= Steel =

Steel is an alloy of iron and other elements , primarily carbon , that is widely used in construction and other applications because of its high tensile strength and low cost . Steel 's base metal is iron , which is able to take on two crystalline forms (allotropic forms) , body centered cubic (BCC) and face centered cubic (FCC) , depending on its temperature . It is the interaction of those allotropes with the alloying elements , primarily carbon , that gives steel and cast iron their range of unique properties . In the body @-@ centred cubic arrangement , there is an iron atom in the centre of each cube , and in the face @-@ centred cubic , there is one at the center of each of the six faces of the cube . Carbon , other elements , and inclusions within iron act as hardening agents that prevent the movement of dislocations that otherwise occur in the crystal lattices of iron atoms .

The carbon in typical steel alloys may contribute up to 2 @.@ 1 % of its weight . Varying the amount of alloying elements , their presence in the steel either as solute elements , or as precipitated phases , retards the movement of those dislocations that make iron comparatively ductile and weak , and thus controls its qualities such as the hardness , ductility , and tensile strength of the resulting steel . Steel 's strength compared to pure iron is only possible at the expense of iron 's ductility , of which iron has an excess .

Steel was produced in bloomery furnaces for thousands of years , but its extensive use began after more efficient production methods were devised in the 17th century , with the production of blister steel and then crucible steel . With the invention of the Bessemer process in the mid @-@ 19th century , a new era of mass @-@ produced steel began . This was followed by Siemens @-@ Martin process and then Gilchrist @-@ Thomas process that refined the quality of steel . With their introductions , mild steel replaced wrought iron .

Further refinements in the process , such as basic oxygen steelmaking (BOS) , largely replaced earlier methods by further lowering the cost of production and increasing the quality of the product . Today , steel is one of the most common materials in the world , with more than 1 @.@ 3 billion tons produced annually . It is a major component in buildings , infrastructure , tools , ships , automobiles , machines , appliances , and weapons . Modern steel is generally identified by various grades defined by assorted standards organizations .

= = Definitions and related materials = =

The noun steel originates from the Proto @-@ Germanic adjective stakhlijan (made of steel) , which is related to stakhla (standing firm) .

The carbon content of steel is between 0 @.@ 002 % and 2 @.@ 1 % by weight for plain iron ? carbon alloys . These values vary depending on alloying elements such as manganese , chromium , nickel , iron , tungsten , carbon and so on . Basically , steel is an iron @-@ carbon alloy that does not undergo eutectic reaction . In contrast , cast iron does undergo eutectic reaction . Too little carbon content leaves (pure) iron quite soft , ductile , and weak . Carbon contents higher than those of steel make an alloy , commonly called pig iron , that is brittle (not malleable) . While iron alloyed with carbon is called carbon steel , alloy steel is steel to which other alloying elements have been intentionally added to modify the characteristics of steel . Common alloying elements include : manganese , nickel , chromium , molybdenum , boron , titanium , vanadium , tungsten , cobalt , and niobium . Additional elements are also important in steel : phosphorus , sulfur , silicon , and traces of oxygen , nitrogen , and copper , that are most frequently considered undesirable .

Alloys with a higher than 2 @.@ 1 % carbon content , depending on other element content and possibly on processing , are known as cast iron . Cast iron is not malleable even when hot , but it can be formed by casting as it has a lower melting point than steel and good castability properties . Certain compositions of cast iron , while retaining the economies of melting and casting , can be heat treated after casting to make malleable iron or ductile iron objects . Steel is also distinguishable from wrought iron (now largely obsolete) , which may contain a small amount of carbon but large amounts of slag .

= = Material properties = =

Iron is commonly found in the Earth 's crust in the form of an ore , usually an iron oxide , such as magnetite , hematite etc . Iron is extracted from iron ore by removing the oxygen through combination with a preferred chemical partner such as carbon that is lost to the atmosphere as carbon dioxide . This process , known as smelting , was first applied to metals with lower melting points , such as tin , which melts at about 250 ° C (482 ° F) and copper , which melts at about 1 @,@ 100 ° C (2 @,@ 010 ° F) and the combination , bronze , which is liquid at less than 1 @,@ 083 ° C (1 @,@ 981 ° F) . In comparison , cast iron melts at about 1 @,@ 375 ° C (2 @,@ 507 ° F) . Small quantities of iron were smelted in ancient times , in the solid state , by heating the ore in a charcoal fire and welding the clumps together with a hammer , squeezing out the impurities . With care , the carbon content could be controlled by moving it around in the fire .

All of these temperatures could be reached with ancient methods used since the Bronze Age . Since the oxidation rate of iron increases rapidly beyond 800 ° C (1 @,@ 470 ° F) , it is important that smelting take place in a low @-@ oxygen environment . Unlike copper and tin , liquid or solid iron dissolves carbon quite readily . Smelting , using carbon to reduce iron oxides , results in an alloy (pig iron) that retains too much carbon to be called steel . The excess carbon and other impurities are removed in a subsequent step .

Other materials are often added to the iron / carbon mixture to produce steel with desired properties . Nickel and manganese in steel add to its tensile strength and make the austenite form of the iron @-@ carbon solution more stable , chromium increases hardness and melting temperature , and vanadium also increases hardness while making it less prone to metal fatigue .

To inhibit corrosion , at least 11 % chromium is added to steel so that a hard oxide forms on the metal surface ; this is known as stainless steel . Tungsten interferes with the formation of cementite , allowing martensite to preferentially form at slower quench rates , resulting in high speed steel . On the other hand , sulfur , nitrogen , and phosphorus make steel more brittle , so these commonly found elements must be removed from the steel melt during processing .

The density of steel varies based on the alloying constituents but usually ranges between 7 @,@ 750 and 8 @,@ 050 kg / m3 (484 and 503 lb / cu ft) , or 7 @.@ 75 and 8 @.@ 05 g / cm3 (4 @.@ 48 and 4 @.@ 65 oz / cu in) .

Even in a narrow range of concentrations of mixtures of carbon and iron that make a steel , a number of different metallurgical structures , with very different properties can form . Understanding such properties is essential to making quality steel . At room temperature , the most stable form of pure iron is the body @-@ centered cubic (BCC) structure called alpha iron or ? @-@ iron . It is a fairly soft metal that can dissolve only a small concentration of carbon , no more than 0 @.@ 005 % at 0 ° C (32 ° F) and 0 @.@ 021 wt % at 723 ° C (1 @,@ 333 ° F) . The inclusion of carbon in alpha iron is called ferrite . At 910 ° C pure iron transforms into a face @-@ centered cubic (FCC) structure , called gamma iron or ? @-@ iron . The inclusion of carbon in gamma iron is called austenite . The FCC structure of austenite can dissolve considerably more carbon , as much as 2 @.@ 1 % (38 times that of ferrite) carbon at 1 @,@ 148 ° C (2 @,@ 098 ° F) , which reflects the upper carbon content of steel , beyond which is cast iron . When carbon moves out of solution with iron it forms a very hard , but brittle material called cementite (Fe3C) .

When steels with exactly 0 @.@ 8 % carbon (known as a eutectoid steel) , are cooled , the austenitic phase (FCC) of the mixture attempts to revert to the ferrite phase (BCC) . The carbon no longer fits within the FCC austenite structure , resulting in an excess of carbon . One way for carbon to leave the austenite is for it to precipitate out of solution as cementite , leaving behind a surrounding phase of BCC iron called ferrite that is able to hold the carbon in solution . The two , ferrite and cementite , precipitate simultaneously producing a layered structure called pearlite , named for its resemblance to mother of pearl . In a hypereutectoid composition (greater than 0 @.@ 8 % carbon) , the carbon will first precipitate out as large inclusions of cementite at the austenite grain boundaries and then when the composition left behind is eutectoid , the pearlite structure forms . For steels that have less than 0 @.@ 8 % carbon (hypoeutectoid) , ferrite will first form until the remaining composition is 0 @.@ 8 % at which point the pearlite structure will form . No

large inclusions of cementite will form at the boundaries . The above assumes that the cooling process is very slow , allowing enough time for the carbon to migrate .

As the rate of cooling is increased the carbon will have less time to migrate to form carbide at the grain boundaries but will have increasingly large amounts of pearlite of a finer and finer structure within the grains ; hence the carbide is more widely dispersed and acts to prevent slip of defects within those grains , resulting in hardening of the steel . At the very high cooling rates produced by quenching , the carbon has no time to migrate but is locked within the face center austenite and forms martensite . Martensite is highly strained and stressed supersaturated form of carbon and iron and is exceedingly hard but brittle . Depending on the carbon content , the martensitic phase takes different forms . Below 0 @.@ 2 % carbon , it takes on a ferrite BCC crystal form , but at higher carbon content it takes a body @-@ centered tetragonal (BCT) structure . There is no thermal activation energy for the transformation from austenite to martensite . Moreover , there is no compositional change so the atoms generally retain their same neighbors .

Martensite has a lower density (it expands) than does austenite , so that the transformation between them results in a change of volume . In this case , expansion occurs . Internal stresses from this expansion generally take the form of compression on the crystals of martensite and tension on the remaining ferrite , with a fair amount of shear on both constituents . If quenching is done improperly , the internal stresses can cause a part to shatter as it cools . At the very least , they cause internal work hardening and other microscopic imperfections . It is common for quench cracks to form when steel is water quenched , although they may not always be visible .

= = = Heat treatment = = =

There are many types of heat treating processes available to steel . The most common are annealing , quenching , and tempering . Heat treatment is effective on compositions above the eutectoid compositions (hypereutectoid) . Hypoeutectoid steel does not harden from heat treatment . Annealing is the process of heating the steel to a sufficiently high temperature to relieve local internal stresses . It does not create a general softening of the product but only locally relieves strains and stresses locked up within the material . This process goes through three phases : recovery , recrystallization , and grain growth . The temperature required to anneal a particular steel depends on the type of annealing to be achieved and the constituents of the alloy .

Quenching and tempering first involves heating the steel to the austenite phase then quenching it in water or oil . This rapid cooling results in a hard but brittle martensitic structure . The steel is then tempered , which is just a specialized type of annealing , to reduce brittleness . In this application the annealing (tempering) process transforms some of the martensite into cementite , or spheroidite and hence it reduces the internal stresses and defects . The result is a more ductile and fracture @-@ resistant steel .

= = Steel production = =

When iron is smelted from its ore , it contains more carbon than is desirable . To become steel , it must be reprocessed to reduce the carbon to the correct amount , at which point other elements can be added . In the past , steel facilities would cast the raw cast iron product into ingots which would be stored until use in further refinement processes that resulted in the finished product . In modern facilities , the initial product is close to the final composition and is continuously cast into long slabs , cut and shaped into bars and extrusions and heat treated to produce a final product . Today only a small fraction is cast into ingots . Approximately 96 % of steel is continuously cast , while only 4 % is produced as ingots .

The ingots are then heated in a soaking pit and hot rolled into slabs , billets , or blooms . Slabs are hot or cold rolled into sheet metal or plates . Billets are hot or cold rolled into bars , rods , and wire . Blooms are hot or cold rolled into structural steel , such as I @-@ beams and rails . In modern steel mills these processes often occur in one assembly line , with ore coming in and finished steel products coming out . Sometimes after a steel 's final rolling it is heat treated for strength , however

this is relatively rare .

= = History of steelmaking = =

= = = Ancient steel = = =

Steel was known in antiquity , and possibly was produced in bloomeries and crucibles .
The earliest known production of steel are pieces of ironware excavated from an archaeological site in Anatolia (Kaman @-@ Kalehoyuk) and are nearly 4 @,@ 000 years old , dating from 1800 BC . Horace identifies steel weapons like the falcata in the Iberian Peninsula , while Noric steel was used by the Roman military .
The reputation of Seric iron of South India (wootz steel) amongst the rest of the world grew considerably . South Indian and Mediterranean sources including Alexander the Great (3rd c . BC) recount the presentation and export to the Greeks of 100 talents worth of such steel . Metal production sites in Sri Lanka employed wind furnaces driven by the monsoon winds , capable of producing high @-@ carbon steel . Large @-@ scale Wootz steel production in Tamilakam using crucibles and carbon sources such as the plant Av?ram occurred by the sixth century BC , the pioneering precursor to modern steel production and metallurgy .
The Chinese of the Warring States period (403 ? 221 BC) had quench @-@ hardened steel , while Chinese of the Han dynasty (202 BC ? 220 AD) created steel by melting together wrought iron with cast iron , gaining an ultimate product of a carbon @-@ intermediate steel by the 1st century AD . The Haya people of East Africa invented a type of furnace they used to make carbon steel at 1 @,@ 802 ° C (3 @,@ 276 ° F) nearly 2 @,@ 000 years ago . East African steel has been suggested by Richard Hooker to date back to 1400 BC .

= = = Wootz steel and Damascus steel = = =

Evidence of the earliest production of high carbon steel in the Indian Subcontinent are found in Kodumanal in Tamil Nadu area , Golconda in Andhra Pradesh area and Karnataka , and in Samanalawewa areas of Sri Lanka . This came to be known as Wootz steel , produced in South India by about sixth century BC and exported globally . The steel technology existed prior to 326 BC in the region as they are mentioned in literature of Sangam Tamil , Arabic and Latin as the finest steel in the world exported to the Romans , Egyptian , Chinese and Arab worlds at that time ? what they called Seric Iron . A 200 BC Tamil trade guild in Tissamaharama , in the South East of Sri Lanka , brought with them some of the oldest iron and steel artifacts and production processes to the island from the classical period . The Chinese and locals in Anuradhapura , Sri Lanka had also adopted the production methods of creating Wootz steel from the Chera Dynasty Tamils of South India by the 5th century AD . In Sri Lanka , this early steel @-@ making method employed a unique wind furnace , driven by the monsoon winds , capable of producing high @-@ carbon steel . Since the technology was acquired from the Tamilians from South India , the origin of steel technology in India can be conservatively estimated at 400 ? 500 BC .
Wootz , also known as Damascus steel , is famous for its durability and ability to hold an edge . It was originally created from a number of different materials including various trace elements , apparently ultimately from the writings of Zosimos of Panopolis . However , the steel was an old technology in India when King Porus presented a steel sword to the Emperor Alexander in 326 BC . It was essentially a complicated alloy with iron as its main component . Recent studies have suggested that carbon nanotubes were included in its structure , which might explain some of its legendary qualities , though given the technology of that time , such qualities were produced by chance rather than by design . Natural wind was used where the soil containing iron was heated by the use of wood . The ancient Sinhalese managed to extract a ton of steel for every 2 tons of soil , a remarkable feat at the time . One such furnace was found in Samanalawewa and archaeologists were able to produce steel as the ancients did .

Crucible steel , formed by slowly heating and cooling pure iron and carbon (typically in the form of charcoal) in a crucible , was produced in Merv by the 9th to 10th century AD . In the 11th century , there is evidence of the production of steel in Song China using two techniques : a " berganesque " method that produced inferior , inhomogeneous , steel , and a precursor to the modern Bessemer process that used partial decarbonization via repeated forging under a cold blast .

= = = Modern steelmaking = = =

Since the 17th century the first step in European steel production has been the smelting of iron ore into pig iron in a blast furnace . Originally employing charcoal , modern methods use coke , which has proven more economical .

= = = = Processes starting from bar iron = = = =

In these processes pig iron was refined (fined) in a finery forge to produce bar iron , which was then used in steel @-@ making .

The production of steel by the cementation process was described in a treatise published in Prague in 1574 and was in use in Nuremberg from 1601 . A similar process for case hardening armour and files was described in a book published in Naples in 1589 . The process was introduced to England in about 1614 and used to produce such steel by Sir Basil Brooke at Coalbrookdale during the 1610s .

The raw material for this process were bars of iron . During the 17th century it was realized that the best steel came from oregrounds iron of a region north of Stockholm , Sweden . This was still the usual raw material source in the 19th century , almost as long as the process was used .

Crucible steel is steel that has been melted in a crucible rather than having been forged , with the result that it is more homogeneous . Most previous furnaces could not reach high enough temperatures to melt the steel . The early modern crucible steel industry resulted from the invention of Benjamin Huntsman in the 1740s . Blister steel (made as above) was melted in a crucible or in a furnace , and cast (usually) into ingots .

= = = = Processes starting from pig iron = = = =

The modern era in steelmaking began with the introduction of Henry Bessemer 's Bessemer process in 1855 , the raw material for which was pig iron . His method let him produce steel in large quantities cheaply , thus mild steel came to be used for most purposes for which wrought iron was formerly used . The Gilchrist @-@ Thomas process (or basic Bessemer process) was an improvement to the Bessemer process , made by lining the converter with a basic material to remove phosphorus .

Another 19th @-@ century steelmaking process was the Siemens @-@ Martin process , which complemented the Bessemer process . It consisted of co @-@ melting bar iron (or steel scrap) with pig iron .

These methods of steel production were rendered obsolete by the Linz @-@ Donawitz process of basic oxygen steelmaking (BOS) , developed in the 1950s , and other oxygen steel making methods . Basic oxygen steelmaking is superior to previous steelmaking methods because the oxygen pumped into the furnace limited impurities , primarily nitrogen , that previously had entered from the air used . Today , electric arc furnaces (EAF) are a common method of reprocessing scrap metal to create new steel . They can also be used for converting pig iron to steel , but they use a lot of electrical energy (about 440 kWh per metric ton) , and are thus generally only economical when there is a plentiful supply of cheap electricity .

= = Steel industry = =

It is common today to talk about " the iron and steel industry " as if it were a single entity , but

historically they were separate products . The steel industry is often considered an indicator of economic progress , because of the critical role played by steel in infrastructural and overall economic development .

In 1980 , there were more than 500 @,@ 000 U.S. steelworkers . By 2000 , the number of steelworkers fell to 224 @,@ 000 .

The economic boom in China and India has caused a massive increase in the demand for steel in recent years . Between 2000 and 2005 , world steel demand increased by 6 % . Since 2000 , several Indian and Chinese steel firms have risen to prominence , such as Tata Steel (which bought Corus Group in 2007) , Shanghai Baosteel Group Corporation and Shagang Group . ArcelorMittal is however the world 's largest steel producer .

In 2005 , the British Geological Survey stated China was the top steel producer with about one @-@ third of the world share ; Japan , Russia , and the US followed respectively .

In 2008 , steel began trading as a commodity on the London Metal Exchange . At the end of 2008 , the steel industry faced a sharp downturn that led to many cut @-@ backs .

The world steel industry peaked in 2007 . That year , ThyssenKrupp spent $ 12 billion to build the two most modern mills in the world , in Calvert , Alabama and Sepetiba , Rio de Janeiro , Brazil . The worldwide Great Recession starting in 2008 , however , sharply lowered demand and new construction , and so prices fell . ThyssenKrupp lost $ 11 billion on its two new plants , which sold steel below the cost of production .

= = Recycling = =

Steel is one of the world 's most @-@ recycled materials , with a recycling rate of over 60 % globally ; in the United States alone , over 82 @,@ 000 @,@ 000 metric tons (81 @,@ 000 @,@ 000 long tons) was recycled in the year 2008 , for an overall recycling rate of 83 % .

= = Contemporary steel = =

= = = Carbon steels = = =

Modern steels are made with varying combinations of alloy metals to fulfill many purposes . Carbon steel , composed simply of iron and carbon , accounts for 90 % of steel production . Low alloy steel is alloyed with other elements , usually molybdenum , manganese , chromium , or nickel , in amounts of up to 10 % by weight to improve the hardenability of thick sections . High strength low alloy steel has small additions (usually < 2 % by weight) of other elements , typically 1 @.@ 5 % manganese , to provide additional strength for a modest price increase .

Recent Corporate Average Fuel Economy (CAFE) regulations have given rise to a new variety of steel known as Advanced High Strength Steel (AHSS) . This material is both strong and ductile so that vehicle structures can maintain their current safety levels while using less material . There are several commercially available grades of AHSS , such as dual @-@ phase steel , which is heat treated to contain both a ferritic and martensitic microstructure to produce a formable , high strength steel . Transformation Induced Plasticity (TRIP) steel involves special alloying and heat treatments to stabilize amounts of austenite at room temperature in normally austenite @-@ free low @-@ alloy ferritic steels . By applying strain , the austenite undergoes a phase transition to martensite without the addition of heat . Twinning Induced Plasticity (TWIP) steel uses a specific type of strain to increase the effectiveness of work hardening on the alloy .

Carbon Steels are often galvanized , through hot @-@ dip or electroplating in zinc for protection against rust .

= = = Alloy steels = = =

Stainless steels contain a minimum of 11 % chromium , often combined with nickel , to resist

corrosion . Some stainless steels , such as the ferritic stainless steels are magnetic , while others , such as the austenitic , are nonmagnetic . Corrosion @-@ resistant steels are abbreviated as CRES .

Some more modern steels include tool steels , which are alloyed with large amounts of tungsten and cobalt or other elements to maximize solution hardening . This also allows the use of precipitation hardening and improves the alloy 's temperature resistance . Tool steel is generally used in axes , drills , and other devices that need a sharp , long @-@ lasting cutting edge . Other special @-@ purpose alloys include weathering steels such as Cor @-@ ten , which weather by acquiring a stable , rusted surface , and so can be used un @-@ painted . Maraging steel is alloyed with nickel and other elements , but unlike most steel contains little carbon (0 @.@ 01 %) . This creates a very strong but still malleable steel .

Eglin steel uses a combination of over a dozen different elements in varying amounts to create a relatively low @-@ cost steel for use in bunker buster weapons . Hadfield steel (after Sir Robert Hadfield) or manganese steel contains 12 ? 14 % manganese which when abraded strain hardens to form an incredibly hard skin which resists wearing . Examples include tank tracks , bulldozer blade edges and cutting blades on the jaws of life .

In 2016 a breakthrough in creating a strong light aluminium steel alloy which might be suitable in applications such as aircraft was announced by researchers at Pohang University of Science and Technology . Adding small amounts of nickel was found to result in precipitation as nano particles of brittle B2 intermetallic compounds which had previously resulted in weakness . The result was a cheap strong light steel alloy ? nearly as strong as titanium at ten percent the cost ? which is slated for trial production at industrial scale by POSCO , a Korean steelmaker .

= = = Standards = = =

Most of the more commonly used steel alloys are categorized into various grades by standards organizations . For example , the Society of Automotive Engineers has a series of grades defining many types of steel . The American Society for Testing and Materials has a separate set of standards , which define alloys such as A36 steel , the most commonly used structural steel in the United States .

= = Uses = =

Iron and steel are used widely in the construction of roads , railways , other infrastructure , appliances , and buildings . Most large modern structures , such as stadiums and skyscrapers , bridges , and airports , are supported by a steel skeleton . Even those with a concrete structure employ steel for reinforcing . In addition , it sees widespread use in major appliances and cars . Despite growth in usage of aluminium , it is still the main material for car bodies . Steel is used in a variety of other construction materials , such as bolts , nails , and screws and other household products and cooking utensils .

Other common applications include shipbuilding , pipelines , mining , offshore construction , aerospace , white goods (e.g. washing machines) , heavy equipment such as bulldozers , office furniture , steel wool , tools , and armour in the form of personal vests or vehicle armour (better known as rolled homogeneous armour in this role) .

= = = Historical = = =

Before the introduction of the Bessemer process and other modern production techniques , steel was expensive and was only used where no cheaper alternative existed , particularly for the cutting edge of knives , razors , swords , and other items where a hard , sharp edge was needed . It was also used for springs , including those used in clocks and watches .

With the advent of speedier and thriftier production methods , steel has become easier to obtain and much cheaper . It has replaced wrought iron for a multitude of purposes . However , the

availability of plastics in the latter part of the 20th century allowed these materials to replace steel in some applications due to their lower fabrication cost and weight . Carbon fiber is replacing steel in some cost insensitive applications such as aircraft , sports equipment and high end automobiles .

= = = Long steel = = =

As reinforcing bars and mesh in reinforced concrete
Railroad tracks
Structural steel in modern buildings and bridges
Wires
Input to reforging applications

= = = Flat carbon steel = = =

Major appliances
Magnetic cores
The inside and outside body of automobiles , trains , and ships .

= = = Weathering steel (COR @-@ TEN) = = =

Intermodal containers
Outdoor sculptures
Architecture
Highliner train cars

= = = Stainless steel = = =

Cutlery
Rulers
Surgical instruments
Watches
Guns
Rail passenger vehicles
Tablets
Trash Cans

= = = Low @-@ background steel = = =

Steel manufactured after World War II became contaminated with radionuclides due to nuclear weapons testing . Low @-@ background steel , steel manufactured prior to 1945 , is used for certain radiation @-@ sensitive applications such as Geiger counters and radiation shielding .