The Making of Structural Steel

(Report Assignment)

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Steel Structures I

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Report

” The Making of Structural Steels “

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- **Abstract**

Structural engineers are always susceptible to be working with structural steel, whether it is a bridge, steel piles, a tower or a simple structure made of steel, it is a must that the engineer possesses high awareness of the nature of steel, its mechanical properties and its suitability for each application. In this paper, I will introduce some of the basic principles that are involved in the process of manufacturing steel so that to a solid understanding of the steel background is acquired. The main topics included in this report are: Stages of steel manufacturing, chemical composition of steel, shaping of steel, mechanical properties of steel heat treatment processes and structural grades of steel.

- **Introduction**

In the structural industry, one of the most employed construction materials is the structural steel. Structural steel has manifested its advanced utility through the numerous characteristics and advantages it possesses. Limitless types of structural systems, such as bridges, high rise buildings or even small projects use structural steel as their primary construction material due to its very reliable and predicted behavior, its high strength all accompanied by its relatively light weight.

Steel in general, is an alloy consisting mainly of iron with a certain percentage of carbon. Carbon, in addition to other additives and elements are responsible for the enhancement of the mechanical properties of steel, mainly its strength, and strain response. It is crucially important to recognize the fact that steel characteristics and mechanical properties are mainly governed by its chemical composition and the processes by which it is manufactured, hence, controlling the two previous factors is of vital necessity.

Even though the process of steel manufacturing is a very complex and involved operation, it may be briefly described as the process in which iron ore, coal and limestone are fed into a blast furnace, so that the enormous heat of the furnace turns them into molten iron, which is then treated by thermo-mechanical processes in order to produce the final product of structural steel.

1. Stages and Processes of Structural steel making

a. Iron Making:

The metallurgical process of converting iron ore into hot metal, iron pellets, or cast iron utilizing either a blast furnace or any number of alternative iron making processes producing direct reduced iron. Iron making is a reduction process in which the iron-bearing material is reduced to elemental iron typically by the introduction of heat, oxygen and carbon.

The process of iron making starts after iron is obtained by mining. Mined iron might be in different mineral forms, usually magnetite or hematite. These minerals are subjected to separation processes to separate the iron from other impurities, the most common separation techniques include magnetization, flotation or electrical separation. The yield of the separation process is then transformed into small granular pieces known as "Pellets" which are easier to be fed into the blast furnace.

The limestone is fed into a rotating inclined cylinder that has a burner at the opposing lower end called "Lime Kiln". The heat produced by the burner reduces the limestone into lime (CaO) and carbon dioxide ($CO2$). Afterwards, the lime is cooled, screened and sized before it is used in the making of steel. Lime is considered to be a material of high reactivity, its main use is to produce the slag which is the substance responsible for collecting the impurities from the molten iron.

Coke is produced by burning the bituminous coal in an oven battery having an oxygen deficient environment. The coke battery consists of multiple ovens that are charged by crushed coal. The coal is then heated to 1800^{o}F for a period not less than 18 hours. Upon the heating period, the volatile substances such as tar, ammonium sulfate, benzol and naphtha are driven out leaving the coke which is the pure form of carbon. When subjected to oxygen, the coke immediately ignites, so it is suddenly quenched allowing it to cool and readjust its mineral composition. The coke is then prepared by sizing and screening, before it is ready to be fed into the blast furnace.

The major role of a blast furnace is to produce “Pig iron” which is the reduced form of the iron ore being the main ingredient used to make the steel. Iron ore, limestone and coke are alternatively fed into the top of the blast furnace, and then heated by a hot blast air with a temperature 1000-1200^{o}C that is blown from the bottom end of the blast furnace. A cycle of chemical reactions between the carbon from the coke and the oxygen from the ore takes place. These chemical reactions start by the formation of carbon monoxide (CO) resulting from burning the coke, then the (CO) reacts with the oxygen coming from the iron ore forming carbon dioxide (CO2), which once again breaks into (CO) due to the heat and the increasing amounts of carbon coming from the added coke. However, both CO and CO2 are driven through an offgassing system into a chamber so that certain volatile impurities are removed. A portion of the hot air is circulated through a heating system driving it back to the blast of the furnace, whereas the other cool potion is utilized for energy generation. The previous process reduces the iron ore into iron in its elemental form with 4% carbon dissolved in it, in addition to some impurities such as 0.7% SiO2, an impurity coming from the iron ore and 0.01% Sulphur, an impurity coming from the coke. At Uniform periods, a tap hole is drilled in the furnace allowing the molten iron to flow through a channel and the down to a torpedo car to be transported to the steel making facilities, the tap hole is welded again. During the runoff of molten iron, the floating slag is collected into a pot by a refractory gate, the slag might be used later in other manufacturing processes such as, the process of making cement.

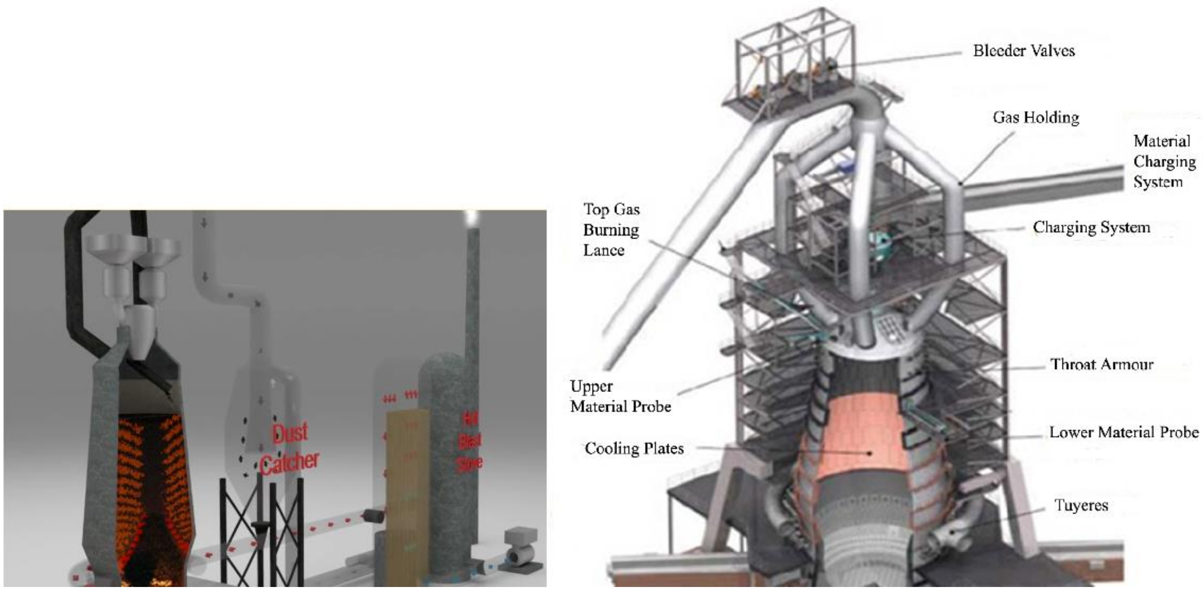

Fig.1: Blas furnace components

The molten iron produced by the blast furnace, scrap and burnt lime are fed into a Basic Oxygen Furnace (AKA converter). Pure Oxygen is blown into the mix through a water cool slot, as a result, chemical reactions between the blown oxygen and the dissolved carbon and silicon are initiated, yielding (CO_2), (SiO_2), heat in addition to other byproducts.

b. **Steelmaking**

is the metallurgical process of converting hot metal into crude steel by the basic oxygen furnace process (BOF) or steel scrap and direct reduced iron (DRI) or pig iron by the electric arc furnace (EAF) of a steelmaking plant.

Basic Oxygen Furnace(BOF):

process is a method of primary steelmaking in which carbon-rich hot metal, delivered by the blast furnace, is made into steel. It was originally developed in the early 1950s in the Austrian cities Linz and Donawitz and is thus referred to as the LD process. The initial high concentration of carbon (4%) is then reduced to 0.04%. Once the carbon is sufficiently reduced, the Oxygen blowing is stopped and the vessel rotates allowing the steel to pour into a ladle. The vessel then rotates in the opposing direction, so that the slag is tapped into a different ladle to be heated again.

The energy used for heating the steel is generated by an electrical setup, mainly consisting of a transformer, power conducting cables, arms, electrodes as well as the reduced iron and scrap metal charging equipment.

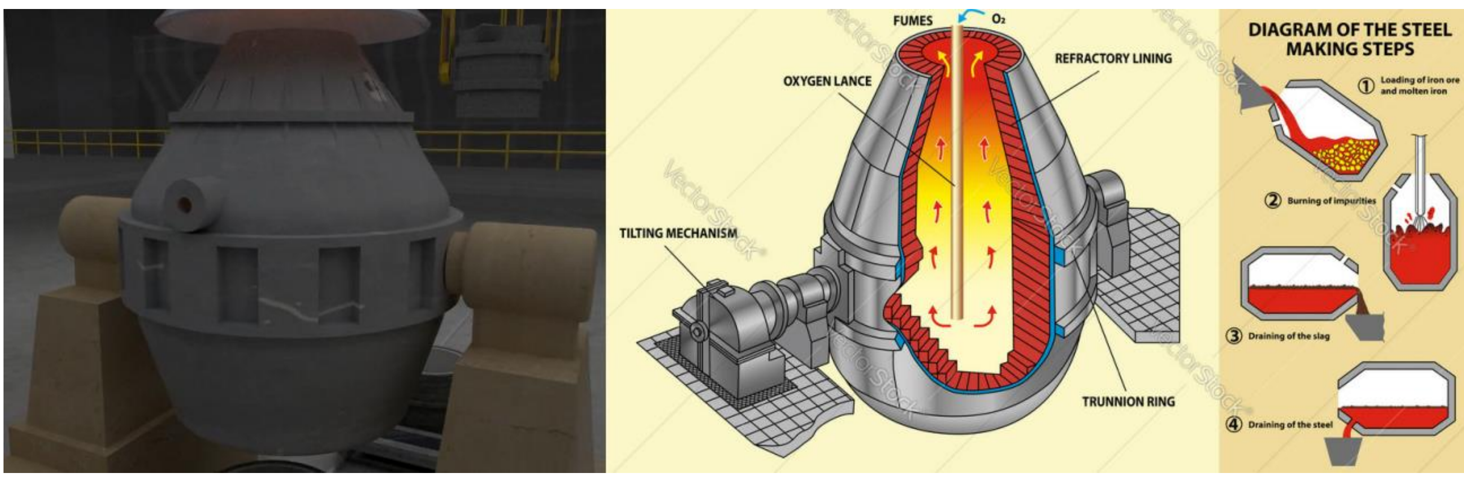

Fig.2: BOS furnace

Electric Arc Furnace (EAF)

Electrical energy is utilized to create a heat of steel. The furnace is charged with raw iron and scrap. The electrodes deliver high power electric arcs through the iron/scrap mix, the generated heat melts them and turns them into liquid steel. It is common for EAF's to use Oxygen and carbon injecting burners installed in the inside walls of the furnace, for the maximum utilization of the generated heat as well as to improve the formation of the slag. Similar to BOF, the EAF the vessel rotates to pour the liquid steel into a ladle for further treatment, and the slag is poured in another ladle for the next heating.

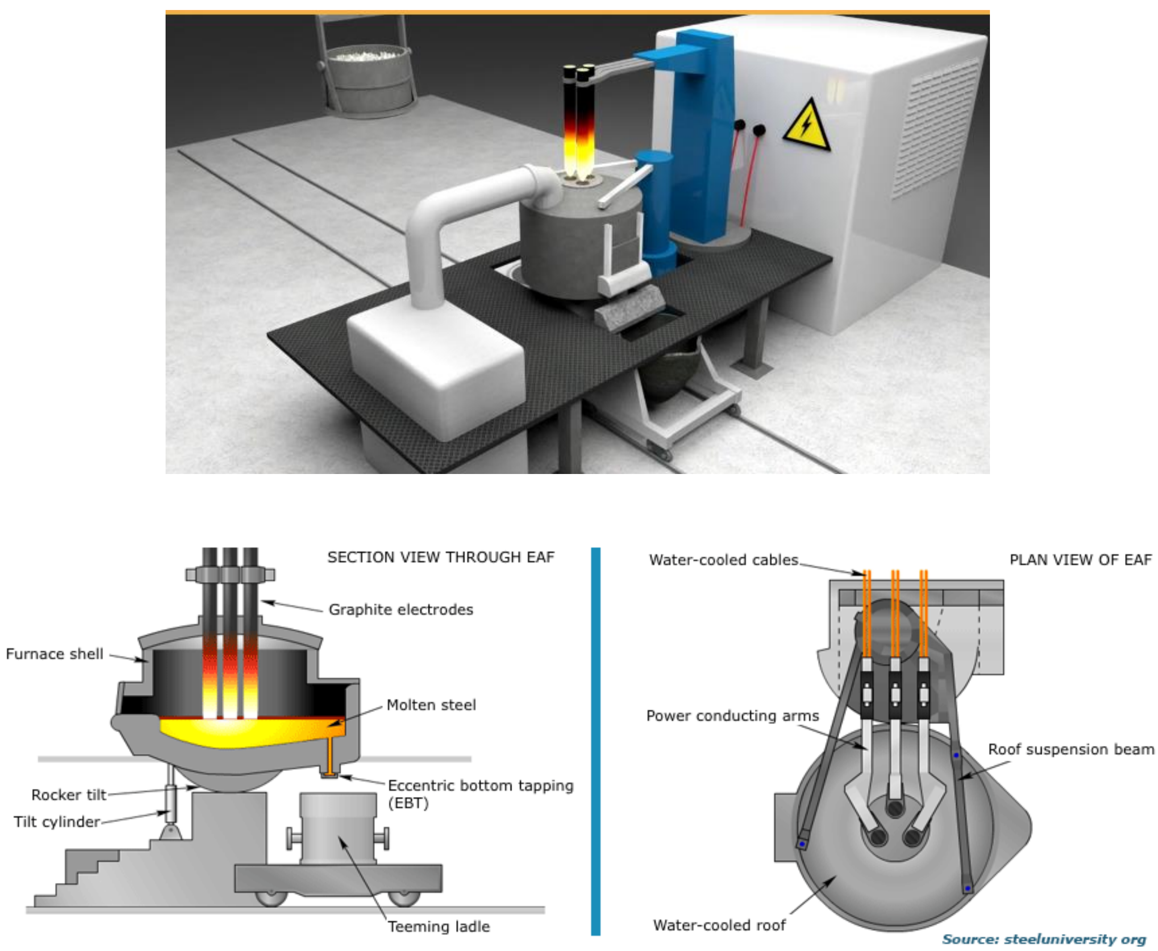

Fig.3: Electric Arc Furnace

c. **Secondary refining**

is a metallurgical process performed after the primary EAF or BOF steelmaking processes in a separate station with the purpose of temperature homogenization and chemistry adjustments for carbon, sulfur, phosphorus, oxygen and precise alloying, inclusion control, degassing, and others prior to casting. This process is carried out in the ladle at one of the following secondary refining stations as required for each specific steel treatment: refining station, argon oxygen decarburization (AOD), **ladle metallurgy furnace (LMF)** and **vacuum degassing.**

Vacuum degassing

The steel produced from the primary stage contains some impurities some of which are Aluminum Oxide (Al_2O_3) and Manganese Sulfides (MnS). In order to remove such substances, the liquid steel is stirred with certain gases like Argon. The bubbles of the argon gas are able to attract the impurities, and then float to the surface of the liquid steel. The layer of slag floating above the steel absorbs these impurities. Some elements are then added to the steel for further refinement and tuning of its chemical structure, these elements may contain Calcium, Aluminum or ferroalloys. In addition to capturing the impurities, the bubbling of the Argon produces a stirring behavior that ensures the homogeneity of the steel. To achieve more advanced alloy recovery, a Composition Adjustment by Sealed Argon bubbling with Oxygen Blowing (CAS-OB) system. In this system, a bell is lowered into the steel surface simultaneously with the blowing of Argon from the bottom, which creates a steel "eye". However, the CAS-OB is designated such that it has an inert atmosphere to guarantee a complete isolation of the steel from the outside atmosphere. The two snorkels of the RH degasser are inserted into the surface of the ladle. Argon gas is injected so that the steel is sucked up through the leg of the degasser and ponded within the lower vessel of the degasser, then it is circulated again to the ladle through the lower leg. The internal atmosphere of the vessel has a very low pressure (1-2 torr) which makes the suction process easier, also, such a low pressure catalyzes the reaction between carbon and oxygen in the steel. The resulting gases of the chemical reaction, namely, CO and CO_2 are evacuated from the chamber. The main aim of the process is to further reduce the carbon concentration from 0.04% to 0.001%. Similarly, a Vacuum Tank Degasser (VTD) is also responsible for further refinement functionalities, for instance, it reduces the concentration of unwanted dissolved gases like H_2, N_2, O_2, improve temperature and composition homogeneity of the steel bath. Moreover, it removes oxidized materials from the liquid steel, which creates a preferable environment for final desulfurization. Same as in RH-Degasser, the liquid steel is stirred by injected Argon to assure its uniformity, as well as to ease the gas evolution. It is worth mentioning that there are three methods for gas evacuation from chambers, these are: mechanical pumps, steam jet ejectors or water ring pumps.

Ladle metallurgy furnace

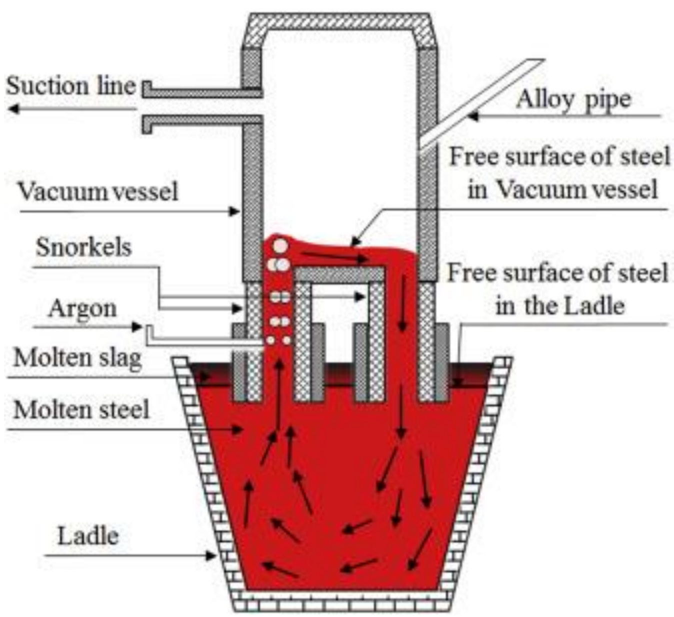

Fig.4: Vacuum Degasser

primarily designated to relieve the primary steelmaking furnace of many secondary refining operations. Below are some of its most important functionalities:

- It uses graphite electrodes to reheat the liquid steel by electric power.
- Induces gas stirring for homogenizing the steel bath temperature and chemistry.
- Prevents refractory from being damaged by the arc.
- Captures impurities and oxide inclusions.
- provides a suitable environment for final desulphurization.

Other minor operations include:

- Conducts Alloy bulk or trim chemical manipulation.
- provides a suitable environment for both deep and normal desulphurization.
- Cored wire addition for trimming or morphology control.

Casting is a process in which the liquid steel is transformed into a semi final product of predetermined geometry under controlled cooling. The most common products produced by

d. Casting

the casting process include blooms, slabs, strips, thin slabs, billets or net shapes. In this report only the first three types are to be discussed:

Blooming

A process in which blooms are continuously casted by a bloom caster. Blooms are the semi finished product of steel usually used in the production of long and heavy structural members such as the structural columns and beams. The cross section of a bloom is usually square or rectangular with the sides ranging from 200 to 600 mm depending on the type of the final product. The casting process takes place when the ladle pours the liquid steel into a tundish, the steel in the tundish flows down to the nozzle of the tundish to be tapped into the casting mold. The main use of the tundish is to maintain a continuous casting rhythmus, by providing a buffer between the alternating ladles. The tundish is considered the last chance for the trapped inclusions to float and be absorbed by the slag before entering the mold. As the steel is being casted, the mold is moving upward and downward allowing the steel to compact itself. While in the mold, the molten steel is supplied with a certain amount of mold powder or oil to prevent it from sticking to the mold. The steel then leaves the mold and enters the "spray chamber" which sprays the surface of the steel with steady water sprays so that the steel is solidified to some degree. When the entire cross section of the steel is frozen, the process is termed " metallurgical length of the caster. The large solidified product is then cut into individual blooms by a gas torch system. The blooms are transported to the proper mill by an overhead crane or rail cars.

Slabs

A typical slab is usually casted such that it has a rectangular cross section with a thickness of (150-500mm) and (1-3.05 m) width. The process in which a slab is casted is quite similar to that of a bloom including the flow of liquid steel from the ladle to the tundish and then to the mold through the tundish nozzle. Same process goes for the spray chamber and the cutting mechanism.

Steel Strips

A steel strip is a thin continuously casted product, having an initial thickness of 10 mm, which is then formed in rolls to its final thickness. The major difference between this product and the previous two is that there is no solidification mold, instead, two drums rotating in opposite directions are used to draw down the steel, exerting a solidifying force on it. Also the strip casting facility uses a descaler to remove the scale, water cooling sprays and a coiler. the strip is then coiled in the form of steel rolls, which are usually used in the production of hollow sections through cold rolling.

2. Chemical Composition of Steel

Ordinary steel or carbon steel consists of iron and carbon only. However many of the steel products characteristics may be changed or enhanced by chemical manipulation through adding other elements with different proportions. The most common elements that are used in the manufacturing of steel are Manganese, chromium, Nickel, Molybdenum, silicon, tungsten and Sulphur.

Carbon (C): it is the most important element in the steel making process, All steel alloys must contain carbon. In general, more addition of carbon results in raising the yield point of the steel, and thus its strength whereas the steel becomes more brittle and loses some of its ductility. Also, if the carbon content in steel exceeds a certain value (around 0.23%) it tends to lose much of its weldability. It was also found that high carbon concentrations are related to reducing corrosion resistance. It is always recommended to not exceed 0.20% carbon content for structural steel. On the other hand, going below 0.16% would result in significant strength reduction.

Chromium (Cr): Adding chromium to certain steel types might have many preferable effects on its quality, including hardness improvement and enhancement of the corrosion resistance. Steel which contains 13% chromium or more is usually called stainless steel. It is common to use chromium with nickel and copper since this combination improves the corrosion resistance of the steel.

Manganese (Mn): It acts as a stabilizing material through the molecular rearrangement it imposes on the steel. It is also considered an effective deoxidizer and a desulfurizer during the manufacturing process. The hardness and strength of steel are also increased by adding Manganese due the atomic structure it creates in the steel (lattice structure). Addition of Manganese to the steel (especially when combined with sulfur and oxygen) is crucial to improve the hot rolling process of steel. The typical range of Manganese amount in steel is usually 0.5% to 1.5%..

Molybdenum(Mo): it functions as carbonizing agent, which prevents the undesired brittleness that carbon adds to steel. Furthermore, it enables the steel to retain strength under high temperature as well as improving the steel ability to resist wearing. The amount of added Molybdenum varies highly between different grades of steel, however, it is usually within 0.08% and 0.65%.

Nickel (Ni): Adding Nickel to steel makes it better at resisting fracture due to low temperature as well as improving its resistance to acids and bases. The amount of Nickel in steel is usually between 0.25% and 1.50% depending on the grade of the structural steel. Nickel also helps steel to retain its desirable ductility.

Aluminum (Al): Aluminum is the element responsible for the development of the crystalline microstructure of steel. It is also considered a very powerful deoxidizing agent in steel.

Vanadium: Usually added to steel by amounts within 0.03%-0.18%. Its function in steel is similar to some degree to that of Aluminum, which is the refinement of the fine grained microstructure of steel. It also enhances the steel’s ability to resist low temperature fracturing (fracture toughness). Wear resistance and ductility are also increased by Vanadium addition.

Copper(Cu): Copper is the main corrosion resisting element in steel, with a percentage not less than 0.2%

Silicon(Si): Silicon addition is correlated to better strength development in steel, as well as increasing its elastic limit. Similar to Aluminum, Silicon is considered a primary deoxidizer during the manufacturing process of the steel. However, high silicon contents are found to decrease the weldability of steel. The Silicon content should be less than 0.4% in most types of structural steels.

Colombium(Cb): Its main use is to enhance strength characteristics of the structural steel, In addition to fight against external corrosive agents that steel might be exposed to.

Sulfur (S): It is an undesirable elements in structural steel. It has significant impact in lowering the toughness and ductility of steel which might lead to cracking of steel while shaping by rolling or when the steel is forged. Corrosion resistance is decreased by adding sulfur as well as its weldability. High concentration of Silicon might induce segregation in the crystalline microstructure of the steel while manufacturing. The Silicon content should be subjected to serious monitoring, namely, 0.05% is the maximum allowable concentration.

Phosphorus (P): Is also an unwanted element in steel with similar negative impacts as those of sulfur. including, bad weldability, lowering corrosion resistance and reduced plasticity.

These were the major elements that most of the structural steels are chemically composed by, and are usually added by relatively significant amounts. However, there are many other elements added to steel in smaller amounts for certain functionalities such as tungsten, titanium, Nitrogen, Boron. Majorly, these elements are used to support and enhance the desired effects of the previous primary elements.

3. Shaping of Steel

Shaping of steel as a final commercial product, either flat or long, is accomplished by rolling or forging the corresponding semi-finished cast products or blanks. When steel is cast into either slabs, blooms, billets, rounds or ingots, the internal, as-cast crystal structure is set up with very poor mechanical and physical properties. The process of incrementally reducing the cross-sectional area of the semi-finished cast product breaks down the as-cast structure while the steel is at an elevated temperature. Upon cooling, the steel will recrystallize and form a grain structure, which provides a basis for further processing to establish the final product's mechanical properties. Commercial steel products include plate, hot rolled coils (HRC), cold rolled coils (CRC), structural long products, bars and wire rods, rails, seamless tubes, and pipes.

Hot Rolling:

Hot rolling is a process in which steel is shaped by roll pressing at a very high temperature. Getting steel to high temperatures above 1700^{o}F makes the shaping process much easier, since the steel goes above its recrystallization point at such temperatures. The final manufacturing process starts with the suitable semi final steel product, which might be a bloom, a slab, a billet or any other type. The product is first heated to be then inserted in a large roll (two counter rotating rolls) that flattens the heated steel. The steel is maintained at its high temperature and then is rolled through another specified roll series to obtain its final dimensions. If the semi final product is a sheet steel, it is made into coils before cooling

Upon cooling, the steel shrinks to some instinct, which results in changing the dimensions of the final product, thus, it is not recommended to use hot rolled steel in high specifiction projects. Rather, it is used where no crucial restrictions are required on the dimensions of the member. Some of the applications that use hot rolled steel are rail tracks and small scale construction projects. Most types of hot rolled steels lack quality finished, due to the scaled surfaces that appear due to cooling from the tremendous heating temperatures. However, in cases where surface finish is necessary, some treating operations such as grinding, acid bath pickling or sand blasting. Compared to cold formed steel, hot rolling needs much less processing which is the reason why it's cheaper. Also the less precise finishing and shrinkage results in making the edges of the steel products slightly rounded.

Cold forming:

Cold forming of steel is majorly the extended shaping process of the hot rolled steel. It essentially includes another rolling process of steel at room temperature so that higher precision and dimensional quality control along with better surface finish are furtherly achieved. even though cold forming is mainly flattening of sheets through a roller series, cold forming also includes other different finishing processes such as grinding, turning polishing which all are processes used for further refinement of hot rolled steels. Cold rolling usually produces more finished and smooth surfaces with restrict tolerances, that have greasy texture. Unlike hot rolling, cold forming products have square and well defined edges. cold rolled steels usually posses better characteristics than hot rolled ones, where the strength and hardness is higher for the cold rolled products, furthermore, it is better at resisting tensile breaking and deformation. The additional processes conducted by cold rolling induce internal stresses within the product which may result in warping of steel if the these stresses were not relieved prior to fabrication. The higher shape quality and dimensional precision of hot rolled steels make them more suitable for precision demanding projects as well as projects that take aesthetic aspects in consideration.

4. Heat treatment of steel

Quenching:

A process in which the final steel product is rapidly cooled in water or oil by immersion. Bringing steel to quench is crucial for adjusting and maintaining the mechanical properties associated with the fine grained crystalline structure (the phase distribution) which would be considerably decreased with slow cooling. The process starts by uniformly heating the steel piece for about 815 to 900o C. It is also important to avoid overheating and uneven heating the sample to achieve the specified material properties. The workpiece is then suddenly submerged in an oil or water bath so that it cools in a sudden action. Also, it is very important to maintain uniformity in the temperature of the submerging material. Water is considered a very good quenching fluid especially where significant hardness is required. However, water may induce cracking and distortion of the final product. Mineral oils may be utilized when hardness may be compromised. Using oils for quenching may result in sludge accumulation which lowers the efficiency of the process. The direction and position of quenching should be considered if distortion is to be lessened. For instance, long cylindrical workpieces should be quenched vertically whereas sheets and flat products should be quenched on edge. On a microscale, when steel quenches, an internal phase transformation series take place, where austenite turns into martensite in large amounts. The latter would cause the steel to be excessively hard and brittle.

Tempering:

As mentioned above, the products treated by quenching are very brittle, this is where tempering is needed. This heating treatment process includes heating the steel to high temperatures without reaching its melting point since this would cause the destruction of the very hard quenched microstructure (Mertinsite) , and cooling it afterwards (usually in air). Such a process is used for reliving the internal stresses in steel as well as reducing its brittleness which is beneficial in making the steel tougher. Depending on the application and the grade of steel, tempering treatment temperatures vary, usually from 315^o to 1270^o C. The time and temperature of heating should be precisely controlled so that all the specified properties are achieved. Steel tempered at high temperatures usually has a lower hardness, yield strength and tensile strength in the favor of achieving higher elasticity and plasticity. On the other hand, tempering steel at low temperatures is utilized in reliving the internal stresses in steel and to decrease its brittleness while retaining most of the hardness.

Other Important heat treatment operations are:

Annealing:

In annealing, the metal is heated beyond the upper critical temperature and then cooled at a slow rate. Annealing is carried out to soften the metal. It makes the metal more suitable for cold working and forming. It also enhances the metal’s machinability, ductility and toughness. Annealing is also useful in relieving stresses in the part caused due to prior cold working processes. The plastic deformations present are removed during recrystallisation when the metal temperature crosses the upper critical temperature. Metals may undergo a plethora of annealing techniques such as recrystallisation annealing, full annealing, partial annealing and final annealing.

Normalising:

Normalising is a heat treatment process used for relieving internal stresses caused by processes such as welding, casting, or quenching. In this process, the metal is heated to a temperature that is 40° C above its upper critical temperature.This temperature is higher than the one used for hardening or annealing. After holding it at this temperature for a designated period of time, it is cooled in air. Normalising creates a uniform grain size and composition throughout the part. Normalised steels are harder and stronger than annealed steel. In fact, in its normalised form, steel is tougher than in any other condition. This is why parts that require impact strength or need to support massive external loads will almost always be normalised.

Hardening:

The most common heat treatment process of all, hardening is used to increase the hardness of a metal. In some cases, only the surface may be hardened. A work piece is hardened by heating it to the specified temperature, then cooling it rapidly by submerging it into a cooling medium. Oil, brine or water may be used. The resulting part will have increased hardness and strength, but the brittleness increases too simultaneously. Case hardening is a type of hardening process in which only the outer layer of the work piece is hardened. The process used is the same but as a thin outer layer is subjected to the process, the resultant work piece has a hard outer layer but a softer core. This is common for shafts. A hard outer layer protects it from material wear. When mounting a bearing to a shaft, it may otherwise damage the surface and dislocate some particles that then accelerate the wearing process. A hardened surface provides protection from that and the core still has the necessary properties to handle fatigue stresses.

Ageing:

Ageing or precipitation hardening is a heat treatment method mostly used to increase the yield strength of malleable metals. The process produces uniformly dispersed particles within a metal's grain structure which bring about changes in properties.

Precipitation hardening usually comes after another heat treatment process that reaches higher temperatures. Ageing, however, only elevates the temperature to medium levels and brings it down quickly again.

Some materials may age naturally (at room temperature) while others only age artificially, i.e. at elevated temperatures. For naturally ageing materials, it may be convenient to store them at lower temperatures.

Stress Relieving:

Stress relieving is especially common for boiler parts, air bottles, accumulators, etc. This method takes the metal to a temperature just below its lower critical border. The cooling process is slow and therefore uniform.

This is done to relieve stresses that have built in up in the parts due to earlier processes such as forming, machining, rolling or straightening.

5. Mechanical properties of Steel

Most of the mechanical properties that structural engineers consider for designing steel structures are obtained from the stress strain diagram which is obtained from the tensile test of steel. This test is performed through loading a specimen of a certain length (L_0) and a certain cross sectional area (A_0) with a normal tensile load, and observing the change of the specimen's length (δ) that corresponds to each loading magnitude. The test's main objective is to determine the tensile strength of steel, in addition to constructing a relationship between the loading and deformation. However, it is impractical to perform the test on each element that differs in size (different L_0 and A_0), hence, rather than drawing a force-elongation curve, the values of force are turned into stress values (σ, force per unit area), and the elongation values are turned into strain values (Ɛ, elongation per unit length -dimensionless-), and therefore, a Stress-Strain diagram is constructed instead.

There are two types of Stress-Strain diagrams: The Conventional or Nominal Stress-Strain diagram, and the true Stress-Strain diagram. The true Stress-Strain diagram is built by using the instantaneous area ($\sigma = PA$) in calculating the stress, and the instantaneous specimen length (L) in calculating the strain ($\varepsilon = \delta A$). However, this type of Stress-Strain diagram is rarely used. Instead, in most engineering applications, engineers prefer to use the conventional one. Unlike the previous type, the conventional Stress-Strain diagram uses the original cross sectional area and length (A0 and L0) to calculate the stresses and strains throughout the experiment.

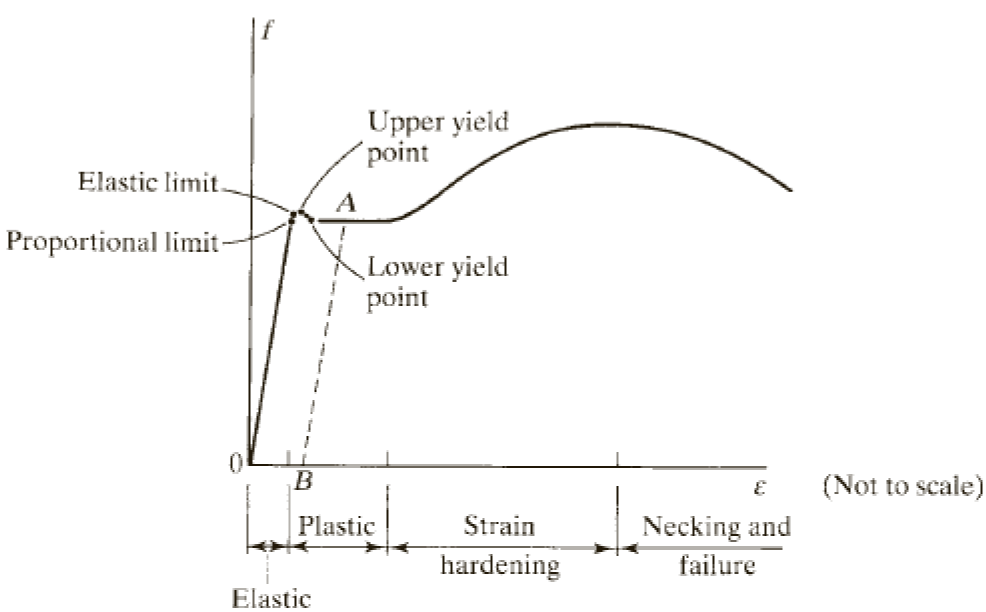

Fig.5: Stress–strain diagram

The curve is usually divided into 4 regions as follows:

1. **Elastic Behavior**: during this region, one could say that the strain is linearly proportional to the stress (in most of the region). In other words, by increasing the stress value the strain is also increased at a constant rate. The curve remains a straight line until the proportional stress limit (σpl) is reached. The term elastic means that if the load is removed while the specimen is still in the elastic region, the original dimensions of the specimen are restored. The slope of the straight line is called 'the modulus of elasticity' or 'Young's modulus' (E); and it is a unique characteristic which indicates the material's shape restoration capacity, as well as its ability to resist deformations. The relationship between the three values (σ,ε and E) is called Hook's law, and it only applies within the elastic region.
2. **Yielding:** if the stress slightly increases beyond the elastic limit, the material loses its elasticity and starts to yield and to deform permanently. This behavior is called yielding, and it happens when the stress reaches a value called the yielding stress (σY) and the deformation caused by stresses above this value are called 'plastic deformations'. It could be noticed that within this region the material keeps to elongate under the influence of the same magnitude of load. The material in this state is said to be 'perfectly plastic'.
3. **Strain Hardening**: after yielding ends. The curve goes back to rise up, but flattens gradually until it reaches a maximum value of stress called the ultimate stress (σu). The term strain hardening refers to the increase in the curve, which implies that the material has gained some of its ability to resist a higher load.

4. **Necking**: this is the region where a huge localized decrease in the specimen's cross sectional area occurs. The curve within this region starts to go down until the specimen's fail and fractures at the fracture.

There are other properties and mechanical characteristics that are involved in the design process:

Young's Modulus of Elasticity (E): this modulus express how the steel responds to deformation due to external stresses and loadings. Most types of steel have E within a range of 190 to 210 GPa. And it is represented by the slope of the curve within the elastic region.

Yield strength (f_y):

Which is the stress if exceeded, the steel starts behaving plastically and is no further elastic. Most structural steels have fy between 350 and 1750 MPa.

Poisson's ratio (U):

The ratio of the steel's longitudinal elongation or contraction to its axial elongation or contraction. Most steels have U between 2.6 and 3.0.

Hardness:

It is the ability of steel to resist abrasion or scratching or abraision. This property is mainly significant while dealing with mechanical objects rather than structural such as drills, tool bits and mills nevertheless, structural steels should have hardness of 86-388 Kg.

Toughness:

it is the steel's ability to absorb maximum energy and to deform plastically before it fractures. It is also the ability to resist brittle fracture that is dependent on a number of factors that should be considered at the specification stage. A convenient measure of toughness is the Charpy V-notch impact test. This test measures the impact energy required to break a small notched specimen, at a specified temperature, by a single impact blow from a pendulum.

Ductility:

Ductility is a measure of the degree to which a material can strain or elongate between the yield and ultimate fracture under tensile loading. The designer relies on ductility for a number of aspects of design, including redistribution of stress at the ultimate limit state. As well as providing sufficient warning before failure.

Weldability:

Welding steel is to perform local melting on its surface. Most of the structural steel are considered weldable. This is a very important characteristic of structural steel especially when steel joints are made. The cooling of the welded area can be quite fast because of the ambient temperature, e.g. the beam, offers a large 'heat sink' and the weld (and the heat introduced) is usually relatively small. This can lead to hardening of the 'heat affected zone' (HAZ) and to reduced toughness. The greater the thickness of material, the greater the reduction of toughness.

6. Structural Steel Grades and Shapes:

Standard Organizations have classified structural steels into various categories depending on their chemical composition and physical properties so that to assure that the manufactured steel is consistent with the specifications and standards.

American grades of structural steel:

American grades of structural steel are specified by ASTM. The following table illustrates the properties of the most common amerian grades of structural steel:

Standards	Grades	Yield strength Re	Tensile strength Rm	Ratio Re / Rm	Minimum elongation		Notch impact test	
					min. 200 mm [8 in.]	min. 50 mm [2 in.]	ASTM A673, standard position longitudinal flange	
		MPa [ksi]	MPa [ksi]		%%		Temperature °C (°F)	Energy average J [ft-lbf]
A36 - 04b	A36	≥250 [36]	400-550 [58-80]		20	21		
A572 - 04	Grade 42 Grade 50 Grade 55 Grade 60 Grade 65	≥290 [42] ≥345 [50] ≥380 [55] ≥415 [60] ≥450 [65]	≥415 [60] ≥450 [65] ≥485 [70] ≥520 [75] ≥550 [80]		20 18 17 16 15	24 21 20 18 17		
A588 - 04	Grade B Grade C	≥345 [50] ≥345 [50]	≥485 [70] ≥485 [70]		18 18	21 21		
A709 - 04a	Grade 36 Grade 50 Grade 50S	≥250 [36] ≥345 [50] 345-450 [50-65]	400-550[58-80] ≥450 [65] ≥450 [65]	 ≤0.85	20 18 18	21 21 21		
A913 - 04	Grade 50 Grade 65	≥345 [50] ≥450 [65]	≥450 [65] ≥550 [80]	≤0.85	18 15	21 17	21 [70] 21 [70]	≥54 [40] ≥54 [40]
A992 - 04a	A992	345-450 [50-65]	≥450 [65]	≤0.85	18	21		

Other Structural grades are listed below:

Carbon steels

- A36 - structural shapes and plate
- A53 - structural pipe and tubing
- A500 - structural pipe and tubing
- A501 - structural pipe and tubing
- A529 - structural shapes and plate

High strength low alloy steels

- A441 - structural shapes and plates
- A572 - structural shapes and plates
- A618 - structural pipe and tubing
- A992 - W shapes beams only
- A270 - structural shapes and plates

Corrosion resistant high strength low alloy steels

- A242 - structural shapes and plates
- A588 - structural shapes and plates

Quenched and tempered alloy steels

- A514 - structural shapes and plates
- A517 - boilers and pressure vessels

European grades of steel:

European structural steel is governed by the European standard EN 10025, which follows the European Committee for iron and steel Standardization (ECISS).

The most common types of European structural steel are S235, S275 and S355, which are used at a very wide range for construction purposes.

The grade's abbreviation is formulated as follows:

For S235 J2 K2 C Z W JR JO:

- **S**: Indicating structural steel
- **235**: The minimum yield strength of the steel (tested at a thickness of 16 mm)
- **J2/K2/JR/JO**: The toughness of steel in accordance with the Charpy impact or 'V'notch test methodology
- **W**: Weathering steel (atmospheric corrosion resistant)
- **Z**: Structural steel with improved strength perpendicular to the surface
- **C** : Cold-formed

Table (2): US and Euoropian equivalent grades

US	EU
A283C	S235
A570Gr40	S275
A572Gr50	S355

Sructural steel members come in various shapes and profiles, the most common of which are illustrated in the figure below:

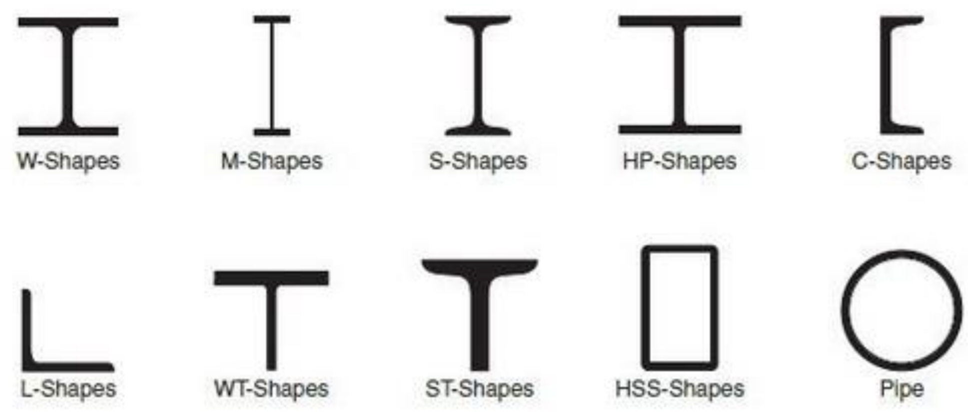

Fig.6: Structural steel common shapes

• **W-shapes**: which have essentially parallel inner and outer flange surfaces.

• **M-shapes**: which are H-shaped members that are not classified in ASTM A6 as W-, S-, or HP-shapes. M-shapes may have a sloped inside flange face or other cross-section features that do not meet the criteria for W, S, or HP-shapes.

• **S-shapes:** (also known as American standard beams), which have a slope of approximately 16 $^{2}/_{3}$ percent (2 on 12) on the inner flange surfaces.

• **HP-shapes**: (also known as bearing piles), which are similar to W-shapes, except their webs and flanges are of equal thickness and the depth and flange width are nominally equal for a given designation.

• **C-shapes**: (also known as American standard channels), which have a slope of approximately 16 $^{2}/_{3}$ percent (2 on 12) on the inner flange surfaces.

• **MC-shapes**: (also known as miscellaneous channels), which have a slope **other than** 16 $^{2}/_{3}$ percent (2 on 12) on the inner flange surfaces.

• **HSS**: a) Rectangular HSS, which have an essentially rectangular cross-section, except for rounded comers, and uniform wall thickness, except at the weld seam(s). b) Square HSS, which have an essentially square cross-section, except far rounded corners, and uniform wall thickness, except at the weld seam(s). b) Round HSS, which have an essentially round cross-section and uniform wall thickness, except at the weld seam(s).

•**Angles**: (also known as L-shapes) have legs of equal thickness and either equal or unequal leg sizes. Angles are designated by the mark L, leg sizes (in.) and thickness (in.). For example, an L4X3X1/2 is an angle with one 4-in. leg, one 3-in. leg, and 1/2-in. thickness.

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