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Carbon Steels

Pure iron is soft and ductile to be more practical in use. But when carbon is added, useful set of alloys are produced. They are known as **carbon steel.** The amount of carbon will determine the hardness of the steel.
The carbon amount ranges from 0.1% to 4%.

About steel

The term steel is used for many different alloys of iron. These alloys vary both in the way they are made and in the proportions of the materials added to the iron. All steels, however, contain small amounts of carbon and manganese. In other words, it can be said that steel is a crystalline alloy of iron, carbon and several other elements, which hardens above its critical temperature. Like stated above, there do exist several types of steels which are (among others) plain carbon, stainless steel, alloyed steel and tool steel.

Plain carbon steel

Carbon steel is the most widely used kind of steel. Most carbon steel has a carbon content of less than 1%. Carbon steel is made into a wide range of products, including structural beams, car bodies, kitchen appliances, and cans. In fact, there are 3 types of plain carbon steel and they are low carbon steel, medium carbon steel, high carbon steel, and as their names suggests all these types of plain carbon steel differs in the amount of carbon they contain.

The factors affecting the properties of carbon steels are carbon content and the microstructure. Carbon has a strengthening and hardening effect. It lowers ductility, machinability, weldability, corrosion resistance, thermal and electrical conductivity and magnetic permeability. Carbon steel does not contain more than 0.5% of silicon and 1.5% of manganese. Most of the steel produced nowadays is plain carbon steel.

The plain carbon steels varying from 0.05% carbon to 1.7% carbon with small percentages of silicon, Sulphur, phosphorus and manganese are divided into the following types:

Plain Carbon Steel	*% of Carbon*
Dead Mild Steel(Low Carbon Steel)	0.05 - 0.15 % carbon
Mild Steel	0.10 - 0.30 % carbon
Medium Carbon Steel	0.30 – 0.50 % carbon
High Carbon Steel	0.50 - 0.90 % carbon
High carbon Steel (Tool Steel)	0.90 – 1.50 % carbon

General properties of plain carbon steel

Generally, with an increase in the carbon content from 0.01 to 1.7% in the alloy, its strength and hardness increases but still such an increase beyond 1.5% causes appreciable reduction in the ductility and malleability of the steel.

Low carbon steel or mild steel, containing carbon up to 0.25% responds to heat treatment as improvement in the ductility is concerned but has no effect in respect of its strength properties.

Medium carbon steels, having carbon content ranging from 0.25 to 0.50% improves in the machinability by heat treatment. It must also be noted that this steel is especially adaptable for machining or forging and where surface hardness is desirable.

High carbon steels, is steel-containing carbon in the range of 0.50 to 1.7% and is especially classed as high carbon steel. In the fully heat-treated condition it is very hard and it will withstand high shear and wear and will thus be subjected to little deformation. Moreover, at maximum hardness, the steel is brittle and if some toughness is desired it must be obtained at the expense of hardness. Depth hardening ability (normally termed as hardenability) is poor, limiting the use of this steel.

Furthermore, as it has been seen that hardness, brittleness and ductility are very important properties as they determine mainly the way these different carbon content steels are used. Considering the microstructure of slowly cooled steel; for mild steel, for instance, with 0.2% carbon. Such steel consists of about 75% of proeutectoid ferrite that forms above the eutectoid temperature and about 25% of pearlite (pearlite and ferrite being microstructure components of steel). When the carbon content in the steel is increased, the amount of pearlite increases until we get the fully pearlitic structure of a composition of 0.8% carbon. Beyond 0.8%, high carbon steel contain proeutectoid cementite in addition to pearlite.

However, in slowly cooled carbon steels, the overall hardness and ductility of the steel are determined by the relative proportions of the soft, ductile ferrite and the hard, brittle cementite. The cementite content increases with increasing carbon content, resulting in an increase of hardness and a decrease of ductility, as we go from **low carbon** to **high carbon** steels.

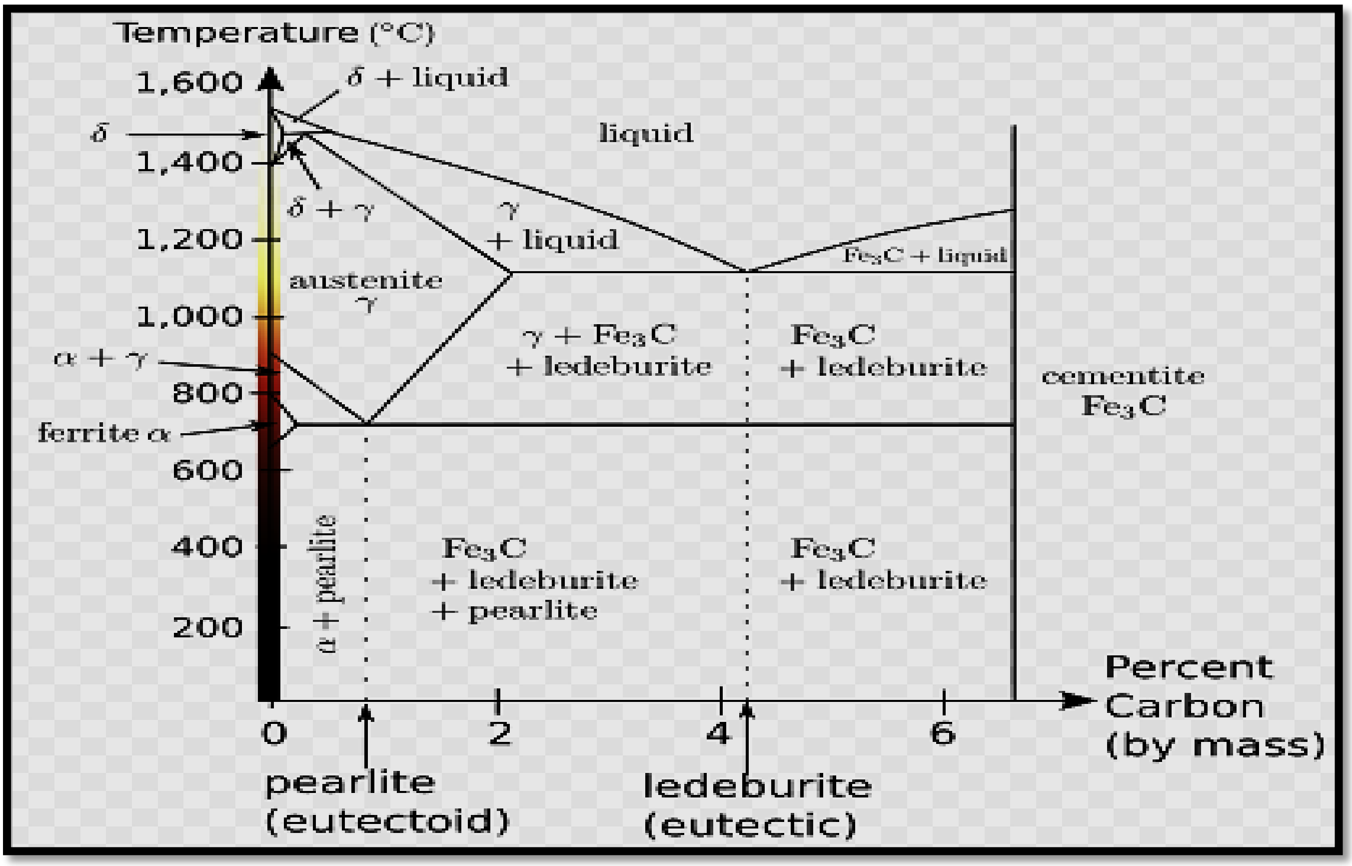

Figure 1. Iron-Carbon phase equilibrium diagram.

Mechanical Properties and Application of Carbon Steel						
Type of steel	% carbon	BHN No.	Tensile Strength	Yield Strength	% elongation	% Reduction in area
Dead mild Steel	0.05-0.15	100-110	390	260	40	60
Uses: Chains, stampings, rivets, nails, seamwelded pipe, tin plates, automobile body. Steel and material subject to drawing and pressing.						
Mild Steel	0.10-0.30	120-150	420-555	355-480	36-21	66-55
Uses: Structural steels, universal beams, screw, drop forging,case hardening steel, gears free cutting steel, shaft.						
Medium Steel	0.30-0.50	150-350	700-770	550-580	18-20	51-53
Uses: Conecting rods, shafting, axles, crankhooks, forging, Gears, Dies, Rotors, Tyres, Wheels.						
High carbon	0.50-0.90	350-600	1200-665	750-645	10-12	35-33
Uses: Loco Tyres, rails, wire ropes, Drop Hammer Dies, Saws, Screw Drivers, Band Saw, Hammers, Laminated Springs, Cable wire, Large Dies for cold press, drills.						
Tool Steel	0.90-1.10	550-600	580	415	13	26
Uses:Axes kinves, drill, tapes, screws ring dies.						
High Carbon	1.10-1.50	600-750	500	375	13	20
Uses: Ball Bearing, files, broaches, boring and finishing tools, machine parts where resistance to were is essential.						

Physical properties of plain carbon steel

There are also other properties of plain carbon steel that needs to be considered and these properties are being illustrated as shown in table 1 below:

Material	Density 10^3 kgm^{-3}	Thermal conductivity Jm^{-1}K^{-1}s^{-1}	Thermal expansion 10^{-6}K^{-1}	Young's modulus GNm^{-2}	Tensile strength MNm^{-2}	% elongation
0.2% C Steel	7.86	50	11.7	210	350	30
0.4% C Steel	7.85	48	11.3	210	600	20
0.8% C Steel	7.84	46	10.8	210	800	8

Limitations of plain carbon steel

The plain carbon steels do have some appreciable properties but also consists of some limitations. These are:

1. There cannot be strengthening beyond about 100000 psi without significant loss in toughness (impact resistance) and ductility.

2. Large sections cannot be made with a martensite structure throughout, and thus are not deep hardenable.
3. Rapid quench rates are necessary for full hardening in medium-carbon leads to shape distortion and cracking of heat-treated steels.
4. Plain-carbon steels have poor impact resistance at low temperatures.
5. Plain-carbon steels have poor corrosion resistance for engineering problems.
6. Plain-carbon steel oxidizes readily at elevated temperatures.

Effect the residual elements on the properties of the steel

Steel, is an alloy, which is mainly produced from pig iron. In fact, the manufacture of steel is quite a long process as it comprises of numerous stages and one of these stages is refining. Indeed, once produced in furnace, the steel does contain quite significant amount of impurity and thus, it requires to be refined to a certain degree. However, even after the refining process, the steel still contain small amounts of residual elements (also termed as trace elements) which has some negative influence on the properties of steel. For instance, carbon steel is an alloy made up of mainly iron and carbon but still other elements do exists in this alloy as shown in table below:

Elements	Maximum weight %
C	1.00
Cu	1.60
Mn	1.65
P	0.40
Si	0.60
S	0.05

Out of these elements, Phosphorus, Sulphur and Silicon are considered as trace elements as they have negative impacts on the steel.

Indeed, there are many elements which are considered as being residual elements and these elements are:

Residual elements	Symbol
Phosphorus	P
Sulphur	S
Oxygen	O
Hydrogen	H
Tin	Sn

Effects of residual elements on steel

Like stated above, the presence of these trace elements are undesirable due to their bad effects on the steel and its properties. In fact, here is in more details, the description of these elements as well as their drawbacks they cause on steel.

Phosphorus

Phosphorus is an element, which affects primarily the **ductility** and the **toughness** of steel and this mostly when the steel is in the quenched and tempered conditions. In fact, the phosphorus has a tendency to **react** with the **iron** to form a compound known as iron phosphide **(Fe_3P)** which has the particularity of being **brittle.** Hence, phosphorus renders steel **less tough and ductile while it increases brittleness.**

Silicon

Although the fact, that silicon is not that harmful to steel, still it has some bad effects on its properties. In fact, silicon has the particularity of **impairing hot and cold workability and machinability.** The presence of Silicon in low carbon steel is also **detrimental since it affects the surface quality of the steel.**

Oxygen

Oxygen is really a poison to steel. Indeed, when present in steel, it has a very bad effect on its mechanical properties. To be more precise, oxygen **reduces the impact strength** of steel, whereas it has the tendency to **increase its ageing brittleness, red shortness, woody and slanty fractures**. In brief Oxygen **reduces the toughness of steel**.

Hydrogen

Like Oxygen, Hydrogen also is injurious to steel as it causes embrittlement by decreasing of elongation and reduction of area without any increase of yield point and tensile strength. Indeed, hydrogen is the source of redoubtable snowflake formation and it favors the formation of ghost lines in the steel structure. Furthermore, atomic hydrogen engendered by pickling penetrates into the steel and forms blowholes. This element also acts as a decarburizing agent when it is in the moisted form (at high temperatures).

Sulphur

Sulphur is a trace element, which has a great **tendency to segregate** (that is to isolate itself in the structure). It also reacts with iron to form iron sulphides which produces red or hot-shortness, since the low melting eutectic forms a network around the grains so that these hold but loosely together, and the grain boundaries may easily break up during hot forming. Sulphur plays a great role also in the drop in weldability, impact toughness and ductility of steel.

Tin

Tin is also considered as being a residual element and this simply because, just as steel, **it causes hot shortness**. In addition to this, **tin is also a source of temper embrittlement.**

Nitrogen

This is not the most harmful trace element since it **only causes a decrease in toughness of the steel.**

The properties of Carbon steel can be enhanced by using the appropriate alloying elements. Discuss the general effects of alloying elements in an alloy

An alloy is a mixture of two or more metals, or a metal and some other material. Most alloy contain a large amount of one metal, called the **base metal**, and smaller amounts of one or more other metals or nonmetallic materials. Many pure metals are too soft, corrode too easily, or have other mechanical or chemical disadvantages can be overcome if the metals are combined with other metals into alloys. Most alloys are harder than the metals from which they are made. They are also less malleable. They are harder to hammer into shape. Most alloys are less ductile than pure metals. That is, they are less easily drawn into fine wires and similar shapes. But most alloy are more fusible and more easily melted, than the pure metals of which they are composed. Some alloys will even melt at the comparatively low temperature of hot water.

Few alloys can conduct electricity as well as many metals in their pure forms.

General effects of alloying elements

- Improves tensile strength without appreciably lowering ductility.
- Improves toughness.
- Improves hardenability which permits hardening of larger sections than possible with plain carbon steels or allows quenching with less drastic rates.
- Reducing the hazard of distortion and quench cracking.
- Retain strength at elevated temperatures.
- Obtain better corrosion resistance.
- Improves wear resistance.
- Imparts a fine grain structure to the steel.
- Improves special properties such as abrasion resistance and fatigue behavior.

How do alloying enable achievements of such improved properties of steel

In fact, the properties of alloys are quite dependent on the relationship between chemical composition, processing and their microstructure.

For instance, whenever an element is added to a pure metal, the latter alters the size of the lattice structure of the metal and depending on the alloy formed, it can also change its lattice type. Sometimes metals do react together to form intermetallic compounds with very complex lattice structure. Such compounds melt at a fixed temperature and have a lower conductivity and ductility but greater strength and hardness than an alloy of face centered body, centered or hexagonal lattice structure. Thus, alloys increases strength and hardness of metal by changing its structure.

Furthermore, like stated above, alloying enables the formation of fine grain size since it favours the ability of the metal to be hardened by quenching in oil or air rather than in water. Indeed, oil is a cooling agent offering slow cooling rate and thus the grain form more regularly with time and hence they are finer.

4. Discuss the effects of each of the different alloying elements in steel

Steel is one of the world's cheapest and useful metals. Indeed, steel founds application in numerous fields, from building construction purposes to kitchen utensils. Hence, so as to be able to respond to such a great demand and to suit the requirements to different applications, steel needs to offer several desired properties and these properties is achieved by alloying it. Like stated above, several other elements need to be added to iron and carbon to form adequate alloys with enhanced properties. Alloyed steel in brief is made by adding a small percentage of alloying metals to liquid steel to subsequently alter the hardness, toughness, elasticity or durability. Naturally each of the alloying elements will have a specific property on the steel and are added to it in certain proportions on the different properties required.

The different alloying elements on steel are

(1) Carbon,(2) Magnesium,(3) Silicon,(4) Copper,(5) Chromium,(6) Molybdenum,(7) Vanadium,(8) Nickel,(9) Aluminium,(10) Boron,(11) Titanium,(12) Zirconium,(13) Calcium,(14) Lead,(15) Nitrogen,(16) Tungsten

The effects of the above alloying elements in steel

Carbon:

Carbon is an element whose presence is imperative in all steel. Indeed, carbon is the principle hardening element of steel. That is, this alloying element determines the level of hardness or strength that can be attained by quenching. Furthermore, carbon is essential for the formation of cementite (as well as other carbides) and of pearlite, spheridite, bainite, and iron-carbon martensite, with martensite being the hardest of the microstructures. Carbon is also responsible for increase in tensile strength, hardness, resistance to wear and abrasion. However, when present in high quantities it affects the ductility, the toughness and the machinability of steel.

Manganese:

Manganese also contributes greatly towards increasing strength and hardness, but to a less extent than carbon. To be more precise, the degree to which manganese increases hardness and strength is dependent upon the carbon content of the steel. In fact, manganese contributes to the increasing the strength of the ferrite, and also toward increasing the hardness of penetration of steel in the quench by decreasing the critical quenching speed. Moreover, still consisting of a considerable amount of manganese can be quenched in oil rather than in water, and are therefore less susceptible to cracking because of reduction in the shock of the quenching. This alloying is also considered as a degasifier reacting favorably with sulfur to improve forging ability and surface quality. This is achieved by interacting with the Sulphur to give manganese sulphides. Naturally in doing so, the risk of hot shortening is considerably decreased. In addition, manganese enhance the tensile strength, the hardness, the harden ability, the resistance to wear, and it increases also the rate of carbon penetrating in the coefficient of thermal expansion of steel whereas it is detrimental to both thermal and electrical conductivity.

Copper:

Although being favorable when it comes to render steel more resistant to corrosion, copper is not considered as such as being a good alloying element since it does have some bad repercussions on the steel. Indeed, copper is harmful to the surface quality of steel and it renders the steel less machinable at high temperatures.

Chromium:

Among the alloying elements of steel, chromium forms part of those which **best promote hardenability**. In fact, its effect on steel is quite similar to that of manganese in the way that it enhances much hardness penetration. When being present in reasonable quantities, chromium contributes much in **reducing the quenching speed**. In fact, such a slow quenching is achieved thereby enabling steel to be oil or air hardened. Chromium is also recommended when there is good wear resistant steel of appreciable toughness required. Chromium is also very popular as alloying element as it is quite efficient in rendering steel resistant to staining and corrosion. Moreover, chromium forms carbides that improve edge-holding capacity. Steel, rich in chromium have also high temperature strength and they are quite resistant to high-pressure hydrogenation.

Nickel:

Nickel is beneficial to steel in the way that it boost up the strength of ferrite. It is a fact that nickel causes considerable increase in the impact strength of steel. Nickel found its common use generally in low alloy steels. This is so because this alloying element increases appreciably toughness and hardenability. In addition, nickel also exhibits the tendency of reducing distortion and cracking of the steel.