CHAPTER 3

STEEL MAKING PROCESS

3.1 INTRODUCTION

Humans have been involved in the manufacture of steels for hundreds of years. Steel kindled the industrial revolution and remains the most important part of the current industrialized financial system. Steel is extensively used in buildings, industry, vehicles, packaging, energy sector, agriculture, home appliances, etc., and hence it is hard to envisage a world devoid of steel. Steel’s adaptability, in terms of its strength-to-weight ratio, its properties and composition, and its capability to be endlessly recycled into new goods makes steel aside from other materials and has been useful in its continuing achievement. This chapter discusses about the steel history, metal properties, steel types and the processes involved in steel making.

3.2 HISTORY OF STEEL MAKING

The iron and charcoal jointly came during thirteenth Century BC. Ancient blacksmiths noticed that iron when left in charcoal furnaces turns out to be sturdy and rigid. In the beginning of the third century BC, the wootz steel was made by south Indian craftsmen using crucibles. In Roman epoch, the regal armies, Greece, Rome, China, and Persia, were desirous for robust, long-lasting weapons and protective shields. The way of tempering the work-hardened steel was learnt by Romans to minimize its frailness. During the third century AD, the craftsmen of Chinese produced good quality steel,
probably having a little bit of similarity to the Bessemer process that was developed only in Europe during the nineteenth century. In the fourth century, the rust resistant steel was produced. The oldest existing example of rust resistant steel is the Iron Pillar of Delhi, India.

During the tenth to thirteenth centuries, the procedure of making iron based on raw-material was realized. Around 300BC to 1700AD, the Damascus steel produced in India was used in making swords. The land of Serendib, Sri Lanka, appears to have been the world’s primary provider of crucible steel in the twelfth century, prior to its further improvement as late as 1740 by English inventor Benjamin Huntsman. In the sixteenth century, manual on metallurgy was published by Italian metallurgist Vannoccio Biringucio. Steel was perceived and entrenched as a precious material in the eighteenth century. In the same period, costly steel was manufactured in constrained amounts by artisans and costly was furthermore exploited in applications other than artillery and protective shield. In the eighteenth century, Sweden was leading in the production of steel and novel methods started to develop, which improved its reliability and quality.

In 1709, coke was initially used for smelting iron mineral. Charcoal and wood, which were getting to be distinctly harder to acquire, were slowly replaced. In 1712, first financially viable steam engine was constructed by English ironmonger Thomas Newcomen. Steel combined with steam became progressively the key drivers of the manufacturing rebellion. In 1740, an English inventor Benjamin Huntsman developed the crucible steel method. Superior quality steel was looked for, because of its pervasiveness in clock springs. The Scottish inventor James Watt enhanced the Newcomen device in 1769, and patents first effective steam engine. In 1779, early factories had run effectively with water power, yet by utilizing a steam engine a plant could be situated wherever, not quite necessarily to be near water. In 1783, the steel
roller for the manufacturing of steel was invented by Englishman Henry Cort. In 1794, Welsh Ironmaster Philip Vaughan patented a design for steel ball rollers to hold up the axle of a carriage.

An English engineer Henry Bessemer was born in 1813, at Charlton, in Hertfordshire. Bessemer was a productive creator throughout his life. His name was essentially known regarding the Bessemer process for the making of steel. It has made him well known all through the humanized world. The harvesting machine produced in 1834 by Cyrus McCormick, an American originator and organizer of the McCormick Harvesting Machine Company, went into extensive usage. It was most widely utilized after the American Civil War (1861–1865). In 1834, combine harvester was invented by Hiram Moore. In 1837, Deere’s plough modernized farming, facilitated agriculturists to achieve more from their terrain than at any other time and to nourish their nation’s inhabitants. Also, in 1837, both in Europe and in the US, cultivation progressively became automated, utilizing machineries that depend on the quality of steel. In 1855, the Bessemer process was the principal cheap manufacturing process for the large scale manufacturing of steel from liquid pig iron.

Sir Carl Wilhelm Siemens developed the Siemens regenerative heater in the 1850s, and alleged in 1857 to recoup enough warmth to save 70–80% of the fuel. In 1860, the primary moves from rustic to urban presence, the steel rails, which is the base of railways, start to open up the United States (US). In the years after the Civil War, the American steel manufacturing plants developed with amazing rate as the country’s economy, prolonged to turn out to be the biggest in the world. In 1865, combined with former steel manufacturing process, the Bessemer process, the open hearth furnace guaranteed that the manufacturing of steel improved massively. In 1868, Robert Mushet invented the tungsten steel. In 1873, Barbed wire, which
was the primary wire technology proficient of controlling cattle, played a vital part in the safeguarding of range rights in the US West. In 1876, Amalgamated Association of Iron, Steel, and Tin Workers (AAISTW) were formed in the US to represent iron and steel workers. However, technological advances were already lessening the number of expert laborers in industries. In 1883, Brooklyn Bridge in New York City (first steel wire suspension bridge) and first skyscraper (ten stories) in Chicago was constructed.

During the twentieth century, there was critical development and nationalization of steel making because of the requests for military appliances. In World War I, shipping and rail transport created closed boundaries, but opened them amid World War II. The U.S. Steel Recognition Strike of 1901, which did not succeed was an effort by AAISTW to reverse its deteriorating fortunes. In 1912, stainless steel came into the picture. Stainless steel brought enormous advantages both to people and industry. The creation of stainless steel, which was formally hundred years of age in May 2012, was usually ascribed to one Harry Brearley from Sheffield. During 1914-1918, World War I artillery comprised of different sorts of steel weapons standardized and enhanced over the previous period together with some recently created varieties utilizing inventive technology and a quantity of ad-lib weapons utilized in trench war. Military technology prompted to essential advancements in artillery, bombs, poison gas, and guns, along with the warship, tank, and the warplane.

During 1939-1945, the twentieth century’s two world wars had immense outcomes in manufacturing of steel. Similar to other ponderous industries, steel manufacturing was nationalized in numerous countries because of requests for military appliances. Steel was necessary for the ships and railways that conveyed goods and troops. Steel plates were considered essential in the improvement of shipping and different types of transport, and
also for apparent military utilizations. Huge advancements were made in steel manufacturing processes in the 1950s and 1960s, which permitted steel production to move far from shipping and military to vehicles and home goods, which brought a massive development in the scope of steel home goods that were made accessible to customers. Post-war European Union (EU) trade was also a vital reason in the hunt for resources and the sales of completed merchandise.

The European Coal and Steel Community (ECSC) was formed subsequent to the Treaty of Paris (1951) by 'the inner six': Italy, France, the Benelux countries (Belgium, Netherlands and Luxembourg) and West Germany. In 1950s, Electric Arc Furnace (EAF) was developed. During the 19th century, several men had utilized an electric arc to dissolve iron. The invention of EAF facilitated the scrap steel to be effectively and inexpensively reprocessed. In the same 1950s, continuous casting also known as strand casting was evolved. The procedure of strand casting is to solidify the liquid metal into 'semi-finished' materials for consequent rolling in the finishing factories. At the end of 1950s, shipping containers, which were huge recyclable steel boxes utilized for intermodal consignments, facilitated normalization. In 1959, the most recent technologies were offered by Mini mills in smaller plants, which privately owned corporations could have enough funds to operate. The growth of mini mills concurred with an expansion in the accessibility of scrap.

In 1967, the World Steel Association was established as the International Iron and Steel Institute (IISI) in Brussels, Belgium to advance steel and its manufacturing plant to prospective clients, the media, and the community. Nucor, which is presently one of the biggest steel manufacturers in the US, chose to enter the extensive goods market in 1969. They decided to set up a mini mill, with an EAF as its steel manufacturing core, a shift that
was almost immediately trailed by other producers during the 1970s. Duplex stainless steel was developed in 1970. Stainless steel was utilized for constructing both realistic and artistic reasons. Stainless steel was in trend during the Art Deco period. In 1990s, the steel manufacturing plant has perceived its concentration to move in the direction of the rising market, as these needed an enormous quantity of steel for industrialization and urbanization. The fall of the Berlin Wall in 1989 was pursued by the demise of the Soviet Union during the 1990s. Russia had formerly been the world's largest steel manufacturer.

ArcelorMittal was the first worldwide steel corporation in 2006 from the conquest and the amalgamation of Arcelor by Mittal Steel. During its development, it was the world's largest steel producer. In 2011, Nippon Steel unified with Sumitomo Metal to develop into the world's second biggest steel manufacturing corporation in the world. During the end of 2011, China was by far the world’s biggest steel manufacturing corporation, with a productivity of a little more than 680 million tonnes. The making of World crude steel has reached 1,621 million tonnes (Mt) in 2015, losing by 2.9% compared to the year 2014. In 2015, China represented 44.8% of the worldwide market for steel, contrasted with 45.9% in 2014.

Steel is hundred percent recyclable without any drop in quality, which makes steel one of the most reused materials on the planet. However, steel manufacturing is not separated; it is presided over by numerous policies, regulations, laws, and limitations. Hence, in future, the community and the government should formulate knowledgeable choices on where and how to wisely include additional guidelines and confinements. Effective steel manufacturing has to work inside these systems and keep on exploring new manageable routes forward into what's to come (Source: The Steel Story).
3.3 PROPERTIES OF METAL

The chemical components containing metallic possessions are known as metals. Metallic properties are characterized as shiny, fine thermal and electrical conductivity, and the capacity of being enduringly moulded or warped at room temperature. Chemical components missing these properties are known as non-metals. Some components, known as metalloids, occasionally perform similar to a metal and at other occasions similar to a non-metal. A few examples of metalloids are tellurium, sulfur, boron, and arsenic.

An alloy is characterized as an element containing metallic properties and is a mixture of two or more components. The components utilized as alloying substances are typically metalloids or metals. The properties of an alloy vary from the properties of the metalloids or unadulterated metals that form the alloy and this variation is what makes the utility of alloys. By mixing metalloids and metals, makers can create alloys that have the specific properties necessary for a particular use. Some examples of alloys are bronze, steel, wrought iron, brass, and pewter.

Steel manufacturers seldom work with components in their unadulterated condition. Mainly the steel manufacturers work with alloys and have to comprehend their attributes. The attributes of alloys are described based on chemical, mechanical, physical, and electrical properties. Chemical properties entail the behaviour of the metal when sited in contact with the air, saline water, or other materials. The mechanical properties relate to flexibility, load-carrying capacity, rigidity, and wear resistance. Physical properties relate to color, thickness, heaviness, and warmth conductivity. Electrical properties include the electrical conductivity, resistance, and magnetic characteristics of the metal.
The metal’s mechanical properties are one of the major considerations at the time of choosing goods for work. The different properties of alloys and metals were ascertained in the laboratories of manufacturers and by the peoples who have interest in metallurgical growth. Some of the metal properties can be found by conducting simple tests, but these analyses are utilized only as an aid to identify a part of the stock.

3.3.1 Mechanical Properties

Ductility, strength, fragility, rigidity, toughness, flexibility, plasticity, and pliability are the mechanical properties that are utilized as measurements of how metals act under a load. These properties are explained based on the sorts of stress or force that the metal must endure and how these are opposed. General sorts of stress are tension, torsion, compression, impact, shear, or a mixture of these stresses.

Tensile stress is developed, when a substance is subjected to elongation. For example, while a wire rope is used for lifting a load or as a guy to fix a satellite dish. Tensile strength is characterized as an opposition to a pull or longitudinal stress and can be gauged in pounds per square inch of cross segment. Compression stress is developed within the substance, when it is subjected to compression. A column which holds the overhead beam is an example for compression. Shear stresses take place inside a substance when exterior forces are applied along parallel lines in reverse paths. Shear forces can isolate a substance by sliding a portion of it in one path and the remaining on the reverse path.

A few substances are uniformly sturdy in shear, tension, and compression. But, numerous substances indicate noticeable variations; for instance, cured concrete has an utmost strength of 2,000 psi in compression, but only 400 psi in tension. Carbon steel has an utmost strength of 56,000 psi in compression and tension, but the utmost shear strength of merely 42,000
psi. So, while dealing with utmost strength, the kind of loading has to be specified at all times.

A substance that is stressed often, fails at a point significantly beneath its utmost strength in compression, shear, or tension. For instance, a thin steel bar can be shattered by hand by contorting it back and forth numerous times in the same position; but, if the equal force is applied in a stable movement (not twisted back and forth), the rod cannot be broken. The propensity of a substance to fail, subsequent to frequent bending at the same point is called as fatigue.

3.3.1.1 Strength

Strength is the property that allows a metal to withstand twisting under load. The eventual strength is the utmost strain that a substance can endure. Tensile strength is a gauge of the opposition to being pulled at a distance when kept in a tensile load. Yield strength or yield point is the property of the substance, characterized as the stress upon which a substance starts to distort plastically.

Fatigue strength is the capability of substance to withstand different sorts of quickly varying stresses and is expressed by the extent of irregular stress for a particular number of cycles. Impact strength is the capability of a material to withstand abruptly applied loads and is gauged in foot-pounds of force.

3.3.1.2 Hardness

Hardness is the property of a substance to withstand enduring indentation. Since there are various techniques of gauging hardness, the hardness of a substance is always denoted based on certain test that was utilized to gauge this property. A few of the techniques utilized for testing are Brinell, Rockwell, or Vickers. Of these tests, Rockwell is the one which is most commonly employed. The fundamental standard employed in the
Rockwell test is that a rigid substance can infiltrate a squashy one. Afterwards the quantity of infiltration is gauged and it is contrasted to a scale. For ferrous metals, that are typically more rigid than nonferrous metals, a diamond tip is utilized and the hardness is specified by a Rockwell “C” number. A metal ball is utilized and the hardness is specified by a Rockwell “B” number for nonferrous metals, which are squashy. The steel and lead can be compared to acquire knowledge about the properties of hardness. Lead can be scraped with a sharp wooden stick, however steel cannot, since it is more rigid than lead.

3.3.1.3       Toughness

Toughness is the property that permits a substance to resist stun and to be disfigured with no breaking. Toughness may be considered as a mix of plasticity and strength.

3.3.1.4       Elasticity

A substance gets disfigured, when a load is applied to it. Elasticity is the capability of a substance to get back to its original shape or size when that load is eradicated. Hypothetically, the limit of elasticity of a substance is the limits to which a substance can be loaded and still regain its original size or shape later than the load is removed.

3.3.1.5       Plasticity

Plasticity is the capability of a substance to disfigure enduringly with no rupturing. The property of plasticity is opposite to that of strength. By alloying the metals cautiously, the mixture of strength and plasticity is utilized to make big structural members. For instance, if the member of a flyover structure turns out to be overloaded, plasticity permits the overloaded member to stream the circulation of the load to different sections of the flyover structure.
3.3.1.6 Brittleness

The property of brittleness is opposite to the property of plasticity. A brittle metal is one that ruptures or breaks earlier than it distorts. The finest examples of brittle substances are glass and white cast iron. Normally, brittle metals have low tensile strength and more compressive strength.

3.3.1.7 Ductility

Ductility is the property that allows a substance to curl, expand, or curve, with no fissuring or rupturing. By this property a material can be made out into a thin wire.

3.3.1.8 Malleability

Malleability is the property that allows a substance to disfigure by squashier forces without making any imperfections. A malleable material is the one which can be carved, hammered into shape, hard-pressed, or rolled into thin sheets (Source: Metal Properties).

3.4 STEEL MANUFACTURING PROCESS

The steel manufacturing is reliant on coal worldwide. Seventy percent of the steel manufactured these days uses coal. The essential element in the steel manufacturing process is the coking coal or metallurgical coal. In 2013, the world crude steel manufactured was 1.6 billion tonnes. The production of steel delivers the merchandises and amenities that are required for the people, for example, healthcare, broadcast communications, enhanced farming practices, finer convey systems, fresh water, and access to consistent and reasonable energy.
Steel is an alloy, which is principally based on iron. Since iron is found as iron oxides in the earth’s crust, the ores have to be transformed, or lessened by utilizing carbon. The key raw material of this carbon is the coking coal. The process flow of steel making is shown in Figure 3.1 (Source: Steel Production).

### 3.4.1 Coke Making

Coking coal is transformed to coke by removing impurities to leave more or less unadulterated carbon. The physical properties of coking coal make the coal to melt, soften, and then re-solidified into rigid but permeable chunks when warmed in the non-existence of air. The coking coal should also have very small amount of phosphorus and sulfur. Nearly all metallurgical coal is utilized in coke kilns.

The coking procedure involves warming of coking coal at about 1000-1100ºC in the non-existence of oxygen to drive away the unstable composites (pyrolysis). This procedure results in a hard permeable substance called coke. Coke is manufactured in a coke battery that is made out of numerous coke kilns stacked in lines into which coal is laden. The coking procedure happens for a long time between 12-36 hours in the coke kilns. After that, the hot coke is extinguished with either air or water to cool it prior to storage or is moved straight to the blast furnace for manufacturing iron.
Figure 3.1 Process of steel making
3.4.2  Iron making

About fifty nations are mining iron ore. Among them China, Australia, and Brazil are the biggest iron ore producers. Approximately 98% of iron ore is utilized in steel manufacturing. At the time of iron manufacturing process, a blast furnace is loaded with the coke, iron ore, and a little amount of fluxes (raw materials, for example limestone that are utilized to collect contaminations). Air that is warmed to around 1200°C is blown into the furnace through spouts at the base. The air makes the coke to ignite, producing carbon monoxide, which reacts with the iron ore and heat for liquefying the iron. At last, the nozzle which is located at the base of the furnace is opened and the impurities (liquefied iron and slag) are evacuated.

3.4.3  Steel Making Methods

Steel is an alloy manufactured through two major methods, namely, Basic Oxygen Furnace (BOF) steelmaking and Electric Arc Furnace (EAF) steelmaking.

3.4.3.1  Basic oxygen furnace steelmaking

The most often employed method for steel manufacturing is the incorporated process of steel manufacturing through blast furnace and BOF. In the BOF, the iron is mixed with changing quantities of steel scrap (less than 30%) and little quantities of flux. About 99% of pure oxygen is blown through the lance to increase the temperature up to 1700°C. The contaminations are oxidized, scrap is liquefied, and the amount of carbon is lessened by 90%, which results in molten steel. The other procedures that follow are the secondary steel manufacturing process, where the steel properties are ascertained by adding other components, such as molybdenum, chromium, and boron to make sure that the accurate requirement can be
A good quality of raw materials is needed for the optimal operation of blast furnace.

The carbon content of coke consequently plays a vital role based on its effect in the furnace and on the quality of warm metal. A blast furnace loaded with good quality coke needs less coke input, results in superior quality warm metal and improved productivity. About 600 kg (0.6 tonnes) of coke manufactures 1000 kg (one tonne) of steel. At present, BOF manufactures around 70% of the global steel. An additional 29% of steel is manufactured in the EAF.

3.4.3.2 Electric arc furnace steelmaking

The EAF steel manufacturing procedure does not entail iron manufacturing. In EAF process the existing steel is reused, which evades the requirement for raw materials and their processing. The furnace is loaded with steel scrap and it can also include a small amount of Direct Reduced Iron (DRI) or pig iron for chemical stability. The EAF function is based on the principle of an electrical charge between two electrodes providing the warmth for the process. The electrical energy is supplied through the electrodes positioned in the furnace and that generates an arc of electricity of about 35 million watts through the steel scrap, which makes the temperature to increase up to 1600°C, liquefying the scrap. The impurities are removed by evacuating the slag and through the utilization of fluxes. EAF does not utilize coal as a raw material, however many are dependent on the power produced by coal-fired power station somewhere else in the network. The coal of about 150 kg is utilized to manufacture 1 tonne of steel in the EAF.
3.4.3.3 Other steel production methods

Pulverized Coal Injection (PCI) method entails the loading of coal straight into the blast furnace to supply carbon for manufacturing iron, reducing the coke necessary for the process. A broader variety of coals can be utilized in PCI, including steam coal that has an inferior amount of carbon than coking coal. This method has more merits, including minimization of general expenses and extending the lifetime of present coke batteries.

Recycling method involves reprocessing of old steel to manufacture new products. Steel recycling conserves natural resources and energy. About 30% of recycled steel is utilized in BOF steel making process and around 90-100% of recycled steel is used in EAF steel manufacturing process.

3.4.4 Ladle Refining Process

The molten steel from primary steel manufacturing furnaces such as EAF and BOF are subjected to ladle metallurgy for good quality or forte applications. The ladle metallurgy is also known as secondary steel manufacturing process or ladle refining process. The ladle refining processes are usually carried out in ladles or Ladle Furnace (LF). Tight control of ladle refining process is related to the manufacturing of high quality steel grades in which the tolerances in uniformity and chemistry are narrow. A few of the actions carried out in ladles comprises an alloy addition, deoxidation, desulphurization, homogenization, vacuum degassing, inclusion removal, and inclusion chemistry adjustment. The principal task of the ladle refining process is to fine tune the composition of the steel to meet the steel grade specifications and client desires (Gosh 2001).
3.4.4.1 Effects of alloying elements in steel

Alloying components are added to make alterations in the steel properties. Carbon (C) is the very significant component in most of the steel, which affects hardness and strength by heat treatment. The increase in the amount of carbon reduces the joinability and ductility. Aluminium (Al) is used as a deoxidizer. It controls the size of the grain. The austenite grain development in reheated steels can be controlled using aluminium. Boron (B) is added to steel to improve its hardenability. Occasionally boron is also added to austenitic stainless steel grades to enhance its high temperature potency. The amount of alloying component Cobalt (Co) can be utilized up to 10% in a few high speed steels. Cobalt turns out to be radioactive when it is revealed to nuclear radiation. Consequently, for radioactive applications it should not be there in steel. In stainless steels, Copper (Cu) can be used for the precipitation solidifying properties. Copper is also utilized in weathering steels.

Chromium (Cr) enhances the oxidation and rust resistance when it is added to steel. Moreover, chromium raises the solidifiability and enhances scratch and wear resistance when mixed with large amounts of carbon. Lead (Pb) advances machinability when it is added to steel. Manganese (Mn) alloying component contributes to stiffness and strength with a changeable quantity of carbon. Manganese is an austenite forming component in a few steels and has a major cause on hardenability. The base metal in steel is Iron (Fe). It can be mixed with other alloying components to make all kinds of steel. Iron is quite squishy and feeble in its unadulterated form. Molybdenum (Mo) is an alloying component added to chromium nickel austenitic steels to oppose corrosion and also in nickel chrome alloy steels to enhance rigidity and strength. Molybdenum is utilized in a few high speed steel grades.
Nickel (Ni) is a significant component which enhances tensile, hardenability, and impact values of steels. Adding nickel to high chromium stainless steels in quantities of more than 8% creates austenitic structures, which provides resistance to rust, corrosion, and high temperature strengths. Niobium (Nb) stabilizes carbon in a similar manner as titanium and makes the steel stronger for high temperature service. Adding, Nitrogen (N) to stainless steel enhances the austenitic firmness with improved yield strength. Phosphorous (P) is usually controlled to low levels. However, higher phosphorous can be utilized to enhance machineability. Selenium (Se) is added to enhance the machinability. Silicon (Si) is a primary deoxidiser in steel, utilized in silicon manganese, rust, and warmth opposing steels. Sulfur (S) is frequently added to steel to enhance the machineability, but does reduce the notch impact robustness and ductility.

Tantalum (Ta) is a refractory metal which extremely opposes rust. Tantalum belongs to the refractory metals group, which are extensively utilized as minor elements in precipitation solidifying stainless steels and alloys. Titanium (Ti) is an alloying element which is usually added to steel for the stabilization of carbide and mixing it with carbon produces titanium carbides. Tungsten (W) is the most significant component in high speed and a few tool steels. In the heat treated state, tungsten maintains rigidity at high temperatures and is mostly helpful for cutting tools. Vanadium (V) facilitates to enhance wear opposition and fatigue stress when utilized with other alloying components. Zirconium (Zr) alloying element can be added to high strength low alloy steels, affecting inclusion development, providing hardness and flexibility in curvature modes (Source: Elements in Steel).
3.4.5 Continuous Casting

Continuous casting is the process of solidifying molten steel from the ladle into a semi-finished slab, bloom, or billet. The semi-finished goods are then subjected to rolling in the finishing plants. In the 1950s, before the development of continuous casting process, the molten steel was poured into fixed moulds to make “ingots”. After that, continuous casting has progressed to attain enhanced manufacture, quality, and inexpensiveness (Source: Steel Works).

3.4.6 Rolling/Finishing

Rolling is the process of shaping metals. The metals are passed over sets of rolls to minimize and make its thickness standardized. The procedure of rolling is analogous to the rolling of dough. Rolling process is categorized into hot rolling and cold rolling based on the temperature of the metal rolled. If the metal’s temperature is higher than its re-crystallization temperature, then the process is called hot rolling and if the metal’s temperature is lower than its re-crystallization temperature, then the process is said to be cold rolling. Based on the usage, cold rolling processes additional tonnage compared to other strain hardening methods, and hot rolling processes the huge tonnage compared to other production methods. Roll stands carrying sets of rolls are gathered collectively into rolling mills that can rapidly process metal, normally steel, into materials such as structural steel, rails, and bars. Most steel manufacturing industries have rolling mill sections that convert semi-finished casting goods into finished goods (Bhardwaj 2014).

3.5 STEEL GRADES

Steel is not a solitary material. There are over 3,500 dissimilar steel grades with a lot of varied physical, chemical, and ecological possessions. About 75% of contemporary steels have been manufactured in the past twenty
years. At present, the engineers require only one-third of the steel for the construction of Eiffel Tower compared to the steel that was utilized earlier. The steels used for manufacturing vehicles nowadays are stronger and thirty-five percent lighter than that was used before (Source: About Steel). Steels fall into four categories, namely carbon steels, alloy steels, tool steels, and stainless steels.

Carbon steel is a metal alloy and it is also known as plain-carbon steel. Carbon steel is a mixture of two components, namely carbon and iron. Some other components are also there in very less amounts to have an effect on its properties. The components like copper (0.60% max), manganese (1.65% max), and silicon (0.60% max) are the only other alloying components allowed in carbon steel. Steel having a low amount of carbon has the properties similar to that of iron, squishy but effortlessly formed. The metal turns out to be sturdy and rigid when the carbon content increases. Normally, excessive amount of carbon lowers the steel’s temperature resistance and its melting point. Low carbon steel also known as mild steel contains about 0.05% to 0.25% of carbon with up to 0.4% of manganese. It is less sturdy, but inexpensive and uncomplicated to shape. By carburizing, the surface rigidness can be improved. The medium carbon steel has about 0.29% to 0.54% of carbon with 0.60% to 1.62% of manganese. It has better wear resistance and it balances strength and flexibility. Mild steel is utilized for vehicle parts and forging. The high carbon steel consists of about 0.55% to 0.95% of carbon with 0.30% to 0.90% of manganese. It is extremely strong and utilized for high-strength wires as well as springs. The very high carbon steel has about 0.96% to 2.1% of carbon and it is specifically processed to produce particular molecular and atomic microstructures (Source: ADI Metal)
Alloy steel contains little quantities of one or more alloying component such as silicon, titanium, aluminium, chromium, nickel, vanadium, and manganese. These additional components in alloy steels create the variation and offer several significant supplementary characteristics or better property compared to usual carbon steels. Alloy steels are the workhorses of the manufacturing industries due to its reasonable price, extensive availability, no processing difficulty, and better mechanical properties. Alloy steels are very much receptive to heat and mechanical treatments when compared to carbon steels (Source: Metal Supermarkets).

Tool steels are particularly rigid alloy steels utilized to produce machine components, equipments, and dies. Other than carbon and iron, tool steels are made from components such as tungsten, nickel, or molybdenum to provide additional rigidness and opposition to wear. By tempering process the tool steels can be made strengthened. In the tempering process the steel is initially heated to a high temperature, afterwards cooled very rapidly, and then heated once more to a lower temperature.

Stainless steels have more amounts of chromium and nickel. Stainless steels are extremely opposed to rust and other chemical effects, and are simple to sterilize, polish, and clean. It is utilized in home cutlery, cutters, and medical appliances (Source: Iron and Steel).

3.5.1 S235JRG2 Steel Grade

S235JRG2 steel grade is a kind of structural steel. The structural steel is a class of steel building substance that is manufactured with a specific shape or cross section, and some particular values of chemical composition and strength. The structural steels are produced in section and plate forms and
are usually utilized in pipelines, flyovers, vessels, and constructions (Source: Structural Steel).

In S235JRG2 steel grade, the term S represents the structural steel, 235 signifies the minimum yield strength of the steel in MPa, which is tested at a thickness of 16 mm, JR indicates the material toughness in relation to the Charpy impact or ‘V’ notch test methodology, G2 represents rimming steel not allowed. S235JRG2 steel grade is largely utilized for tanks, steel flyovers, vessels, and shipping containers for avoiding atmospheric rust usage (Source: AZO Material).

3.5.2 Dataset of S235JRG2 Steel Grade

This research work aims to find out the amount of alloying elements that have to be added during the ladle refining process of steel making with reduced computational error using intelligent techniques like fuzzy clustering, ANN and ANFIS to produce the S235JRG2 steel grade. The dataset of S235JRG2 steel grade is collected from Salem Steel Plant, Salem, Tamil Nadu, India.

The dataset contains 20 inputs and 6 outputs with 4190 data. The description of the input and output parameters are given in Table 3.1 and the sample dataset of S235JRG2 steel grade is given in Table A 1.1. The input parameters denote the temperature and composition of steel analyzed in EAF and LF. The output parameters are the alloying proportions required to be computed and added at the time of ladle refining process according to the inputs to obtain S235JRG2 steel grade.
Table 3.1 Description of the input and output parameters

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<th>Parameter Name</th>
<th>Unit</th>
<th>Description</th>
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<td><strong>Amount of input parameters analyzed in the EAF</strong></td>
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<td>e-C</td>
<td>%</td>
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<tr>
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<td>l-P</td>
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<td>Temperature</td>
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<tr>
<td>Si</td>
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3.6 SUMMARY

This chapter has presented a detailed description about the history of steel making, properties of metal, processes involved in steel manufacturing, types of steel, and the dataset of S235JRG2 steel grade collected from Salem Steel Plant, Salem, Tamil Nadu, India. In the subsequent chapters, the intelligent techniques like fuzzy clustering, ANN and ANFIS are implemented on the collected dataset of steel to validate their performance in finding out the amount of alloying elements that have to be added at the time of ladle refining to produce S235JRG2 steel grade with reduced computational error.