

Metals:

Metals are used for various engineering purposes. They are used for making structural members, doors, windows, roofing materials, pipes and many other products. In order to find the suitability of various metals to be used for a specific work, it is essential to study their composition and properties.

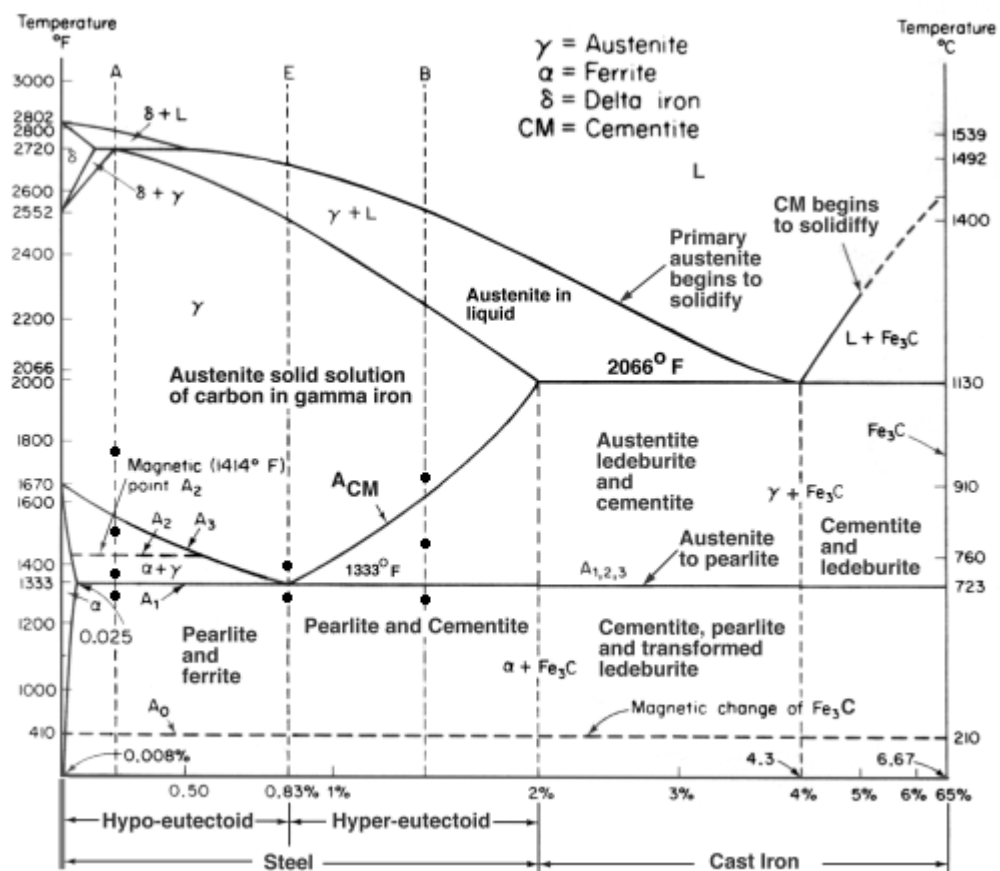


Figure (1): iron carbon diagram

Classification of metals

All the metals used in engineering works can be classified into two categories:

A. Ferrous metals

Ferrous metals are those metals in which the chief constituent is iron. Besides iron, other constituents like carbon, sulphur, manganese

and phosphorus etc. also exist in varying proportions. The ferrous metals which find their common are:

1. Cast

2. Steel

B. Non ferrous metals

Non ferrous metals are those, which do not contain iron, and are used widely in building industry. The important non ferrous metals are copper, lead, tin, zinc and aluminum.

Ferrous metals

1. Cast iron

Besides iron, cast iron contains carbon, silicon, sulphur, phosphorus and manganese in varying proportions:

Iron – 92-95%

Carbon – 2- 4.5 %

Silicon- 1-3 %

Properties:

Cast iron possesses the following important properties:

1. It has fibrous crystalline structure.
2. Brittle and has low resistance to tension and high strength in compression. Tensile and compressive strength of an average quality of cast iron are 150 N/mm^2 and 500 N/mm^2 respectively.
3. Its melting point is about 1200°C .
4. It cannot withstand sudden shocks.
5. Because of being brittle, it can not be welded.
6. Its specific gravity is 7.5.
7. It cannot be magnified.
8. it's neither malleable, nor ductile.
9. It does not rust easily.

Uses:

1. It is used for manufacture of steel and wrought iron.
2. Its high compressive strength makes it suitable for use in making such parts which are subjected to compressive stresses such as supports of heavy machinery.
3. Since it does not rust easily, therefore it is used for parts generally exposed to atmosphere such as lamp posts.
4. It is also used for making rail chairs and carriages wheels.

2. Steel

Steel is the most important material for engineering construction. It contains carbon from 0.15 % (very soft steel) to 1.5 % (very hard steel). It also contains small amount of other elements.

It contains from:

Iron = 99 %

Carbon content – 0.15 – 1.5 %

Phosphorus and sulphur less than 0.1 %

Manganese up to 0.5 %

Silicon up to 0.3 %

The higher is the percentage of the carbon, the harder and tougher is the steel. Depending upon the percentage of carbon contents, Steel can be classified into different groups as under:

1. Very low carbon steel – having percentage of carbon below 0.15 %.
2. Low carbon steel or mild steel –Carbon contents 0.15 – 0.3 %.
3. Medium carbon steel–Carbon contents range from 0.3 – 0.6 %.
4. High carbon steel or hard steel–Carbon contents range from 0.6 – 1.5 %.

Low carbon steel – mild steel:

The percentage of carbon in mild steel varies from 0.15 to 0.3, sulphur, phosphorus, manganese, silicon are present only in minute quantities.

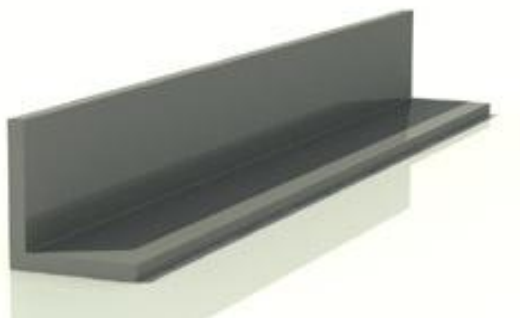
Properties:

1. It has a bright dark bluish color.
2. It has fibrous structure.
3. Its melting point is about 1400 °C.
4. It can withstand sudden shocks.
5. Its tensile strength is high.
6. Its specific gravity is 7.8.
7. It is malleable, ductile and elastic.
8. It can form permanent magnets.
9. It can rust easily and rapidly.
10. It can take a good amount of compression.
11. It can easily forge and welded.

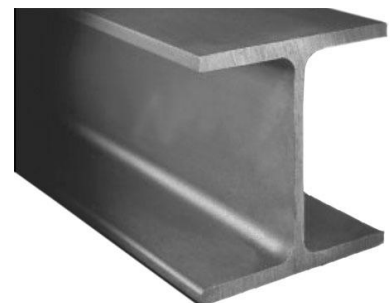
Uses:

The chief uses of mild steel are:

1. It is used for making rolled structural steel sections like girders, angle sections, channel and T- sections... etc.



Angle section



I-section



Cannel section



T-section

2. It is extensively used for making bars and rods which are used as a reinforcing material in reinforced concrete.
3. It is used for making refrigerators and air conditioners.
4. It is used for making plain and corrugated sheets.
5. Structural mild steel is most commonly used for general construction purposes of buildings, bridges, towers and industrial buildings.
6. It also used for making tubes.

High carbon steel:

These are also termed as hard steels and contain carbon varying from 0.6 to 1.5 %. Besides carbon, small percentage of sulphur, phosphorus, manganese and silicon are also present.

Properties:

1. It has granular structure.
2. It is very hard.
3. Its specific gravity is 7.9.
4. It cannot easily forge and welded.
5. It can absorb shocks and vibrations in better way.
6. It is more elastic than mild steel.
7. It is brittle and less ductile than mild steel.
8. It rusts readily.
9. It can form permanent magnets.
10. It cannot take much of compression.

Uses:

1. It is used for parts of structures and machinery where hard, tough, elastic, shock- proof and durable material is required.
2. It is used in pre stressed concrete.
3. It is used for making knives, needles, bolts and surgical instruments.

Steel reinforcement for concrete:

The most common material in construction besides concrete is steel. Concrete, though it has a high compressive strength, its tensile strength is usually much lower and mounts up to 8 – 12 % of its compressive strength. Steel, therefore, is used in concrete structural elements to bare tensile loads and bending moments. The major components of steel are Iron and carbon which ranges between 0.01 and 1 percent. Sulfur, phosphorus, manganese, silicon and as much as 20 other alloys are present in steel and are added in various quantities to steel during its manufacturing process depending on the desired hardness, toughness and tensile strength of steel

Reinforcing steel bars are usually manufactured in 3 different forms:

- Plain bars
- Deformed bars
- Plain & deformed wires



Figure 1: Plain Bars

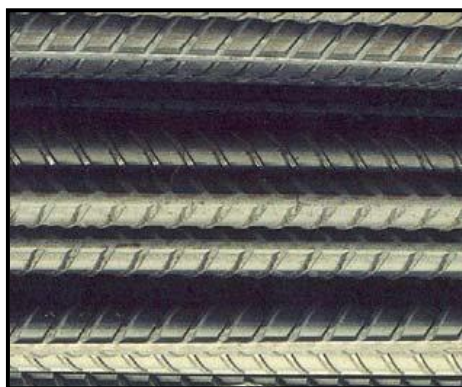


Figure 2: Deformed Bars



Figure 3: Plain & Deformed wires

The deformation in deformed steel bars is intended to increase the bonding between steel and concrete and to prevent slippage of the steel reinforcement bars. Steel reinforcement bars are produced mainly with four different yield strengths, shown in the table below. The grade of steel indicates its yield strength in Ksi.

Type	σ_{yield} (psi)	σ_{yield} (MPa)	Grade
Type 1	40,000	300	40
Type 2	50,000	350	50
Type 3	60,000	400	60
Type 4	75,000	500	75

Table 1: Reinforcement Steel Strength

All structural concrete contains steel reinforcement in the form of bars or welded mesh to compensate for the low tensile strength of the concrete. Bars with nominal diameters from 4 to 50 mm diameter are available. The steel is produced in either the basic oxygen process, in which up 30% scrap steel can be added to the pig iron from the converter, or in the electric arc furnace process, in which 100% scrap steel can be used for the charge. Billets are produced from continuous casting, which is then reheated to 1100–1200°C and hot rolled to the required bar diameter, which increases strength and closes any defects in the billets. A pattern of ribs is rolled onto the steel in the last part of the rolling process to improve the bond between the steel and the concrete in service.

The steel is low carbon, with typical levels of 0.2% carbon, 0.8% manganese and 0.15% silicon. If the steel is obtained from electric arc furnaces then the larger quantities of scrap steel used for the charge can lead to significant proportions of other alloying elements from the scrap. Nearly all reinforcement in current use has a yield stress of 500 MPa. The strength is achieved by one of four processes:

- **Micro-alloying**, in which smaller quantities of specific alloying metals that have a strong effect on the strength are added, the most common being vanadium at 0.05–0.1%.
- **Quenching and self tempering (QST)**, in which water is sprayed onto the bar for a short time as it comes out of the rolling mill; this transforms the bar surface region into hard martensite, allowing the core to cool to a softer, tougher mixture of ferrite and pearlite. Heat diffusing from the core during cooling also tempers the martensite and the result is a bar with a relatively soft ductile core and stronger harder surface layer.
- **Cold rolling**, in which a hot-rolled round section bar is squeezed by a series of rollers, thus cold-working the steel.
- **Cold stretching or drawing**, in which the hot-rolled steel is drawn through a series of dies, thus reducing the cross-sectional area and producing wire with a plain round section.

These processes produce steel with somewhat different ductilities. BS 4449 specifies three grades: B500A, B500B and B500C. The first B in each case is for ‘bar’, 500 is the yield strength in MPa, and the final letter, A, B or C, is the ductility class. The minimum elongations at maximum force for classes A, B and C are 2.5, 5.0 and 7.5%, respectively (with the tensile: yield strength ratios being 1.05, 1.08 and 1.15–1.35, respectively). Micro-alloying and QST can produce higher-ductility grades B and C, cold rolling the lower-ductility grade A and cold stretching grade B. The grades can be identified by differing rib patterns, defined in BS 4449. Other important properties are:

1. Bendability. The bars are made from relatively high-strength steels and because the surface ribs acts as stress concentrators, may fracture on bending to the required shape for construction if the bend radius is too

tight. BS 4449 specifies that bars with diameters ≤ 16 mm should be capable of being bent around a former with a minimum diameter of 4 times the bar diameter, and bars with higher diameters around a former of 7 times the bar diameter.

2. Fatigue properties. Fatigue cracking under cycling load will initiate at the root of the ribs and therefore a sharply changing cross-section at this point should be avoided in the rolling process.

3. Bond to concrete. This is a function of the surface and rib geometry, and is independent of the steel properties. BS 4449 gives examples and limits to the dimensions of suitable geometries and bond test methods.

4. Weld ability. Welding of bars is required when forming mesh or prefabricated cages of reinforcement which are increasingly important for the reduction of labour-intensive bar-fixing operations on site. As with other steels this depends mainly on the CEV. Typical values are 0.3–0.35 for QST bar, 0.4–0.5 for micro-alloy and stretched bar and 0.2–0.3 for cold-rolled bar. The differences in values should therefore be taken into account when selecting a welding procedure.

5. Corrosion resistance. Although concrete normally provides an excellent protective medium for steel, there are circumstances in which this protection can break down and the steel can corrode. Stainless steel reinforcing is produced for use in such situations.

Factors affecting mechanical properties of steel

1. Carbon content

- A. The strength and hardness of steel increases as a percentage of carbon increases up to 1.5 %.
- b. The elongation decreases as the carbon content increases and the metal becomes less resistance to impact.
- C. The elastic range remains nearly on the same linearity, indicating that the modulus of elasticity is nearly the same and can be considered constant for various types of steel.
- D. The plastic region decreases as the carbon content increases and appears to be nil for hard steel (high carbon steel).
- E. The area under stress – strain curve varies with carbon content; it decreases as the percentage of carbon increases. This area represents the amount of work stored in specimen.

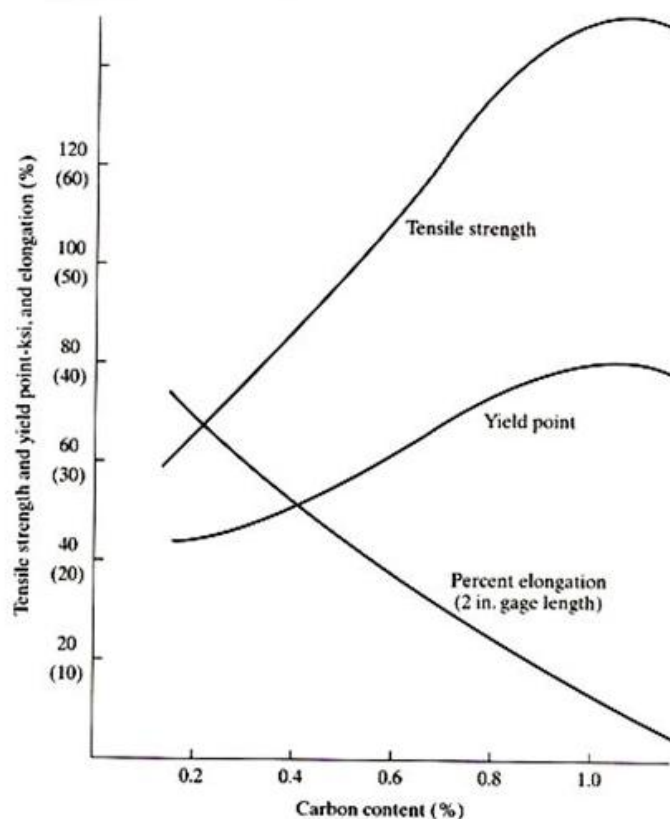


Figure (2): Effect of carbon content on mechanical properties of steel

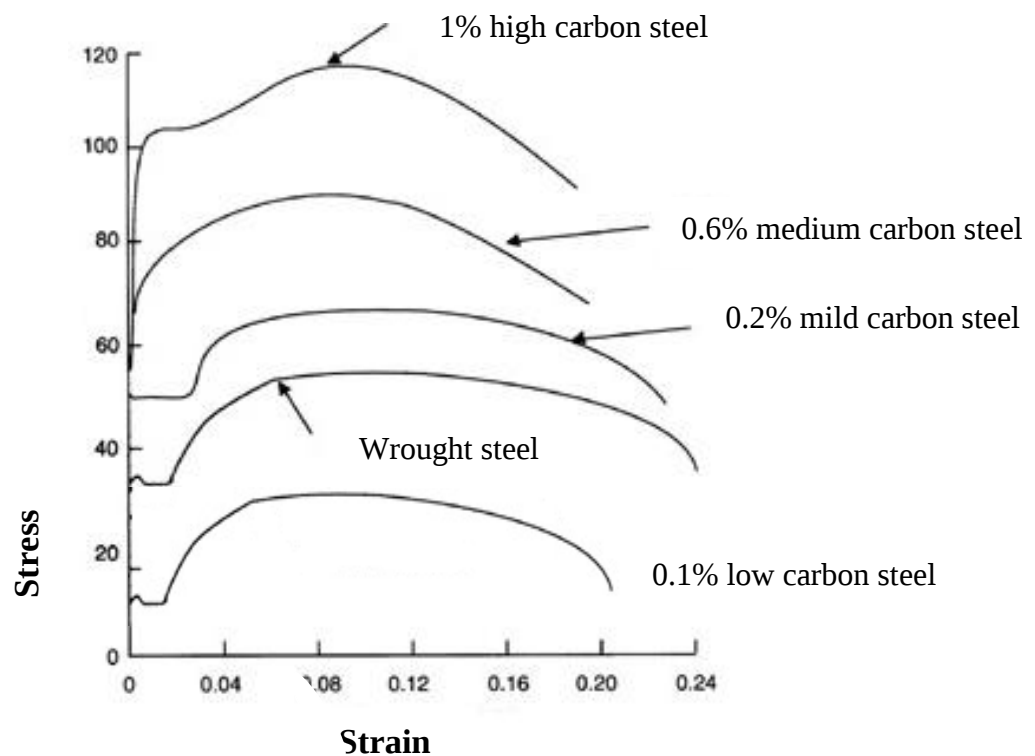


Figure (3): Effect of carbon content on stress strain behavior of steel

2.The percentage of impurities:

The impurities present in steel are:

- 1. Silicon:** If percentage of silicon is less than 0.2%, it has no appreciable effect on physical properties of steel, but when silicon content is between 0.3-0.4%, the strength and modulus of elasticity are increased without decreasing ductility.
- 2. Sulphur :** If sulphur content is between 0.02-0.1%, it has no effect on ductility and strength, but when the percentage of sulphur is higher than 0.1%, the strength and ductility decreases.
- 3. Phosphorus:** If the percentage of phosphorus exceeds 0.12%, the strength, ductility and resistance to impact are decreased.
- 4. Manganese :** When the manganese content is between 0.3-1 %, it helps to improving the strength of mild steel, but when it's content exceeds 1.5%, the steel becomes brittle and losses it's structural value.

3. Heat treatment

It is possible to alter the properties of steel by heating and cooling steel under controlled conditions. The term heat treatment is used to indicate the process in which the heating the heating and cooling of solid steel is involved to change the structural and physical properties of steel. The purpose of heat treatment is:

1. To alter magnetic properties of steel.
2. To change the structure of steel.
3. To increase resistance to heat and corrosion.
4. To increase surface hardness.
5. To make steel easily workable.
6. To vary strength and hardness.

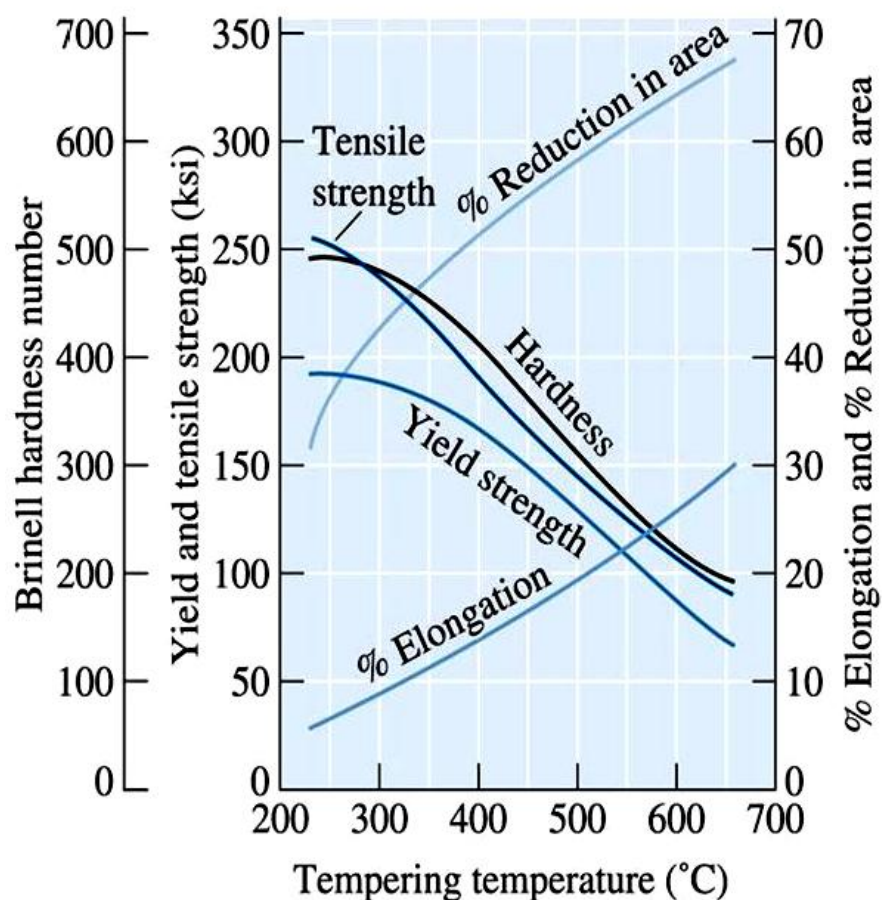


Figure (4): Effect of temperature on mechanical properties of steel

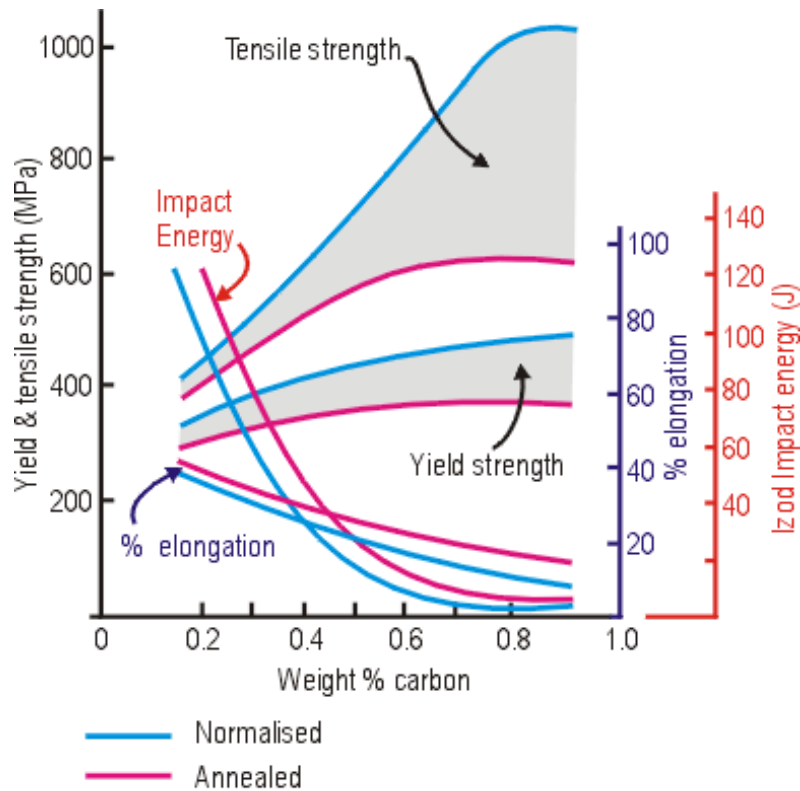


Figure (3): Effect of heat treatment on mechanical properties of steel

Tensile requirements	Grade	
	Grade 300	Grade 400
Tensile strength, min., MPa	500	600
Yield strength, min., MPa	300	400
Elongation in 200mm, min., % For bar diameter(mm):		
10	11	9
15,20	12	9
25	-	8
30	-	7
35	-	7
45,55	-	7

Grade	Nominal size of bar mm	Specified Characteristic strength, N/mm^2	Minimum elongation of gauge length*, %
250	All sizes	250	22
460/425	6 up to and including 16	460	12
	over 16	425	14

* Gauge length is five times the diameter of the bar

The plain carbon steels have limits on their engineering application because:

1. High- strength steel can only be obtained by increasing the carbon content to such a level that the material becomes brittle. High strength cannot be obtained with good ductility and toughness.
2. Hardness requires water quenching. The severity of this rapid rate of cooling often lead to distortion and cracking of the steel.
3. Large sections such cannot be hardened uniformly. The hardness depends on the rate of cooling and this will vary across a large section.
4. Plain carbon steels have poor resistance to corrosion and oxidation at a high temperature.

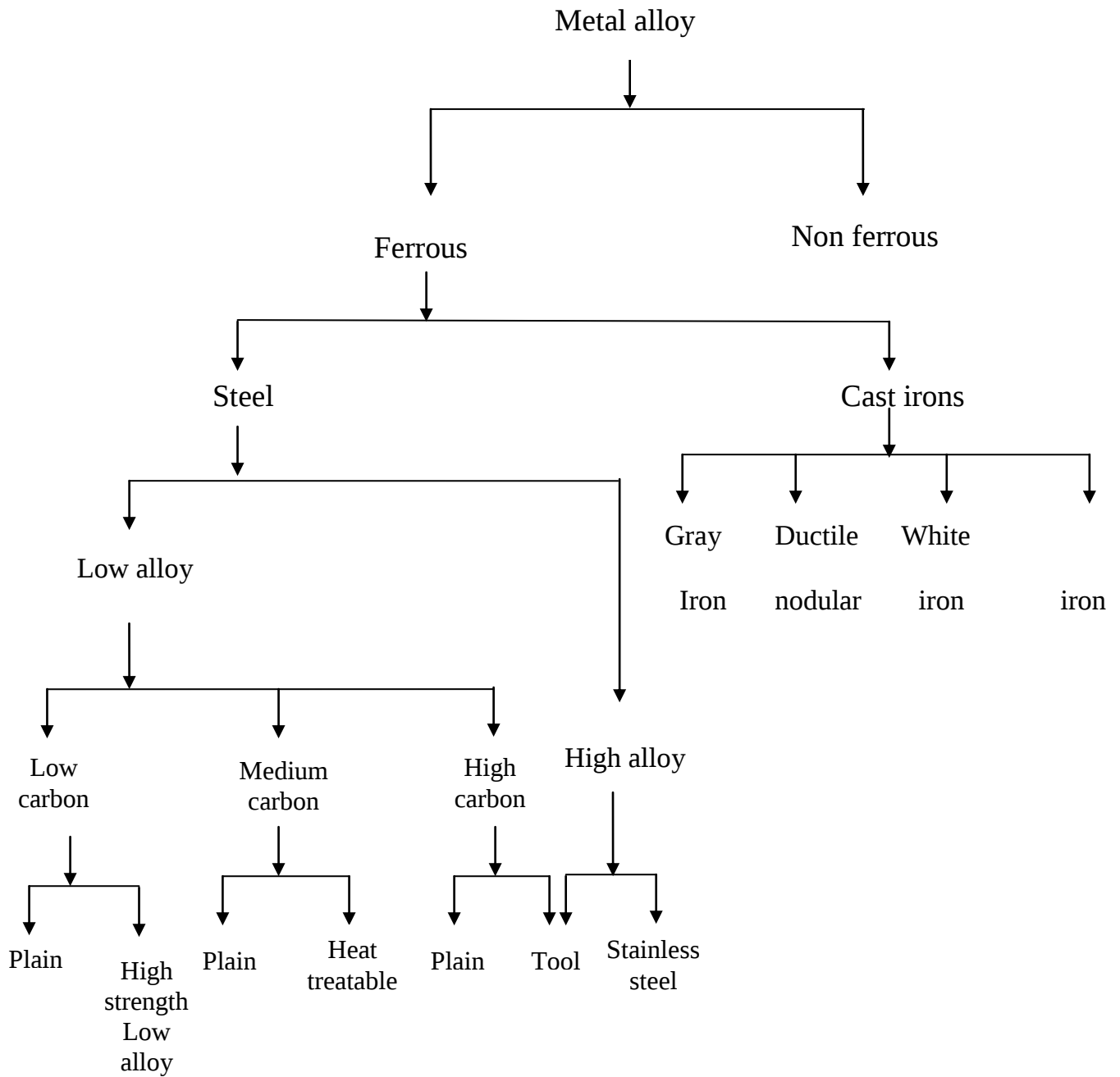


Figure (4): Classification scheme for the various ferrous alloys.