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IRON AND STEEL HERITAGE OF MANKIND

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ABSTRACT

Early iron encountered by man was meteoritic iron. Some sort of rude man-made iron started appearing around 2000 BC in many parts of the then known world. Rapid developments in the manufacture and use of iron making took place around 1400 BC in the Hittite federation in modern day Turkey. Socio-political conditions were probably responsible for this. By 1200 BC, knowledge of iron making spread in the east to Assyria and Babylon and in the south to Palestine and Egypt. Towards the west the spread was slower and the Celtic people made an important contribution towards spread of metalworking in Europe including ironmaking. In India and China ironmaking probably developed separately and by 600 BC excellent steel was being made in India. This was highly sought after by the Persians, the Romans and others. In China, bronze working developed to very high levels but iron making developed to a lesser extent. However, controlled liquid pig iron production developed in China by 200 AD, at least 1200 years before it developed in Europe.

Historical developments of modern iron and steel making, seen from the European scenario, starts with early Roman ironworking, development of the Catalan forge, Stuckofen in Germany and the production of liquid pig iron from shaft furnaces by 1400 AD. The next major development was the use of reverberatory furnaces in early 17th century and the use of coke in blast furnaces in the early 18th Century. The period 1700 AD to 1850 AD was a very important period in the development of iron making, wrought iron making and steel making. The period saw large scale cast iron production in blast furnaces, refining of the cast iron in refinery furnaces to get improved cast iron and refining in reverberatory furnaces to get some form of wrought iron. Cementation processes and crucible processes for steelmaking developed during this time. A number of such processes were in use in the British Isles during this time. In India also, during this period a number of ironmaking sites were there, each unique in its own *way. Bessemer steelmaking was the start of modern steelmaking technology. The development of Bessemer steel making was quickly followed by open hearth steelmaking, basic Bessemer steelmaking and then in 1900 by electric steelmaking. After 1950, oxygen steelmaking developed extensively. Also, after 1970 direct reduction processes for ironmaking have found their own important place in the scheme of things.*

Keywords : *Iron and steel heritage, Iron making in Europe, Manmade iron, Iron in ancient times.*

IRON IN ANCIENT TIMES

Thanks to the work of archaeologists, we have a fairly clear account of the use of iron in antiquity. Scattered writings, inscriptions, tools, implements and jewelery used by historic ancient people as well as prehistoric people are available. The 'iron' unearthed includes iron, steel and wrought iron in the modern sense. The earliest iron which man used was meteoritic iron. The names for iron given by ancient people was 'star metal' or 'stone from Heaven'. These iron materials contained nickel from 7 to 15%, (even 30% sometimes). These do not easily rust and were used for making implements. Some of the pieces were massive. Native iron is very rarely found. One such case is in Greenland [1] where iron occurs as grains or nodules in basalt (iron bearing igneous rock) that 'erupted through beds of coal'. Two rare iron alloys, awarnite ($FeNi_2$) and josephinite (Fe_3Ni_5) have also been found in the form of small granules.

MANMADE IRON

The earliest archaeological evidence for manmade iron comes from the early part of the third millenium BC. An object unearthed is an iron instrument (probably a dagger) from Ur [2]. Two authentically dated iron objects can be attributed to 2500 BC (Syria). Two others have been found in Anatolia, *c.* 2000 BC. Two lumps of unworked iron have been discovered at Lapithos in Cyprus c. 1800 BC, in a grave site. One cube of iron was found at Knossos in Crete (1800 BC). It appears that these were all manmade. In the tomb of Pharoah Tutankhamen near Thebes in Egypt a dagger having an iron blade 21.2 cm. long was found. (*c.* 1350 BC). The blade is manmade iron. Also found in the tomb was a 'head-rest' of welded iron 4 cm greatest height and 5 cm greatest length. In addition tools made of iron were found. The blades of the tools have dimensions 1.6 to 2.4 cm long, 0.3 to 0.85 cm wide and 0.5 mm thick. The Amarna tablets of Amenhotep III period (1377 BC) mention iron as a very precious metal. Iron artifacts unearthed from various places dating from 1000 BC onwards show that iron metallurgy was very well developed by 600 BC in West Asia.

One can draw the following conclusion about iron metallurgy in ancient times. Some knowledge of ironmaking was present in some parts of the world, around 2000 BC. This was in a very small way to use iron ore and treat it like copper ore and the product was a dirty lump with a non-metallic appearance, friable and easily shattered if hammered. The product did not possess the ductility or malleability the ancient smiths expected of the metals they knew then. Around 1400 BC procedures were developed for hammering a hot spongy aggregate of iron metal, slag and dirt. By heating the spongy lump to red heat it would no longer be brittle. It could be shaped while hot and during the process of shaping, particles of iron in the lump would weld together and the nonmetallics forced out of the aggregate. To prevent reoxidation, a charcoal cover was necessary. Repetition of this procedure of reheating and hammering would lead to bars of wrought iron. This probably developed independently in West Asia, in India and in a few other places.

In West Asia ironmaking technology was first developed in the land of the Hittites around 1400 BC and rapidly spread in their territory. Since then, the beginning of iron making in its broad sense is attributed to the Hittites. Iron ore is available in plenty in the mountains of Anatolia (Turkey) especially in the basin of river Halys. Crude artifacts of iron were made by Hittites around 1800 BC. In the early period, iron was five times as expensive as gold. The Hittites however did not possess very high metal working skills. The Assyrians and the Syrians obtained iron from Hittites and produced much finer articles. It is worthwhile pondering at this stage as to why iron making developed among the Hittites. In ancient times the area covering Nile Valley, modern Lebanon, Israel coast, Syria and Tigris-Euphrates valley was called as the 'fertile crescent'. Around 1700 BC the barbarians, experts in chariot warfare, invaded the crescent even down to Egypt. The chariot and its bowmen could be resisted only by a well armed close-knit infantry, which did not exist [6]. Arms made of bronze were in use then and these were expensive. There was a need for a cheaper and more abundant material and this probably led to increased ironmaking in the Hittite territory. The Hittites gained an upperhand as they could mobilise a large number of men armed with iron spear heads. This infantry could match the invaders on chariots. By 1500 BC the Hittites were in command. This was mainly due to their ironmaking skills. The Hittite confederacy was broken around 1200 BC by invaders from south eastern Europe. Refugees from Hatti carried the knowledge of ironmaking to distant lands. Very soon the Assyrians, Babylonians, Palestinians and Phoenicians gained knowledge of iron making. A find from the time of Sargaon II of Assyria (722–705 BC) contained 160 tons of iron, in the form of bars (to be forged into weapons) and as iron chains. Egypt found it usually more convenient to import iron than make it. Iron making also spread to the south of Nubia to Kush (Sudan) kingdom. Iron working to the south of the Sahara was limited to ancient practices till recent times. However, observations of old ironmaking furnaces in Tanzania show that in the shaft furnaces, iron makers used some type of ceramic tuyeres which penetrated well into the furnace. This led to preheating of the air before it entered the furnace, causing higher temperatures and consequent production of a high carbon iron bloom [8].

Iron making has been known for a long time and the Indian 'steel' has been highly sought after since 700 BC by Persians and others. Iron objects found in Sri Lanka and Malaysia reveal a high level of ironmaking in 5th century A.D. Accounts of various types of Indian ironmaking in the 18th and 19th century have been given by East Indian Company officials [3,7]. These confirm that a very high quality steel was made in India. Merchants from Persia used to come and camp in Andra Pradesh and Karnataka areas, get their supply of wootz metal in the form of cakes and take them home for further processing into implements. This was in the early 19th century. A scientific analysis of Indian steelmaking was done by the Russians in 1840's. One must also mention that in the 18th century not only did India make good steel but the level of technology in other fields was also of a very high order [3]. Systematic work is being now done by PPSI foundation of Chennai on this.

In China bronzemaking reached high levels by 1500 BC. However, in ironmaking a notable contribution was the controlled production of liquid pig iron in iron smelting furnaces. This was in the 2nd or 3rd century AD. In the ancient world, now and then by accident liquid pig iron might have been produced. It is interesting to note that the cast iron objects found in China contain high amounts of phosphorous (in some cases 5-7%) which would have lowered the melting point of this iron [2, 8].

IRONMAKING IN EUROPE

Major contributions to the spread of metal working in Europe was made by the Celtic people. They were spread over a region from Gaul to the Black Sea. The Myceneans and the Dorian Greeks developed ironmaking in Greece. Ironmaking was fairly wide spread in Europe before Roman times. As part of the Roman empire many regions in Europe were involved in ironmaking. A recent study shows that in the Magdalensberg mountains in Carinthia, Austria, iron of very good quality was being made around 500 BC. The high manganese content of iron ore found in this area brought about the good quality of this iron, which is also called Noric iron [5]. The Romans also used good quality 'Seric' iron, which was imported from India [2]. The quality of iron implements made in Europe up to the Middle Ages was not as good as that made in West Asia. However, the knowledge of hardening was probably greater in Europe. In Japan high level of skills existed in swordmaking.

Metal working in Central Europe is normally divided into the following periods: early Hallstatt 750 to 600 BC, Middle Hallstatt 600 to 500 BC, and La-Tene period, 450 to 50 BC. Many of the implements and weapons found in ancient times show that the carbon content in them was not uniform. A steel chisel, from the Roman period showed carbon varying considerably from 0.03 to 1.3% in different parts of the chisel. The portions of highest carbon contents are not limited solely to the working parts of the tool. A comparison from different sources of the composition of various iron artefacts made in antiquity can be seen from Table 1. The first two of the samples are from Central Europe and the third sample is Delhi iron pillar, *c* 300 AD.

Table 1 : Comparison of composition of iron artifacts made in antiquity

Element	Sample 1	Sample 2	Sample 3
Carbon	0.16	0.43	0.08
Silicon	0.05	0.36	0.046
Manganese	Nil	0.48	Nil
Sulphur	0.12	0.25	0.006
Phosphorus	0.057	0.24	0.114
Copper	Nil	Nil	0.034
Iron	Remainder	Remainder	Remainder

An iron bloom weighing 150 kg found on the site of a Roman station consisted of smaller pieces (each being about 20 kg) welded together. The average composition of the bloom is carbon 0.097, silicon 0.046, manganese 0.04, phosphorus 0.044, sulphur 0.025. However, microscopic analysis shows that in three regions within the bloom carbon contents are 0.75, 0.8 and 1.6%. Some samples of cast iron were also found in Britain from the time of the Roman occupation. These show a total carbon content of 3.2 to 3.5% and phosphorous 0.18 to 0.76%. One sample contains 0.48% sulphur. The production of the cast iron was probably brought about by the abnormal behaviour of some furnaces.

Many of the weapons found in Europe were made from flat forged strips subsequently piled and forge-welded into the shape of a sword or a spear-head.

The flat pieces were carburised on their surfaces during the process. The swords manufactured around 800 AD show on their faces patterns of a flattened band or bands of twisted bars. By the processes of natural rusting and of etching by weather these faces developed wavy patterns. This was different from the 'Damascened' patterns associated with blades made in Syria. One way of making swords during 1000 AD was to alternate plates of carburised iron with non-carburised iron plates. The pile was then lightly forge welded and crimped into a concertina type of pattern and forged again to its original length. Arrow heads were less difficult to make because it was not necessary to carburise surfaces. Most of the arrow heads were plain wrought iron. The production of armour also involved fewer metallurgical problems, plain wrought iron was adequate.

European technology developed rapidly from 1100 AD. We find developments in iron making with increase in the height of the shaft furnaces, leading to the production of liquid pig iron in the Blauöfen around 1400 AD. Our knowledge of ironmaking furnaces used prior to 17th century is meagre. The majority were of the hearth type, the remainder shaft type furnaces different in shape, size and materials of construction whereas the fundamental metallurgical principles were the same. Ore in lumps or in fully divided forms was mixed with charcoal and charged into furnaces. Charcoal served three purposes, as fuel, reducer and protector to shield hot reduced metals. The Catalan process or the Catalan hearth process or the Catalan forge was used for making iron. These furnaces were 20" square and 16" deep with a passage for air tuyeres. The shaft furnace, Stuckofen (high bloomery), evolved from the Catalan type of hearth furnace. These were 10 to 16 feet high, 3 to 4 feet cross section. Another type of oven called the wolf oven 6 to 7 feet high was similar to the Osmund furnace used in Sweden and similar to the shaft furnace used in India. The reverberatory furnace was developed by Roverson in the 17th century.

The use of charcoal was banned in the British Isles in the 16th century. This led to trials in using coal for various manufacturing processes. The beer industry after a 'bitter' experience in using coal for heating, finally found that coke was a better substitute and the industry started using coke successfully. The glass industry and the iron industry followed suit. By 1709 Abraham Darby had established at Coalbrookdale in Shropshire, the first blast furnace to smelt iron ore using coke. The pig iron thus obtained was usually remelted in reverberatory furnaces and used. Though good iron was made in Sweden and some other places in Europe, Britain became the centre for developments in ironmaking during the 18th century. In the seven year war fought between the British and the French, the British naval cannon proved themselves superior to cannon mounted in French ships. In 1764 and in 1775 French engineers visited Britain to understand the smelting of iron ore with coke and to study production of good quality iron cannon[4]. In 1722 the French scientist Reaumur had remarked that "cannons for land service are made of bronze, but most naval cannon, whether aboard the King's ships or on merchant vessels are made of iron". He felt it was necessary to make the iron cannon larger than bronze ones of the same caliber, in order that they could resist the explosive force of gun powder. Reaumur wrote that when bronze cannons burst they split asunder, but the more rigid iron guns broke into many pieces killing the gunners and spreading terror amongst the survivors. The iron produced in coke blast furnaces was not very clean and contained coke particles. It had to be refined in coal fired reverberatory furnaces. This refined iron was used for casting guns.

Coke making was developed in Britain during the 18th century; there were at least four methods for making coke. Coals were usually classified as 'sulphurous' or 'tarry'. A number of processes were patented and practised for cast ironmaking and wrought ironmaking. In 1766, a patent was granted to the Cranege brothers for hand puddling process. In 1784, Cort hollowed out the bottom of the reverberatory furnace to contain metal in the molten state. This process for wrought iron making became popular. However, a number of processes were in operation all over Britain depending on the ore and the type of coal available. A letter from James Watt from Birmingham written on August 25th, 1784 reads: "As to Mr. Cort's process... it is not practised in this neighbourhood, the iron is mostly made by Wright and Jesson's process... by making stampt iron and potting". Some of these processes developed further and were still in use in the early 20th century like the Walloon process, South Wales process, Lancashire process, American Bloomery process and others. A book on metallurgy published in 1923 carries details of all these process. The last hand puddling furnace ceased operation in USA in 1949.

In the first half of 19th century, wrought iron became a very important material for construction. With the advent of the Bessemer steel making process in 1850s, modern steel making started and processes like acid open hearth, basic open hearth, basic Bessemer developed by 1880s. Electric arc furnaces and induction furnaces were available by 1910. As regards iron making, the blast furnace gradually developed during the 19th century and the early 20th century. Major developments in iron making took place after 1950 with an increase in the capacity of blast furnaces first in the USSR and then still larger furnaces being designed and installed in Japan. This period also saw the development of a number of direct reduction process for iron making including Rotary Kiln processes, Midrex process, HyL process and others. In steelmaking, major changes occurred after 1950 with the LD converters and since then the use of oxygen steelmaking and continuous casting has been established. Iron and steel have withstood competition from other materials during the last fifty years and will maintain their own premier position in future also.

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