

Steel in Ancient Greece and Rome

by: E.A.Ginzel 1995

Introduction

In an introductory lecture on mineralogy¹ the writer was informed of the importance of iron in the Hellenistic Era by the lecturing professor. In this period, iron was considered a precious metal by Alexander. During his world tour of conquest Alexander gave his generals instructions to seize any iron found. Strangely it was not for its merits in weaponry that it received the status of precious, but instead for its application to lapidary work. The polishing of facets on precious stones, especially diamonds, is facilitated by holding the precious stone to the flat surface of a rotating metal disk. The disk is coated with a fine abrasive that is imbedded in the metal. For polishing diamonds the abrasive is a diamond dust; however, only rotating platters made of iron can hold the diamond abrasive without the abrasive being plucked out during the polishing of diamonds.

Iron is no longer considered a precious metal but its production and application in modern industry ranks it as the single most important metal in modern engineering. In its modern applications, iron is alloyed with carbon and other metals to produce a wide variety of alloys we call steel.

It has been traditionally accepted that steel was not a metal alloy found in the ancient world. To refute this traditional theory a background on the origins of iron smelting and explanations of modern alloy definitions will be provided.

Since steel is an alloy of primarily iron and carbon, any discussion of the alloy must address the background of iron. Friend² and Parr³ indicate iron was known around 4000BC when it would have been pounded into shape. However, the source of this iron must have been celestial (meteorites) as the smelting

¹ Salter, D.L.; Earth 231 Lectures

² Friend, J.A.N., page 30

process was probably not used on iron at that time. Further evidence for the celestial source of this iron is in the chemical analysis of artifacts. The high nickel content of these artifacts is typical of meteorites and the nickel content would also account for the lack of oxidation (rusting). Original smelting of iron is given several different origins but generally considered a serendipitous result of the juxtaposition of iron ore and heat. Some^{4, 5} suggest metallic iron was found in ashes of campfires built on outcroppings of iron ore or iron oxides. Considering the required heat this is a highly unlikely scenario. Friend quotes a paragraph from a 1912 article in the Journal of the Institute of Metals by Gowland who indicates such a campfire could possibly account for the first metallurgical furnace for copper⁶. As for iron, the most plausible theory seems to be one put forward by Aitchison⁷. He suggests it was copper and bronze smelters who found iron in some of their melts when iron ores got mixed with copper ores. This theory is all the more feasible as these people would be the only ones to have the facilities to produce the required heat as well as the skill in ore production.

Whatever the actual origin of iron smelting it was a well known process by the end of the second millennium BC. Numerous quotations are found in the Homeric poems (circa 880 BC) referencing implements of iron. Herodotus makes reference to it in his “History” (446 BC) and Aristotle (350BC) attributes the sources of iron to mines in Elba and the Chalybian mines near Ambus⁸.

By Roman times the process of iron smelting was well known and Mediterranean Europe could be considered well into the Iron Age.

Smelting

³ Parr, J.G., page 33

⁴ Compton's, Interactive Encyclopaedia

⁵ US Steel, page 1

⁶ Friend, J.A.N., page 16

⁷ Aitchison, L., page 100

The melting point of pure iron is 1540°C. Landels points that even by Roman times European furnaces were not producing heat much over 1100°C⁹. Smelting of iron, unlike the smelting of the lower melting point metals, copper, zinc and tin, did not involve the iron turning to the liquid state. Instead, it was a solid state conversion requiring chemical reduction of the ore. Ore was placed in a pit and mixed in a hot charcoal fire. Air was forced into the dome covered structure via bellows through a fireproof clay nozzle called a tuyere. After a sustained temperature of 1100°-1200°C, slag (oxidised non-metallics) fell to the bottom leaving the spongy mass containing the iron. Holes forming the sponge texture were a result of the removal of the non-metallics when the slag melted out. The spongy mass is called a bloom by some^{10 11}. This spongy mass was then pounded, usually while still hot, and more slag dropped out as the metal was concentrated into a denser mass. The pounded metal was called wrought iron.

Aitchison gives a mean composition of a typical bloom but this could vary widely, depending especially on the origin of the ore;

| | |
|-------------|-----------|
| Carbon | 0.097% |
| Silicon | 0.046% |
| Manganese | 0.040% |
| Sulphur | 0.025% |
| Phosphorous | 0.044% |
| Arsenic | 0.049% |
| Copper | 0.010% |
| Iron | remainder |

The issue raised by this paper is whether or not a steel industry existed in ancient Greece and Rome (up to about 500AD). Contrary to some, the author asserts there was in fact a developing steel industry in the ancient Mediterranean world. To some extent we must base this assertion on the definition of steel. Guy¹² defines irons and steels by the carbon content method.

⁸ Friend, J.N.A., page 68-91 (various references from classical works quoted in Chapter VII)

⁹ Landels, J.G., page 31 (Yet he indicates that they could have been made to achieve 1300°C but were not)

¹⁰ Haag, S.P., Lecture notes page 78

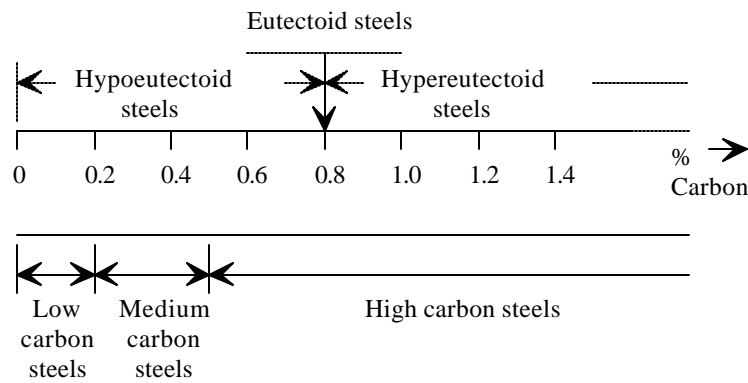
¹¹ Aitchison, L., page 100 (It is interesting to note that in modern steel making the term bloom is restricted to a large section of steel made by rolling after the formation of the ingot. Blooms have round or nearly round cross-sections with its length much greater than its main cross-sectional dimension).

Plain Carbon Steels

Plain carbon steels are steels in which the alloying elements do not play a significant role in determining the properties of the metal. The two systems used are both based on carbon content. The phase diagram of the iron/carbon alloy indicates that at 0.8% carbon a eutectoid composition exists, and a pearlitic structure forms upon slow cooling. With carbon content less than 0.8%, steels are sometimes termed "hypo-eutectoid" and with carbon content greater than 0.8% we have "hypereutectoid" steels.

Unfortunately the classification based on eutectoid structure is coarse and little used for practical purposes. Instead, low, medium and high carbon steel are the preferred groupings used.

Figure 1 Carbon Steel Classifications



Low Carbon Steel (0.06% - 0.25% carbon)

- (0.15% to 0.25% carbon is sometimes called mild steel)
- low cost common construction material
- not considered to be hardenable by heat treatment
- high ductility makes it ideal for press forming (automotive industry, sheets, rods, pipe and wire).
- easily welded, brazed or forged.

¹² Guy, A.G., page 214

Medium Carbon Steel (0.25% - 0.5% carbon)

- stronger than low carbon steels
- can be further strengthened by heat treatment
- harder than low carbon steels but not hard enough to be used as a cutting tool steel
- weldable but not as easily as low carbon steel
- most supplied as hot rolled and machined to final shape

High Carbon Steel (0.5% - 1.6% carbon)

- used only where strength and hardness are more important than ductility
- always given a hardening heat treatment
- used for cutting tools
- even at 1% carbon content a drill bit is too difficult to machine in the normalized condition. To allow machining, prolonged heating just below the eutectoid temperature causes the carbide platelets in the pearlite to "ball up". This produces a spheroidized structure (machinable). After machining, the drill bit can be reheated to the austenite phase (1500°F / 850°C). Water quenching follows and martensite forms. Martensite is a body centred cubic form of iron that traps carbon atoms that were dissolved in the austenite. The great hardness results from distortions in the lattice caused by the trapped carbons.

With over 2% carbon in an iron-carbon alloy the alloy is called grey cast iron". This is no longer considered steel and decarburisation must be used to reduce carbon content to below 2% in order that the alloy again be considered a steel.

Considerable debate exists as to the possibility that true steel production actually occurred in the ancient world. Parr acknowledges the ancients made a case hardened steel but considers this was an accidental by-product of the charcoal next to the bloom. He considers it inappropriate to call the carbon steel alloys made at this time to be the foundation of the steel industry saying this is much like asserting "the baby thrashing the piano next door is making music."¹³ Others also fail to consider the manufacture of steel by the ancients to be an intentional industry^{14 15}.

¹³ Parr, J.G., page 41

¹⁴ Tylecote, R.F., page 41

¹⁵ Friend, J.A.N., page 92

Although quality of the steel produced by the ancients must have been poor and inconsistent, they must have strived to achieve a formula for steel. The fact they did not understand what provided steel its desirable properties is no reason to discredit the infant steel industry. Pliny, in his Natural History, Book XXXIV, describes the process of tempering used by Roman blacksmiths. Although his explanations are incorrect, the fact is made that a hardening process was known and used on iron based tools. Pure iron, even very low carbon wrought iron, cannot be hardened. It is only by a knowledgeable process of introducing carbon into iron that the tempering process would have had any effect on tool hardness. Ignorance of the details of tempering continued into medieval times when various processes were attributed to impart the *best qualities*. Sherby mentions one smith who insisted on quenching the steel in “the urine of a redheaded boy”¹⁶.

Although the exact process was not understood, it was long known that juxtaposition of wrought iron to charcoal increased the hardness of the wrought iron. Two steel making processes were known and practiced in antiquity; the cementation process and the crucible process. The cementation process involved heating wrought iron in contact with a carbon source (usually charcoal) in such a way as to exclude exposure to air. In the crucible process wrought iron bars were melted in crucibles in which charcoal had been placed.

Steel tools made by the cementation process of Roman origin were found in Britain dating to the second century AD¹⁷. Carbon content varied irregularly throughout from 0% to 1.3%. It was this irregular distribution of carbon that made the cementation process, or “home-made” Roman steel less desirable.

It is suggested by Parr¹⁸ that real production of steel began as early as 500 BC in India. This material was referred to as wootz. By Alexander’s time the production of wootz was a well established two step process

¹⁶ Scientific American, page 118

¹⁷ Aitchison, L., page 209

¹⁸ Parr, J.G, page 57

using the crucible method. Two methods could be used, conversion from a cast iron form or conversion from a wrought iron form.

The first was similar to the simple reduction to wrought iron described above. However, the wootz steel makers used a different version of blast furnace. Iron ore and a carbonaceous material were added together in a crucible, this was called the charge. The charge was placed at the top of the furnace and the blast applied to the bottom^{19 20}. If held at a sufficiently high temperature for a long time the bloom would absorb enough carbon to reduce the melting point of the iron. This would result in the mass being melted and cast iron buttons would form in the crucibles. These would have a high carbon content which would need to be reduced (decarburisation) which was the second step in this process. The cast iron buttons were then reheated and turned in the direct blast flame to a temperature just below their melting point. The buttons could then be heated and welded together by pounding. This process provided a fairly homogenous alloy of steel having 1-1.6% carbon content.

The second method employed seems a more straight forward building process and is suggested by Sherby²¹. After a wrought iron bloom was formed by reduction it was broken into small pieces and placed in a sealed clay crucible with a pre measured amount of charcoal. The crucible was about 7cm in diameter and about 15cm tall. Again the crucible was placed in the blast furnace and heated to about 1200°C until the carbon was absorbed by the iron; thereby reducing the melting point. When the crucible was shaken a sloshing sound was sought to confirm the process had been completed. Slow cooling of the crucible over several days would result in an homogenous alloy of steel with 1.5-2% carbon. During the slow cooling a crystal growth occurs that has a large proportion of iron carbide (Fe_3C). Metallurgists identify this white structure on metallographs as cementite. Ancient smiths in the eastern Mediterranean discovered a forging technique that produced an amazing strength and toughness that has only recently been explained²². By heating the wootz to a temperature between 600°C and 850°C cementite would not dissolve into the

¹⁹ US Steel, page 261

²⁰ Parr, J.G., page 57

²¹ Scientific American, page 115

austenite. If it was worked (pounded) at that temperature the cementite crystals would be made smaller and retain the strength of the steel without keeping the brittleness intrinsic with the larger cementite crystals. This metallurgical explanation for the strength and spring properties as well as the swirl colouration of Damascus steels (made by this process since about 330 BC) is a direct contrast to earlier explanations. Friend²³ and Parr²⁴ are amongst those that explain these steels as a blend of cast iron and wrought iron pounded together. However, the evidence assembled by Sherby and Wadsworth²⁵ discredits earlier hypotheses advocating the blend of cast and wrought iron.

Limitations of Steel Development and Applications

Although wootz steel and the Damascus steel manufacturing processes were probably introduced to the west around the time of Alexander, its significance was strangely under exploited, with one exception; the Damascus steel blade swords. To explain why Romans did not adopt or develop the wootz steel manufacturing process and Damascus forging methods must be speculative. Landels puts forward the suggestion that Roman furnace design made production of sufficient heat unattainable, yet he goes on to point out the 1150°C maximum could easily be extended to 1300°C using available technology²⁶. Add to this the fact that the unreliable cementation process used by the Romans provided steels of medium carbon content and this alone could have reduced the temperature to melt the steel to a range reasonably achieved by existing Roman furnaces. The fact remains that opportunity to make improvements in the steel industry existed but was not used. Technical conditions existed during the Roman domination of Europe that **could** have provided the Roman smiths the ability to produce the relatively high quality wootz type steel. The writer suggests two possibilities for the failure of good Roman smiths to make a wootz type steel. One possibility is that the serendipitous actions of forging a lump of the cast iron, that would have inevitably

²² Scientific American, page 116

²³ Friend, J.N.A., page 93

²⁴ Parr, J.G., page 58

²⁵ Scientific American, page 112-120

²⁶ Landels, J., page 31

formed at some point during Roman smelting, did not occur. This was either because the Romans were always fastidious about keeping the unmalleable stuff out of their blooms, or they simply did not experiment with the dirty hard little buttons that would occasionally occur in the furnaces. A second possibility might be that the suppliers of the wootz steel kept the process a secret from their western customers.

Such speculations are not without precedence. The Inca of Peru found no occasion to merit the invention of the wheel and the Chinese did not reveal the secret of the source of silk to their anxious European customers until 552 AD²⁷.

Another issue which merits question is “ why did the ancient Greeks and Romans not do more with the wootz steel than pound it into swords? The ability of a Damascus steel sword to be bent at right angles and still snap back into shape would have revealed its potential as a spring far superior to the bronze and gut used at the time. Hooks, harness rings, tires, chisels, adzes, saws and shovels could all be made of acceptable quality from the home-made Roman steels. Even casehardened cutting edges are commonly found amongst Roman artefacts²⁸. Cranes and other loading devices could have taken advantage of the strength of good steels. Tensile strength of steel per unit length is the main reason for its modern engineering applications. Despite their ability to forge blooms of considerable weight (Aitchison mentions a Roman bloom found in Northumberland, England, weighing 344 pounds²⁹) no attempts seem to be made to fashion large beams girders or other significant support structures using steel. (Small beams have been found in bath houses but were made of wrought iron³⁰).

Iron had various applications as ornamentation, currency and tools, including weapons³¹. Wire made of gold and copper was fabricated and often used in jewellery. Such wires were even twisted into rope-like

²⁷ Compton’s Interactive Encyclopaedia, 1995

²⁸ Aitchison, L., page 209

²⁹ Aitchison, L., page 208

³⁰ Tylecote, R.F., page 55

³¹ Friend, J.A.N. chapters 6,5 and 7 respectively

torcs³² by the Celts. Although they would have had the ability to draw steel into wire and fashion rope from it, as we do with steel cable today, this too seems to have been another missed opportunity.

To summarize, in addition to superiority in spring applications, wootz steel or Damascus steel would have provided better results than the home-made Roman steels in any application where tensile or cantilever loading was required.

It was not until the late medieval period that significant progress in steel manufacturing took place in Europe, and this mainly due to the improved blast techniques. These were primarily due to the use of coal as fuel and allowed increased temperatures to be attained. As a result cast iron became a common product. However, it was not until 1781 that the relationship between iron and steel was explained. This was accomplished by Torben Bergman in his scientific paper “Disseratio Chemica de Analysi Ferri”³³.

Steel, as with many other items and principles, was not understood by the ancients. However, lack of understanding is rarely a barrier to engineering applications. Fortunately our engineering forefathers applied a common modern engineering axiom to the handy material we call steel; “If it works use it.”

References

1. Compton’s Interactive Encyclopaedia, CD-ROM version, copyright 1993, 1994.
2. Friend, J.N.A.; Iron In Antiquity, Charles Griffin and Company Ltd., 1926
3. United States Steel Corp.; The Making, shaping and Treating of Steel, 1957
4. Parr, J. Gordon; Man, Metals and Modern Magic, American Society for Metals, 1958
5. Tylecote, R.F.; A History of Metallurgy, The Metals Society (U.K.) 1976
6. Aitchison, L.; A History of Metals, vol. 1, MacDonald & Evans, 1960
7. Guy, A.G.; Elements of Physical Metallurgy, Addison-Weseley Publishing Co. Ltd., 1960

³² Aitchison, L., page 131

8. Landels, L.G.; *Engineering in the Ancient World*, Clarke, Irwin and Company, 1980
9. Sherby, O.D. and Wadsworth, J.; *Damascus Steels*, *Scientific American* February, 1985
10. Haag, S.P.; *Classical Studies 384 Lecture Notes*, University of Waterloo, 1995
11. Salter, D.L.; *Earth Science 231 (Mineralogy) Lectures*, University of Waterloo Sept. 1972
12. Linnert, G.E.; *Welding Metallurgy*, vol. 1, American Welding Society, 1965

³³ Tylecote, R.F., page 157