis of Carbon
2. State the difference between Rimmed Steel and Killed Steel
3. State the Indian Standard of Specification of Steels
4. State the Properties and Uses of Sulphur
5. State the Properties and Uses of Chromium
6. Why are Tungsten Used as an Alloy in steel
7. What are Stellites and where is it used
8. Which Steel Alloy is preferred for Control rods
9. What areFree Cutting Steels
10. Write the composition of 95Cr5 Mo1