Glossary of terms used in the study of ancient metal-working and associated processes

This glossary is under development by the Material Science-Based Archaeology Group (Oxford University) and the Archaeology Committee of the Historical Metallurgy Society. Please note not all sources are in agreement about the definition of certain terms; some terms have more than one definition depending on context, not all of which may have been included as yet. Please consider this to be very much a work in progress, as can be seen by the number of incomplete and missing entries.

Contributors - C. J. Salter and B. J. J. Gilmour, Materials Science-Based Archaeology Group, Department of Materials, University of Oxford with some help most gratefully received from David Cranstone. If you wish to add an entry, or comment on an existing entry please email David Dungworth.

A

A_1, Ac_1, $Ar_{1,}A_{2,}A_3,A_{CEM}$
Arrest points on the iron-carbon phase diagram.
Acicular
Possessing an elongated or needle shaped structure.
Adit
A level cut from a valley or other low point to intersect mine working at depth. An adit may be used to drain the mine, and/or to provide access to the mine.
Admiralty Brass
see Brass, Admiralty
Ag
Chemical symbol for Silver (from *argentum* - the latin for silver).
Age-hardening
The process of hardening spontaneously over time at ambient conditions. Some steels age-harden as do other alloys. The process was first studied in aluminium-copper where coherent precipitates of different structure form as the first stage of the process.
Al
Chemical symbol for Aluminium
Alchemy
Related terms Alembic**,** cucurbit, retort,
Alembic
The head of a distillation apparatus, which fits over the retort or cucurbit, containing the delivery spout which connects with the condenser.
Alliotrope
Certain substances can exist in more than one crystalline form; for example carbon can be found as graphite, diamond, or the recently discovered buckminster-fullerene. Pure iron has three main allotropes alpha (ferrite) , and gamma (austenite) and delta, which are stable at different temperatures.
Allotropes of Iron
Iron as a solid exists in different allotropic crystalline forms. The most important are alpha iron (ferrite) and gamma iron (austenite). The crystal lattice arrangement of alpha iron is one which is body centred whereas that of gamma iron is a face-centred cubic arrangement. The iron-carbon equilibrium diagram (technically the iron-iron carbide meta-stable phase diagram) shows the temperature ranges in which each form of iron is most stable as well as the carbon solubility range for these allotropes or phases.
The great importance of the two crystalline forms of iron lies in the difference of the solubility in solid solution of carbon between the two. Carbon is virtually insoluble in the body-centred ferrite form, the lattice structure of which will only accept a maximum of 0.04% of carbon. The face-centred cubic lattice of austenite will accept carbon atoms more readily and up to about 2.1% carbon is soluble in alpha iron.
Alloy
A metallic mixture two or more elements. An alloy can be formed from a mixture of two of more metals e.g. copper and tin to form bronze, or by a mixture of a metallic and non-metallic element e.g. iron and carbon to form steel, or cast iron.
It has been suggested that the term alloy should only be used when there is a suggestion that the mixing was deliberate. In the study of ancient metallurgy it is difficult to prove deliberate mixing in some cases, e.g. when the ‘alloy’ could have arisen by co-smelting e.g. Cu-As and Fe-C-P

alloys. So, an alternative use of the term would be - any metallic mixture of elements whose physical, mechanical, or metallurgical properties differed substantially from the constituent elements.

Alluvial Deposit

The local concentration of minerals in old river and stream deposits (Alluvium). These form when minerals weathered and transported from the original solid geology deposits are locally concentrated in the bed of steam. These stream deposit may be buried to some considerable depth below subsequent quaternary gravels. Tin and gold in particular are concentrated in such deposits. Much of the medieval and earlier tin mined in Devon and Cornwall came from streamworks working this type of deposit.

Related terms: Eluvial, Colluvial

Alpha Brass

Low zinc brass. See Brass - alpha

Alpha-Beta Brass

See Brass, Alpha-Beta

Alpha-delta eutectoid (in bronze**)**

A hard constituent normally present in the structure of cast bronze containing more than about 6% tin. (Delta phase intermetallic composition, $Cu_{31}Sn_8$).

Alpha-iron

See Ferrite

Aludel

Alchemical distillation apparatus. A pear-shaped ceramic or glass vessel open at both ends so that one could fit over another, used in sublimation and distillation to separate the heated retort from the condensing part of the apparatus.

Aluminium (Symbol Al)

Element with atomic weight 26.98, atomic number 13, mp 660.37 ºC, specific gravity 2.69. It is the most abundant of the metallic elements but is very difficult to extract and was not properly known until 1827.

Amalgam

A compound or mixture of mercury with other metals. Mercury may form an amalgam with gold, silver, tin, zinc, lead, copper, and other metals. The microstructure of these amalgams may be complex.

Amalgam gilding

The process used for the gilding of many copper alloys in ancient and historic times. Gold becomes pasty when mixed with mercury and may be applied as a paste over a surface. This can be followed by heating to drive off most of the mercury, or the mercury can be applied to the clean surface of the object to be gilded, followed by the attachment of gold leaf or foil. Gilding

Analysis

Chemical

Chemical analysis is an important aspect of archaeometallurgy. These techniques can identify the metals and alloys used to produce the artefact or debris under study, be used determine the number of structure components used to construct complex artefacts, be used to test whether a group of material is compositional similar, be used to establish metal trade routes, and in a few cases the provenance of the metal. A large number of different techniques are available to the archaeometallurgical, each with its own advantages and draw-backs.

Analysis Technique	Acronym used
Atomic Absorption Analysis	AAA (AAS)
Metallographic	None
Electron Probe MicroAnalysis	EPMA
Energy Dispersive X-ray Spectroscopy	EDS, EDX
Induction Coupled Plasma Mass Spectroscopy	ICP-MS
Induction Coupled Plasma Optical Emission Spectroscopy	ICPS-OES
Proton Induced X-ray Emission	PIXE
X-Ray Diffraction	XRD
X-Ray Fluorescence	XRF

Anhedral
A term used to describe crystal shapes of minerals, meaning that the crystal has no characteristic faces visible. Synonymous terms some times used Allotriomorphic, and Xenomorphic.
Related terms: Euhedral, Subhedral

Annealing
Annealing is a heat-treatment carried out on a metal or alloy, usually with the aim to alter the microstructural or chemical structure of the metal to the advantage of the metal-worker. In a simple metal (pure metal or solid solution) annealing will be used to soften the work-hardened material to allow further deformation (e.g. hammering). The lowest temperature at which a metal will soften varies with the degree of cold-working, greater amounts of work tending to reduce it. With more complex alloys (those with more than one phase present), annealing may be used to alter the microstructure in terms of the phases present, their distribution, or simply to even out the elemental distribution. Thus, an annealing process may be further classified, for example the anneal may be described as a stress-relief anneal, solid solution anneal, or simply normalizing (anneal implied); the additional term indicating the purpose of the heat treatment.
Related terms: Cold Work, Microstructure, Recovery

Annealing twin
In FCC metals, a process of recrystallization (often of worked and annealed metals) in which a mirror plane in the crystal growth results in two parallel straight lines appearing across the grain when the metal is etched.

Anode
Component of a system that is usually corroded (metal is dissolved). In an electrochemical reaction, it is the positive electrode at which oxidation occurs.
Related - Cathode

Anorthite
Anorthite is the calcium rich end member of the both the feldspar series of minerals (the alkali feldspars with orthoclase [$KAl_2Si_3O_8$] at the other end, and the plagioclase feldspars with albite [$Na\ Al_2Si_3O_8$] at the other end). The interstitial material between the main phases in many slags is often described as anothorthic glass (having a composition similar to anorthite). However, this description is misleading as the composition of the glass is not near the composition of anorthite as it often contains high proportion of iron and the other alkali elements. When cooled sufficiently slowly phases other than anorthite predominate. In slags cooled at the normal rate there are many other phases present but at sizes below the resolution of the optical microscope, and when cooled sufficiently slowly phases other than anorthite predominate.

Related terms: Feldspar, phase diagram

Antimony (Symbol Sb)

Element with atomic number 51, atomic weight 121.75, mp 630 ºC, specific gravity 6.62. A lustrous metal with a bluish silvery-white appearance. The metal does not tarnish readily on exposure to air and can be used as a decorative coating. Antimony is found in some copper alloys of antiquity in particular in combination with arsenic. [Chalcolithic - Near East, Nial Mishmal, medieval north-west Europe cheap castings] Copper with antimony contents in the region of 3% show a considerable hardening.

Anvil

A block with one flat face on which the smith shapes his metal by hammering. Although all modern anvils are of steel, the use of stone as well as iron is recorded in the archaeological record. Experimental and ethnographic evidence would indicate that wooden anvils would have been used for bloom smithing.

Related terms: Block anvil, Beaked anvil, Stake

Archaeometallurgy

The application of the materials science to archaeological studies. In particular the study of the processing of metals from ore to final artefact, the trade and use of the artefact and the processes involved its deposition and subsequent corrosion.

Arrest point

Related A1...A3

Argentojarosites

Silver-rich clay-like minerals which sometimes appear in the secondary enrichment zone of metal deposits.

Arrhenius Law

$$1/t = Ae^{-Q/RT}$$

Where

t, is the time required to recover a fixed fraction of the property,

Q, is the activation energy

R, is the universal gas constant

T, is the absolute temperature, (T°C + 273)

Arsenic (symbol As)

Element with atomic number 33, atomic weight 74.9214, specific gravity (grey form) 5.73. The usual variety is grey arsenic which sublimates at 610ºC. Arsenic is a steel-grey colour with a metallic lustre and was the first alloying element of importance. Arsenical copper alloys precede the use of tin bronzes in most areas of both the Old and New Worlds. Arsenic contents usually vary from about 1 to 8%.

Arsenical copper

Copper with a few weight percent arsenic has considerable improved mechanical properties compared with that of a pure copper. At the end of the chalcolithic, in some regions, arsenical copper was used in the placed of pure copper. There has been considerable discussion in the archaeometallurgical literature as to whether this change was due to the deliberate addition of arsenic containing ores to the smelt, an accidental change due to use of different ores, or a change to a lower temperature smelting process which would allow the retention of more of the arsenic present in the ore.

As-cast structure

The metallurgical structure (distribution of phases and grain structure) formed during the solidification of the metal after casting. Such structures are often composed of heavily cored dendrites. The grain sizes and shape vary with distance from the mould surface. The chemical composition very also vary as a result of elemental segregation during freezing, as a result gravity segregation , inverse segregation , heavily cored structures can be produced. To make the metal suitable for use it was sometimes necessary to anneal and mechanical work it to homogenize the metal and reduce the grain size, and allow diffusion to even out local chemical inhomogeneity.

Assay

To test the quality of an ore or metal; in early times by making use of simple chemical reactions which extracted the metal in visible and weighable form. Today calibrated physical instruments are used such as spectrographs.

Atomic Absorption Analysis

A technique that replace OES and in its turn has now been replaced by the various forms of ICPS. It worked by the fact that when the atoms of an element are ionized in a flame they will absorb light of a specific wavelength.

Advantages - cheap, quick, Disadvantages -dissolution, certain elements very difficult, lamps, Detection Limits, Element range

Austenite

A non-magnetic face-centred cubic form of iron normally existing only at high temperature. In pure iron austenite is stable between 910^{o}C and 1390^{o} C, but this phase will dissolve up to 2.1 wt percent of carbon, the presence of which expands the stability range to between723°C and 1493°C. Other elements (Ni and Cr in particular) will expand the austenite stability range to room temperature.

Austenite, Retained

Related terms: Quench, Bainite, Ferrite, Martensite, Pearlite, Nodular pearlite, Troosite.

Austenitizing

Forming austenite by heating a steel to between A1 and A3 (partial austenitizing) or above A1 (complete austenitizing). When used without qualification, the term implies complete austenitizing.

Azurite

A blue-green basic carbonate of copper ($2CuCO_3$. $Cu(OH_2)$).

B

BCC

Body-centred cubic. A unit cell in which atoms are situated at each corner of a cube with one atom in the centre of the cube. Each atom at the corners is shared by each neighbouring unit cell. BCC metals such as barium, chromium, iron, molybdenum, tantalum, vanadium, and tungsten cannot be heavily worked but they have a good combination of ductility and strength.

Related - FCC, CPH

Bainite

Bainite is a term used to describe the microstructures found in rapidly quenched hardenable steels, which have been quenched at a rate intermediate between that necessary to produce fine pearlite and martensite. The structure consists of a fine dispersion of carbide particles in ferrite. There are two forms of bainitic steel structures: Upper and Lower Bainite.

> **Upper Bainite**: A structure composed of ferrite and small carbide (cementite) precipitates which forms by slow quenching of a steel from the austenite region. The upper baintite forms between 500 and 350^{o}C and show a feathery structure on etching.
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> **Lower Bainite**: A structure composed of fine carbide precipitates (Fe_3C and $Fe_{2.4}C$) in ferrite formed by the slow quenching of a steel from the austenite range to below 350^{o}C.

The carbide precipitates form at a constant angle to the direction of the growth of the ferrite needles. The structures looks very similar to lightly tempered marstensite.

Basic Steel Making

Bay

Term used for the dam impounding the pond or lake used to drive the waterwheels used in water-powered blast furnaces and forges.

Beaker Period

The period in which the use of copper metallurgy started in the British Isles. The period is so called because of the burial ritual involved the deposition of a beaker shaped ceramic vessels together with the human remains.

Bellows

A means of blow air into a furnace. Bellows are very rarely preserved in the archaeological record. The main evidence of the various types that could have been used comes from historical or ethnographic sources. Types of bellows that could have been used were :- the pot bellows, bag bellows, box bellows as well as the 'normal' smiths bellows. Initially, bellows were hand or foot powered. With the introduction of water-powered bellows furnace sizes and temperatures could increase if suitable refractory materials were available.

Beneficiation

Methods of improving the concentrating the metal containing minerals in an ore before smelting. In antiquity this was done either by hand sorting, or various washing techniques.

Bessemer Steel Making

Bidri

Name for an Indian copper-zinc-lead alloy, finished by surface treatment to colour it black and often inlaid with silver.

Billet

A block of forged metal. In the bloomery process, billets are an intermediate stage between the bloom and bar iron. As a billet would have been worked more extensively than the bloom, is slag content was lower, and the metal more easily worked by a smith.

This term should be used for blocks of bloomery or wrought iron. (Ingot is often misapplied - as the term ingot implies that the material is the as-cast state.)

Black copper

Crude copper with a high oxygen content. Black copper would require refining to remove the excess oxygen.

Related terms: Blister copper, Matte, White metal

Blast furnace

General A shaft furnace in which the charge and fuel descend from the top, with air or oxygen is blown in near the base. The combustion of the fuel at the base provides both the temperature required for the reactions, and to melt both the desired product and any slag formed , this combustion also provides a sufficiently reducing atmosphere for the reactions to proceed. (Examples non-ferrous Copper, lead, tin.)

Blast furnace - iron

Form, Development in China, in West, Charcoal-fired, Coked-fired,

Blister Copper

The first crude metallic copper produced by the double decomposition of partially oxidised matte.

Oxidisation $2Cu_2S$ (matte)+ $3O_2 = 2Cu_2O + 2SO_2$

Double decomposition $Cu_2S + 2Cu_2O = 4Cu + SO_2$

This metal typically contained 80 to 90 % metal, therefore, it needed considerable further refining to remove the impurities (mainly iron and oxygen).

Blister Steel
Steel produced by the cementation process . This involved heating bars of iron packed in charcoal in sealed sandstone boxes for several days at temperatures around 900^{o}C. This allowed carbon to diffuse in to bar, but the composition of the bars would not be homogeneous. The surface would have a higher carbon content than the core of the bars. To improve the quality of the steel, bars would be repeatedly folded, welded and forged down to produce much more homogeneous shear steel.
Blister steel was so called because the surface developed blister like distortions due to the generation of carbon dioxide during the cementation process. Carbon diffusing into the iron, reacts with iron oxides in the slag inclusions within the metal to form more metallic iron and carbon dioxide.
Blocking
Block Tuyére
Related term: Eisenstein
Bloom
The word is used to describe either the mass of iron and slag produced by the director bloomery process: A semi-congealed, porous or spongy mass of iron still mixed with much non-metallic slag. As this material is very rarely found on archaeological sites. The material unusually described in archaeological reports as blooms are, in fact, consolidated, or semi-consolidate blocks of iron formed by the first forging of the bloom.
The term was also applied to the similar mass of iron and slag that was an intermediate product of the puddling process in which cast iron was converted to 'wrought' iron. In both processes the crude bloom must be extensively worked at welding heat to consolidate the iron and remove excess slag. Unfortunately, the term is used to describe both the crude, unprocessed mixed mass of iron and slag, and the worked and compacted ‘finished’ block of malleable metal. The term billet is preferable for parallelepiped or near parallelepiped shaped worked bloom.
Bloom - forging / refining
The process of forging the mass of slag and iron from either the bloomery furnace or puddling furnace at near welding heat to consolidate (weld together the various pieces of iron) and expel as much of the slag as possible. This process was also known as shingling when applied to the refining of puddled iron.
Bloomery
The term bloomery is used both describe the process by which iron was directly smelted from the ore, and the physical installations used in the process (the furnace, and reheating hearth and anvil settings).
Bloomery - process
The process in which a spongy mass of iron was been produced in a solid condition directly as a result of the reduction (e.g. smelting) of iron ore in a bloomery furnace. Pure iron melts at 1535ºC, but bloomery iron has usually never been heated above c.1250ºC. The crude bloom must be extensively worked at welding heat to consolidate the iron and remove excess slag and charcoal. The carbon content is variable but usually low. However, it was possible to run bloomeries under the right condition so as to produce high-carbon bloomery or ‘natural’ steel which when forged down had properties similar to modern carbon steels.
The bloomery process was the main method by which metallic iron was obtained before the introduction of the indirect or blast furnace process.
Bloomery - furnace types
The archaeological record shows that there was a great variety in the design of bloomery furnaces. There have been a number of attempts to classify the various types of furnace. These

have been made on the basis of the method of ventilation (blowing), or the way in which the slag and metal was removed from the furnace. Other factors that could be included are - the number of blowing positions, the use of tuyère or blowing holes, whether the furnaces are free standing or embanked.

Method of ventilation	**Method of slag removal**	**Furnace Form**
Induced Draught Furnaces	Slag Tapping	Shaft Furnace
Natural Draught Furnaces	Non-Slag Tapping	Developed Bowl Furnace
Wind Powered Furnaces	Non-Slag Tapping - Pit	Long Wall Furnaces
		Bowl Furnace*

***** It is likely that most small 'bowl' (30cm or less in diameter) are in fact the bases of shaft furnaces which the archaeological evidence for the superstructure was either destroyed or not noticed by the excavator, as experimental work shows that it is very difficult to produce sensible amounts of metallic iron in such small furnaces due to the very high heat losses involved.

Bloomery - High

Blow-hole

A void formed in a casting - due to the separation of dissolved gas during solidification of the metal.

Blowing hole

Related term tuyère

Blowing house

A building set aside for the smelting of tin ore (black tin) with the aid of a furnace and water-wheel driven bellows. It sometimes also contained a stamp mill for breaking up the ore driven from the same wheel. A number of relatively well preserved examples exist on Dartmoor, Devon, UK.

Blowing-in

The starting up of a blast furnace.

Blueing

Bog Ore

An iron ore formed by the chemical precipitation of iron oxides in bogs. These were often an important ore source for many early bloomeries. The more common, but related, hard pan iron ores were used extensively in many area of Britain.

Bole Hearth

A primitive method of smelting lead, in which, a fire is built of layers of wood and lead ore, usually close to the top of hill to catch the wind. When set alight the lead some of the lead is smelted to the metal and drains down to the bottom of the fire and runs along collecting channels.

Bowl Furnace

A shallow furnace which is relatively wide compared to its height. Rich copper ores may be smelted in a simple bowl furnace, but yield of iron smelted in a small bowl furnace is likely to be low. Thus, many iron smelting furnaces that have been described as small bowl furnaces are more likely to have been the remains of badly eroded furnaces with substantial superstructures.
Related terms - developed bowl furnace, shaft furnace, wall furnace.

Brass

An alloy of copper and zinc. It used to be made by melting copper in contact with the zinc carbonate, calamine ($ZnCO_3$), under charcoal in a crucible. Early brasses contained 70-90% copper and 10-30% zinc. The colour of brass changes with increasing zinc content from a rich copper-red through to pale yellow to white as the zinc increases. Gilding metal containing 10-15% zinc is suitable for cold working. It is used for ornamental work and jewellery. Red brass contains 30% zinc and 70% copper and has good working properties. The common form of brass is 60% copper, 40% zinc and is known as yellow brass or Muntz metal. In Europe from about 1750 it was made by melting the two metals together (Direct process).

Brass, Admiralty

An out-dated term for an alpha brass in which some zinc is replaced by tin; usually only about 1-2% tin is added.

Brass, Alpha

An alloy of copper and zinc with no more than 38% zinc so that the beta phase is not formed. In antiquity, the cementation process for the manufacture of brass meant that only up to 28% zinc might be absorbed in the copper when the zinc ore was reduced in situ. Most ancient brasses do not contain over 28% zinc.

Brass, Alpha-Beta

A brass with sufficient zinc present to allow the development of the beta phase. The equilibrium range of the alpha-beta composition varies with temperature being 33.5 to 36.8% at the solidus temperature, and 35 to 46.6 % at room temperature. As the beta to alpha reaction is a diffusion controlled reaction, it is relatively slow, thus it is possible to control the relative proportion of alpha to beta phases by a combination of composition and heat treatment so that the combination of tensile strength to ductility can be optimised.

Brass, Beta

The beta phase of the copper-zinc equilibrium phase diagram is an intermetallic phase and is much harder that alpha but will only withstand a small amount of mechanical deformation at room temperature. However at 470°C the ordered Beta prime phase changes to the disordered beta phase which is easier to work, and by 800°C the beta phase is easier to work than the alpha.

Brass, Cartridge

A 70/30 (30 % zinc) brass so named as the good combination of great ductility allied with strength made this alloy suitable for the production of bullet cartridges. However, to maintain these properties it is necessary that the impurity content is low. Iron, lead, bismuth, arsenic and antimony are all detrimental.

Brazing

The joining of two pieces of solid metal by means of a molten alloy of copper and zinc (brass); in modern usage this has been extended to include a wider range of molten metals such as the 'silver solders'. In antiquity, silver-gold, copper-silver and silver-gold-copper alloys were used for brazing (or soldering), especially on precious metals.

Related terms: Solder, Soft-solder, Silver solder

Brescian process.

Carburization process involving the mixing of cast iron and low carbon iron, first described in Europe by Biringuccio in 1540. However, it is likely that some of the Persian crucible steel manufactured at Herat (now in Afghanistan) may have been produced in this manner according to Al Burani (Allan and Gilmour 2000, 61-62)

Related terms: Carburization, Carburization-cofusion

Brinell

The Brinell Hardness Scale in which the hardness is measured by the resistance to indentation of a small steel ball. This method is becoming less common, but does allow some comparison with results from the Vickers Scale at low hardnesses. However, as with other systems that use steel indenters it is unreliable with hard materials as the steel indenter deforms.

Related Terms: Hardness, Vickers Hardness Scale, Rockwell Scale

Bronze

In antiquity and historical usage, an alloy of copper and tin. Usually with up to 14% tin, but many examples of ancient alloys are known with higher tin contents. 14% tin is the limit of solid solution of tin in well annealed alpha-bronzes. In modern usage, the term bronze is associated with a number of copper alloys that may contain no tin at all and in which case the composition of the alloy should be specified.

Bronze - leaded

A bronze containing a significant quantity of lead. Many early copper alloys contain some lead due to impurities in the constituent metals. A leaded bronze is an alloy in which the lead has been added deliberately. If the lead content is less than about 1% wt if likely that the content is accidental. The addition of up to about 2% lead can improve the castability of the metal, but in some cases far greater quantities were added other reason.

Bronze Powder

Powdered metal used to make paints that look like gold or bronze. Although called powdered bronze, these were in fact, brass. The metal was beaten to leaf and then ground by hand to a powder using an organic medium to prevent the flakes sticking. The industry was based in Germany, especially centred at Nuremberg. In 18th century hand manufacture had started in Birmingham, in the early 19th century developed an fully mechanical method of manufacturing bronze powder, about 1840 Henry Bessemer started marketing his powder, under cutting his competitors prices. This provided the financial basis for his experiments for steel production.
Thornton, J. 2000,312 - 313

Bucking

Ore preparation.

Buddle

A method of concentrating crushed ores using gravity separation by washing the ore in a flow of water.

> **Square/rectangular,** in which the crushed ore was washed into the square or rectangular tank at one end with the heavier ore remaining near the point of entry (the head) where the unwanted gangue material would be washed further to the foot of the tank (tail - hence the term tailings for ore waste).
>
> **Round buddle**
>
> A later mechanically powered version

Bulat

The Russian term for crucible steel or Wootz.

Bullion

The term is now applied to any bar or ingot of precious metals, and gold in particular. I have seen it suggested that the term was derived from the small buttons of gold or silver formed by the cupellation process. The Oxford Dictionary suggests that it comes from the French to boil, disappearance of the lead in the cupellation process could easily be thought to be because the lead was boiling off.

The term was also used to describe any small blob or lump of metal.

Burin

Burn

To over heat metal so as to adversely affect its mechanical properties. This may or may not involve the oxidization of the metal. Metal that has received a over-prolonged anneal, leading to the formation of large brittle phases may be described as burnt.

Burnishing

To produce a shiny surface on a metal by rubbing the surface with a hard material, typically a stone or polished steel.

C

Calamine

A mineral containing zinc; in antiquity it was used to signify the carbonate $ZnCO_3$, which is now called smithsonite.

Calcine

Typically, to heat an ore or other mineral in an open hearth.

Campaign

One cycle of use of an iron blast furnace.

Carat

A term used to express the degree of purity or fineness of gold. Pure gold is 24 carat or 1000 fine. The fineness of alloyed gold can be expressed in the number of parts of gold by weight that are contained in 24 parts of the alloy. For example, 18 carat gold contains 18/24 parts of gold and is 75% gold or 750 fine.

Carburization

The process of increasing the carbon content of the surface layers of a metal (often wrought or bloomery iron) by heating the metal below its melting point with carbonaceous matter such as wood or leather charcoal. The process is slow as it controlled by solid state diffusion and results in an uneven distribution of carbon with higher concentrations of carbon at the surface than the centre of the bars. Thus, to produce a steel with a more uniform carbon distribution it was necessary form welded composite by forging the bar and welding it either back on itself or together with other bars.

Related terms: Cementation, Cofusion, Pack, Case-hardening

Carburization - case

See Case-hardening

Carburization - cofusion carburization

In the so-called cofusion carburization process molten cast iron (with its high carbon content) is used to carburize a low carbon iron by either dipping the low carbon iron in molten cast iron. Alternately a suitable amount of low carbon iron was put into a crucible of molten cast iron. Depending on the temperature and composition of the iron and cast iron used either the contents of the crucible would freeze before all the iron dissolved, resulting an inhomogeneous steel, or a more homogenous fully liquid steel was produced. The carbon content of the steel was intermediate between that of the cast iron and the iron. Allen and Gilmour, 61-62 suggest that the Islamic texts describe this as one of the methods of producing crucible steel (called *fulad*) is produced by melting soft iron (bloomery iron) and hard iron (cast iron) together.

Related terms: Crucible steel

Carburization - pack

Where iron is carburised by being heated packed in a carbon rich medium, such as powdered charcoal. This can apply to the processing of nearly finished tools such as files where the heating would be relatively short to give only a surface layer of steel, or, to the more prolonged process required to carburise the thickness of bars.

Cartridge Brass: See Brass: cartridge

Case-hardening

Case-hardening is a process consisting of one or more heat-treatments for producing a hard surface layer of the metal of a near finished artefact. In antiquity this was by a short carburizing process to induce a thin layer of high carbon steel on object of iron. This allows complex shapes to be formed whilst the metal is ductile, but then to give the object a hard wear-resisting surface in its final form. This technique was used to harden the teeth of Iron Age files.

Cassiterite

Tin (IV) oxide SnO_2. Occurs naturally as dark brown/black pebbles - alluvial 'stream tin'. As a pure chemical cassiterite is white, and takes on its dark colour from associated inclusions. believed to be the major source of tin from the Early Bronze Age onwards.

Cast Iron

Iron containing more than 2.1% C (the solubility limit for carbon in austenite) together with other impurity elements such as silicon and phosphorus, which has been cast from the liquid. Without further treatment it is very brittle and not malleable either hot or cold. Cast iron exists in two main forms, white and grey; terms which describe the appearance of the surface exposed when the metal is fractured.

In white iron the carbon is present as cementite (Fe_3C) and as pearlite. Its production is favoured by fast cooling rates and low silicon content. Both irons are brittle - grey iron because of the lack of strength and disposition of the graphite flakes, and white because of the extreme hardness and brittleness of the cementite. Malleable cast irons can be obtained by heat-treatment of white cast irons by converting the combined carbon into free carbon or temper carbon. In the whiteheart process for example, a certain amount of carbon is removed from the surface by oxidation

> **Cast Iron, Grey**
>
> A cast iron in which the carbon is predominately in the form of graphite flakes. The formation of grey cast irons is promoted by high silicon content (highly reducing conditions). It is often stated that early cast irons tend not to be white as the early furnaces would not be sufficiently reducing to reduce enough silicon. However, very early cast iron found on many Roman and later iron smelting site produce some grey cast iron amongst the metallurgical debris. This is because slow cooling also promoted graphite growth over cementite.
>
> Grey cast iron has excellent casting properties and can be machined, but is brittle. It is less easily converted to wrought iron as the carbon in form of graphite flakes and it is more difficult to get the carbon back into the iron so that is is able to diffuse through the metal.
>
> **Cast Iron, Mottled**
>
> A cast iron in which the conditions were intermediate between those for graphite and cementite formation, so that the metal contains patterned regions of white and grey cast iron.
>
> **Cast Iron, White**
>
> A cast iron in which the carbon in the iron is in the form of cementite. As a result this alloy is extremely hard and brittle. This form of cast iron was favoured for conversion to wrought iron the carbon diffuses more easily if it is already combined with iron in the form of cementite. The formation of white cast iron is favoured by low silicon content, phosphorus, and fast cooling rates.
>
> **Cast Iron, Whiteheart**

Casting

1) The operation of pouring metal into a mould and allowing it to solidify.
2) A metallic object that has been made by casting the metal into a shape.

The simplest forms could be produced in an open moulds that are were either uncovered at the time of casting, or had a simple flat plate lid. This form was often used for simple early Bronze Age axes. Piece moulds are made of two or more fitting pieces in stone, bronze, or sand-clay mixture. Hollow-cast objects are usually piece moulds with false cores. A figure was modelled in

clay and a piece mould was built up around the model. The model was removed and could be shaved down in size to provide the core around which the mould pieces and mother moulds would be assembled. Mould design is important for successful casting to prevent various types of casting defects.
Related terms: Lost wax casting, Sand casting, Pattern, Feeder, Header, In-gate, Vent

Casting-on

The process of making a cast part attached to an already existing object or component. In antiquity, a lost wax addition, made by creating a small mould around part of an object and casting on metal directly to it. Often used for dagger handles or repair or construction of large bronze figures.

Catalan furnace

Furnace blown by a 'trompe' for making iron by the direct process (bloomery iron). Used in Catalonia, Ariège, and some other regions bordering the Mediterranean; in the past the term was often used loosely for a bellows-blown low hearth from which the bloom is extracted through the top.

Cathode

In an electrochemical cell, the component on which reduction takes place. In many corrosion processes, the cathodic regions are protected during corrosion, while attack takes place at anodic regions.

CCC

See Continuous Cooling Curve

Cementation - gold/silver

In the case of copper (cement copper) it means the precipitation of fine copper on scrap iron from copper-bearing solutions. Cementation of gold alloys with salt in a cupel may remove silver leaving pure gold behind.

- iron alloys

With reference to iron, this is process in which the carbon content of iron is increased by heating the metal in contact with carbon-rich such as charcoal. Possible first reference is in a treatise published in Prague in 1574. The first English patented was applied for in 1614 by William Elyott and Matthias Meysey, but clearly used much earlier.
The cementation furnace at Derwentcote had two sandstone chests which were packed with iron bars surround with charcoal and had to be heated for several days to allow the carbon diffuse through the section of the bar. The resulting steel was termed blister steel.

Cemented blister bar

Bar of blister steel carburized in a cementation furnace.

Cementite

A carbide of iron with the formula Fe_3C. Very hard and brittle meta-stable phase forming one of the constituents of pearlite - the lamellar eutectoid of ferrite and cementite. It also appears as a separate constituent in the grain boundaries of wrought iron containing about 0.02% C and in steel containing more than 0.8% C. In the latter case it may produce a Widmanstätten structure. It also appears in white cast iron in the pearlite and as a separate constituent. The carbon in cementite is normally referred to as 'combined carbon' to distinguish it from the form of carbon known as graphite.

Chafery

A reheating furnace for working iron blooms in a forge or finery. Can be fuelled with coal or coke as in a smith's fire.

Chalcolithic

The period during which copper began to be used extensively. The period is characterised by the use of either unalloyed copper or copper arsenic alloys. In Britain copper period ran from about 2500 to about 2200BC.
Related term: Eneolitic

Chaplets
Small pegs, wires, or other materials used to hold a hollow lost wax casting in position in the mould by securing the investment or casting core to the mould so that it will not move when the wax is melted out.

Charcoal
Wood heated with a limited air supply, so that part of the wood is converted to pure carbon, driving off the water and other volatile components. It is possible to achieve higher furnace temperatures using charcoal than wood. Early English texts tend to call charcoal coal (cole), and what is now termed coal was described as either mineral coal, or sea coal.

Charge
The load, or the material loading into a furnace or crucible, or the process of loading the furnace or crucible.

Chase/Chasing
A method of producing a design on metal surface by hammering the metal using a punches or chasing tool designed for the purpose. The metal is supported by a stake Unlike engraving, metal is distorted to produce the design, not removed.
Related terms - Engraving, Repoussé.

Cinder

Cire perdue
Term meaning lost wax casting.

Clinker
Term used to describe low density slag-like materials. Usually they are semi-vitrified and vesicular materials with unfused, or partially fused fragments of the charge, hearth lining, or refractory material incorporated with the fuel. They may not necessarily be associated with metal working. When the fuel is coal or coke it usually contains enough rock fragments to produce a clinker if burnt at a sufficiently high temperature. In old reports the term may also have been used interchangeably for slag, and Fuel Ash Slag.
The term was commonly used in the 20th century to describe the larger semi-fused and sintered masses of ashes found in the morning when a household coal fire had burnt out. The term ‘Cinders’ tended to be used for the smaller pieces of similar nature. (There may have been regional variations on this usage.)
The term is best kept for non-metallurgical pyrotechnical ceramic debris - such as was generated in the fireboxes of furnaces for 19th and early 20th century boilers and the like, e.g. boiler clinker

Close Packed Hexagonal
Close-packed hexagonal. A hexagonal net in which the atoms are arranged in a repeating sequence ABABABA...... One unit lattice has a hexagonal prism with one atom at each corner, one in the centre of the bottom and top faces, and three in the centre of the prism. CPH metals tend to be brittle, e.g., cadmium, cobalt, titanium, and zinc.

Coal
Now refers to deposits of fossilized plant remains that have been subjected to moderate heat and pressure to partially converted to carbon and other hydrocarbons. As the original deposits formed in anaerobic swamp conditions coal often is contaminated with iron sulphide. The sulphur from these sulphides make coal unsuitable for many metallurgical processes without conversion to coke.

Coal was used extensively for smithing in the Romano-British period, even in regions well outside the coalfields.
The term coal (in various spellings) was applied to what is now know as charcoal, with coal being referred to as mineral coal, or sea coal.

Cobalt

A metallic element with atomic number 27, atomic weight 58.93, density 8.9 g/cm^3. The element was produced unknowingly by Georg Brandt in 1742, but was not identified until 1780 when Bergman recognized it as new element. However, cobalt compounds had been used to colour glass from at least 1500 BC.

Cobbing

- ore preparation /cobb?

Cohenite

Coherent precipitation

Coining

Coke

Coke is formed by heating suitable coal under partially reducing conditions to drive off the volatile components and reduce the sulphur content. Initially, coke was produced in clamps in manner a very similar to that of charcoal, but later retorts were used so that the gas evolved could be used to heat other parts of the processes involved.
The change from the use of charcoal to coke in iron smelting, pioneered by Abraham Darby at Coalbrookdale after possible experimental work in the Bristol brass industry, was important one of the essential steps of the industrial revolution.

Cold working.

Cold working is the mechanical deformation of metal at, or near, room temperature. This deformation produces a high density of dislocations, and grain deformation in the metal. This results in an increase in hardness at the price of reduced ductility.

Colluvial

Sediments formed by hill-wash, soil creep and landslip. This class of sediment includes scree-slope deposits, and cliff falls.

Columnar

Long column-like grains that can form when a pure metal is cast into a mould. Columnar structures develop under conditions of moderate unidirectional thermal gradients. Columnar structures are also seen in bloomery tap, and smithing hearth bottom slags where the main heat loss is by conduction through the refractory lining.

Continuous Cooling Curve - CCC

Related terms: Quenching, TTT

Continuous precipitation

The formation of a precipitate or inclusion distribution uniformly through the grains themselves.

Constituent

Correct term to be used for multi-phase component of a metallographic structure – e.g. pearlite is a constituent of the microstructure of a hypoeutectiod steel, not a phase.

Component

Cope

The upper part of a two-part mould; the main bottom section of the mould is the drag.
Related terms: Core, Feeder, Riser

Copper (symbol Cu)

An element with atomic number 29, atomic weight 63.54, mp 1083 ºC, specific gravity 8.96. Pure copper is reddish in colour and malleable and ductile. It occurs in native copper in dendritic masses and has been known and used since the later part of the Neolithic period.
Related terms: Brass, Bronze.

Core

Piece of a mould inserted in such a way as to give a hollow, or under-cut feature, in the final casting.

Core-box

A wooden mould usually in two or more parts in which were made the sand-clay cores intended to be placed in clay or metal moulds to make the hollow parts of castings - such as the hole in a socketed Bronze Age axe, or the handle of a medieval cauldron.

Coring/cored

The micro-segregation of an alloy on successive freezing to the solid. Zones are formed, especially in dendritic castings, in which a continuous series of small changes in composition occurs as the dendrite arm is formed. Especially common in ancient cast bronzes and cast silver-copper alloys. Coring is accentuated in alloys with a wide separation between liquidus and solidus curves.

CPH

Close-packed hexagonal

Crazing Mill

A mill for preparing ore using grind stones in a manner similar to a normal flour mill.

Crimping

Mechanical join between two pieces of metal in which they are deformed to shape an overlap or attachment.

Critical Temperature (Transformation temperature)

Generally the temperature at which a change in crystal structure or physical properties occurs. In the heat treatment of steels the lowest temperature at which austenite exists represented by A3 on the equilibrium diagram.

Crucible

A container for melting metal normally made from a refractory clay, often graphitized. Now there is wide range of ceramic materials and surface protective washes to choose from.

Crucible Steel

Crucible steel is a generic term to describe all types of steel formed or melted in a crucible.
Due to the high melting point of pure iron it was not possible to produce steel in the way that was possible with non-ferrous alloys by melting the metals together in a crucible or adding on metal to the melt of the other(s). In addition, even the melting point of steel is higher than the usual furnace operating temperatures, it is only with the ultra-high carbon steels that the melting temperature drops into the normal operating range for ancient furnaces. To add to the difficulties metallic iron is very reactive would attack most refractories extremely fast, hence this technology required the introduction of high quality temperature refractories.
There were three basic ways of making crucible steel.

1. Simply melting a steel of suitable composition.
2. Melting a mixture of low carbon iron and cast iron in a crucible together with a flux to seal the melt to prevent decarburisation.
3. To seal a mixture of phosphorus free low carbon iron and a supply of material with a high carbon content in a crucible, and some fluxing material to form a seal once the mixture had started to melt. Then to heat the crucible so that the iron was carburised to the point that the melting point was reduced to the operating temperature of the furnace.

In the west the first method was developed by Huntsmann (1740s) who melted blister steel in crucibles. Earlier, the second method was used in Italy in the 16thcentury as described by Biringuccio. This has been described as the Brescian or co-fusion process. In Sri Lanka, India, Persia and central Asia there was a long history of producing crucible steel by a variety of processes (variations on 2 and 3 above). Evidence of extensive crucible steel production has been found at Merv (Feuerbach 2002) These steels have been known as Wootz or bulat. Some of these steels are capable of thermo-mechanical processing to produce patterned steel without welding. Such products are often misleading described as being of Damascus steel, however, there is no evidence of self-patterning crucible steels having been produced at Damascus (See Allan and Gilmour 76-79, for discussion of Damascus problem). Such patterned forged crucible steels were not produced by the process of damascening (pattern welding) as was once thought.
Related terms: Wootz, Huntsmann, Watered-silk steel

Crushing - in ore processing

Crystal

Each individual particle of metals and most minerals have their atoms arranged in regular three dimensional arrays. The regions over which the atoms are aligned on a particular set of direction is a crystal or grain. In metals, the boundaries between each aligned region are the grain boundaries.

Crystal Structure

The atoms in most metals and minerals are arranged in a three dimensional repeating units. In most pure metals these repeat units consist of cubic face centred, cubic body centred or a hexagonal repeat units. However, intermetallic and minerals can much more complex atomic arrangements that define the crystal structure. Those materials which do not have a regular repeating arrangement of atoms are described as a amorphous or glassy.

Cucurbit

A retort with a narrow neck which fits into the alembic.

Cupel

A porous ceramic, often made from bone ash or other refractory components. The cupel is used to extract or assay precious metals that have been dissolved in metallic lead by the process of cupellation.
See Parting, Cupellation

Cupellation

A process used for extracting silver and gold from lead. The principle involves first the dissolution of the material to be tested in molten lead, then the oxidation of this lead to litharge (PbO) in a shallow, dish-shaped crucible usually made of bone ash (cupel), leaving the precious metals behind as a molten globule. A temperature of about 1000 ºC is needed. The litharge volatilizes or is skimmed off, or is combined with the bone ash in the cupel.
Related:- Bullion, Parting,

Cupola Furnace

Cuprite

The mineral name for the copper oxide Cu_2O. May be a constituent of copper ores in oxided part of copper veins, and is often seen producing the red glaze colour on copper working crucibles.
Also see Tenorite

Cupro-nickel

Alloys containing copper and nickel, usually from 15% to 70% nickel, but in ancient alloys often with less nickel than this. Alloys with about 25% nickel are now used for coinage metals. Early examples of copper-nickel alloys are also known, the most famous being the Bactrian coinage.
Related terms: Pak Tong

Currency bar
A name applied to some forms Iron Age iron trade bars, of which over 1500 have been found in Britain. The typical 'currency' bar is flat sword shaped bar with a tubular socket at one end. There are a large number of British regional forms, some of which include plough-share, and spit shaped, but also those with welded tips, others without sockets, and other forms of tapered thick bar.
The term was originally applied early in the 20th century when it was thought that they came in various 'denominations'. The great variety of form and weight of these bars shows that, in spite of the writings of Julius Caesar, these bars were not used as currency. It was also thought that they may have been half finished swords (moods), but metallographic analysis of Iron Age swords and the currency bars shows that the swords could not have been formed directly from a currency bar with a great deal of forging and welding.

D

D.P.N. - Diamond pyramid number
A method of hardness testing in which a pyramid shaped diamond is pressed into the surface of the metal under a fixed load. The size of the impression made is related to the hardness of the material. Also known as Vickers Pyramid Hardness test and results quoted as VPN (Vickers Pyramid Number). This measure of hardness is more linear over a greater range of hardnesses than the other hardness tests.
Related terms: Brinell hardness, Rockwell hardness.
Dam - in blast furnace
Damascening
An ancient process of ornamenting a metal surface by the use of pattern-welding. The process was used in imitation of early Middle Ages patterned swords said to be from Damascus. In the damascening process, a bar of steel and iron welded together is repeatedly drawing out, doubled back on itself, and welded together. The surface was later treated with acid to darken the steel areas. Ferrite remains bright. In the East the process of inlaying metal on metal is common, particularly in parts of Iraq and India, where it is known as Kuft work. The technique is still used for high quality shot-gun barrels. Unfortunately, the term is often misused to describe forged cast hypereutectoid steels (Wootz, Watered Steel) as the patterns can be similar although the mode of formation of the pattern is very different.
Damascus Steel
A misnomer for forged crucible steel with an internal pattern of carbides produced by the result of thermo-mechanical treatment. Although this decorative steel was sold thorough Damascus, and the value of the artefacts made of crucible steel was enhance there by the addition of gilt decoration, there is no evidence for it production at Damascus. The term has been used for both self-patterning crucible steels (watered-silk) and pattern-welded steels and has lead to considerable confusion in the older literature on the subject. In the opinion of the author (CJS) this name should no longer be used due to the past confusion.
Dating -
Other than normal archaeological stratigraphic methods there are a number of dating techniques that are of particular interest to the archaeometallurgist.

- **AMS**
- **Archaeo-Magnetic**
- **Radio-carbon (C14)**
- **Thermoluminesence TL**

Dead Roast
Usually applied to the preparation of sulphide ores for smelting. the term is applied to a roasting process which is carried out for sufficient time and under strongly oxidizing conditions to remove all the sulphur.
Detection limit
The lowest concentration of an element or substance that can be detected reliably. Usually set so that the measurement of the signal from the element is either twice or three times the standard deviation of the signal from the background.
Delafossite
Dendrite
Depletion gilding
Depletion silvering
Diamond Pyramid Number
See DPN
Die
Die-casting
Diffusion
The movement of one type of element through another without reaction. Many of the important processes in metallurgy are controlled by diffusion. During solidification, the rate of diffusion of the elements in liquid ahead of a freezing front control whether the solid grows in planar, cellular or dendritic manner. In the solid state, many phase formation, and growth processes are controlled by diffusion. These diffusion controlled processes can be suppressed by rapid-cooling (quenching).
Diffusion bonding
A method of joining to pieces of metal without melting. When two chemically clean metal surfaces, are placed together and heated under pressure but to temperatures under that of the melting point of either of the alloys involved, the atoms in the surface diffuse so that the bond and voids are eliminated.
Direct Process (iron smelting)
Another name for the bloomery process, so named as malleable iron (bloomery iron) is produced directly from the ore. Unlike the indirect, or blast furnace process in which cast iron has to be refined to a malleable form (wrought iron, puddled iron, mild steel).
Direct Process (brass making)
Discontinuous precipitation
Dishing
Dislocation
Dislocation entanglement
Distillation
Drag
The lower part of a two or more part mould.
Related terms - Cope, Core, Feeder, Riser
Drawing
The act of pulling a wire through a drawplate of hard material to reduce its diameter.
Dutch Metal
Brass leaf - or more correctly foil.
Related term: Pinchbeck
Ductility

The ability of a metal to be drawn or deformed. Face Centred Cubic (FCC)metals such as silver or gold tend to have better ductility than other metals.

Duralumin

A trade name for an alloy of aluminium hardened with copper. The earliest commercial light metal alloy. OED gives the first reference as 1910.

Dynamic Recovery

See Recovery - dynamic

E

Electrochemical corrosion

Electrochemical replacement plating

Iron when dipped in solution containing dissolved copper will become coated with metallic copper as the more reactive iron goes into solution. The process has been used to extract copper from ground water leaching through old copper tailings dumps.

Electroless plating

Typically a process to apply a nickel plating (check method used)

Electron Probe MicroAnalysis - EPMA

EPMA is carried out using a specialised type of scanning electron microscope (SEM) which is designed specifically to produce high quality chemical analysis, using wavelength dispersive X-ray detectors. Wavelength dispersive X-ray (WDX) detectors (spectrometers) have much higher sensitivity and resolution than standard energy dispersive detectors (EDX), and the machine is designed to give high and stable electron probe currents, together with a fixed sample-detector geometry with polished samples. This means that the accuracy and detection limits are much better in an EPMA than in a standard SEM fitted with a EDX detector. All results of electron induced X-ray analysis (WDX and EDX) should quote the energy of the incident electron beam as the controls the efficiency of the generation of the various characteristic X-rays and the shape of the continuous bremstrahlung background.

In addition to analysis, EPMAs are also used to produce elemental maps which given an easily understood distribution of the element present on the centimetre to micron scale.

Electroplating

The technique using an electrical current to deposit a thin uniform layer of metal on a conductive object to improve either its mechanical properties, chemical corrosion resistance, or aesthetic appearance. Initially the process, invented by Werner Siemens in 1842, was used to deposit silver on copper and was introduced to England in the following year by his brother Karl Wilhelm.

Electroplated Nickel Silver - EPNS

An alloy of copper, nickel, and zinc typically with composition of 60% copper, 22% nickel, 18% zinc, and electroplated with silver.

Electrum

A naturally occurring alloy of gold and silver.

Elling Hearth

A hole in the ground in which wood was burnt for the production of potash. The potash was recovered by dissolving the soluble constituents of the ashes in water, which could then be concentrated by evaporation. The potash may be used as a mordant in dyeing and for the production of soap. This term has also been used to describe ore-roasting hearths; it stems from an Anglo-Saxon word eilding meaning firing or fuel.

Could this refer to the practice of ‘elyng’ or calcining, by which iron ore was roasted to ‘soften’ it, by removing excess moisture and breaking it into smaller pieces prior to smelting.

‘Elyingwood’ was accounted for at Tudeley ironworks in the 14th century. Schubert describes the process on p.216 of his History of the British Iron and Steel Industry (1957).

Eluvial

A deposit in a soil which has formed by the transport of the material in solution or suspension. Hard pan and bog iron ores are eluvial deposits.

Energy Dispersive X-ray Spectroscopy (EDX,EDS)

Usually this involves the excitation of X-rays by an electron beam in an SEM or EPMA, the their detection using a lithium drifted silicon detector, or more rarely a germanium detector. These detectors a solid state detectors which measure the number of electron-hole pairs produced by each incoming X-ray. As the number of electron-hole pairs is directly proportional to the energy of the x-ray, it is possible to assign an energy to that X-ray. Hence, it is possible measure all X-ray energies up to the limit of the range of the detector simultaneously (0.2 to 20 keV). The disadvantage of this method is that the energy resolution (110-150 eV) is less that that of WDX detectors. This, in turn, restricts the detection limit to a value of typically 0.1% under normal analytical conditions.

Engraving

EPNS - Electroplated Nickel Silver

Equiaxed

A termed used in descriptive metallography indicating that the grain structure of the metal is such that the grains are of equal dimensions or properties in all directions.

Equilibrium phase diagram

An equilibrium phase diagram is a diagram in two or more dimensions giving a plot of the phases present at a given temperature and composition. Two dimensional phase diagrams plot the composition of two elements (horizontal) against temperature (vertical), when three or more elemental are involved it becomes more complex to illustrate the phase diagram on the page. What is usually displayed is a triangular plot of composition, with the temperature of phase boundaries marked, or with the solidus or liquidus surfaces plotted as contour maps. [Diagrams needed].

It should be remembered that the equilibrium phase diagram is just that, it describes the situation at equilibrium. However, some of the reactions described in the phase diagram take a considerable time to complete, and some extremely important phase transformation produce non-equilibrium phase (metastable phases such as martensite). Therefore, although the equilibrium phase diagram can be an extremely important tool to the understanding of the metallurgy of the system, it may be necessary to consider other factors or ways of displaying the way in which the system changes with time, such as the TTT diagram.

Equilibrium structure

The distribution of phases and grains that would exists if the system was held at the specified temperature for an infinite time.

Etching

A process in which corrosive solutions are used to selectively remove or stain selected microstructural components from a polished metal surface so that the microstructure can be seen using a reflected light (metallurgical) microscope or the overall structure of metal can be seen by the naked eye (macro-etch). There are many hundred different etch solutions, each one will reveal one or more specific micro-structural components. The etch characteristics of some etches will be altered by traces of unusual elements, with the result that it may take some time and effort to find the optimum etch conditions for some archaeological alloys as they do not fall into the ‘standard’ compositional ranges for the etches.

Euhedral

A microstructural term derived from rock mineralogy, most frequently used for the description of slag morphologies. An euhedral component of a microstructure is one in which the phase is completely bounded by its characteristic crystallographic faces. Synonymous terms idiomorphic and less commonly automorphic.

Also see Subhedral and Anhedral

Eutectic

1. An isothermal transformation in which a liquid transforms into two separate solid phases. This sort of transformation can only occur at a set composition and temperature. This will be the lowest melting point for any composition composed of those phases where the liquidus and solidus temperatures are the same.
2. An alloy having the eutectic composition.
3. A microstructure consistent with having solidified from a melt of eutectic or near eutectic composition. These compositions are those which have the lowest local melting point. At moderate cooling rates the simultaneous growth of two phases results in growth morphologies with fine regular dispersions of one phase in the other.

Eutectoid

The solid state transformation equivalent of a eutectic, in which one solid phase transforms into two other different phases. The most common example is the transformation of austenitic iron, with 0.8% carbon in solid solution, decomposes into nearly pure iron (ferrite) and iron carbide, (Fe_3C) cementite, usually as alternating parallel plates of the two phases (pearlite).

F

Face-centred cubic, FCC

A material with a face-centred cubic structure has an atomic lattice with an atom at each corner of a cube and an atom at each centre of the cube faces. The structure can also be considered as layers of close packed spheres stacked on top each other in the order ABCABC. This structure is the most compact way of filling space with uniform sized spheres. Hence, this structure has been called close packed cubic in the past. Face-centred cubic metals tend to be soft and easily worked, such as silver, aluminium, gold, copper, lead, and platinum. Iron at elevated temperature takes on the FCC structure (austenite).

Fahlerz

A name, meaning grey or 'pale ore' is applied to ores in which the tennantite - tetrahedrite minerals are the principal component. The series copper-rich mineralization with arsenic (Tennantite) and antimony (Tetrahedrite) end members. The mineral series may also contain additional elements such as silver, nickel, bismuth, cobalt. Thought to be a major ore source for some Bronze Age central European and Irish metallurgical traditions, as well as the alloy used to produce medieval domestic ware in Britain.

Fayalite

The iron silicate Fe_2SiO_4 which has the crystal structure of the mineral class olivines. It is a common constituent of many metal-working slags, particularly bloomery smelting, iron smithing and copper smelting slags. It is often observed as elongate faceted laths. Other olivines such as kirschsteinite $CaFeSiO_4$, (kneblite?) Mn_2SiO_4 may occur in slags.

Fayalitic Slag

A slag in which fayalite is the major component.

FCC

See Face Centred Cubic

Feeder (casting)

Most alloy compositions freeze over a range of temperatures, and most metals contract on solidification from 2 to 7%. Without the provision of a supply of liquid metal to fill the spaces and porosity formed due to this shrinkage the casting may be unsound. This is especially true of larger castings which take longer to freeze. A properly located and designed header and feeder will help to eliminate this problem. The weight of metal in the header-feeder components of the casting may comprise up to 40% of the total weight of the casting, however, this metal would be cut off and recycled. But such a technique was rarely necessary in the thin castings of the Bronze Age.
Related terms: Header, Mmould

Feldspar
Two series of alumino-silicate minerals that are important class of rock forming minerals. The two series are the plagioclase feldspars in which form a continuous solid solution series between the sodium (albite) and calcium (anorthite) rich end members, and the alkali feldspars with a full range of solid solutions between the sodium (albite) and potassium (orthoclase) end members. However, there is only a limited range of solid solubility between orthoclase (potassium) and anorthite (calcium) members. The last component to freeze in many slags have compositions that are close to the composition of anorthite or more rarely orthoclase/leucite.

Ferrite
The low temperature body centred cubic form of iron, almost devoid of carbon but capable of containing various amounts of other elements such as phosphorus. Below the Curie temperature this form of iron is magnetic.

Ferritic iron
Iron consisting mainly of ferrite, this is with insufficient carbon or phosphorus to harden the metal significantly.
Related terms: Phosphoritc iron

Fettling
The verb to fettle means to make ready, or to put in order. It is used in a number of metallurgical contexts. In the case of furnaces, it means the repairing of minor defects in the lining with lute. With castings it is applied to the process of cleaning off the moulding sand and removal of flash and feeders. Similarly, it has been applied to the removal of slag and gromp from the raw bloom prior to forging into a billet.

File
1) A tool with ridges or teeth formed by two intersecting sets of ridges, used shape and finish wood and metal.
2) To file; to use a file to shape wood and metal.

Related: Whetstone, Hone stone, Touch stone, Burnisher

Filing
Removal of metal with a file. Filing is uncommon in ancient metalwork, as the tooth spacing of most early files tended to be rather coarse thus more suitable for woodworking than metal working. It is likely that stone abrasives were the preferred method of final shaping, finishing.

Finery
A hearth in which cast iron was converted into wrought iron by melting and oxidization in an air blast. The process differs from puddling in that the metal and fuel are together in the same hearth. This means that it has to be fuelled using charcoal not coal or coke as the sulphur for these fuels would contaminate the metal and make it hot short
Related terms: Chafery, Puddling furnace.

Finery Forge

Fire-setting

Removing rock or ore from a rock face by lighting a fire against it. It was thought that quenching the rock with water was a necessary step. But in most circumstances fact that the natural expansion and contraction of the rock, and the combination of difficulty of getting water to the site, the time necessary to clear the area of fumes means that water quenching would do little to aid the process.

Flake hammerscale – see Hammerscale

Flan

An intermediate product (blank) from which coins are struck.

Flapping

Rarely used term for stirring the surface of a bath of molten copper for the removal of impurities by selective oxidation.

Flux

A substance added to a (typically oxide) system to lower the melting point. For example, the use of silica sand during hammer welding where it combines with iron oxide to form a fayalitic melt. The addition of lime to the iron smelting charge has a slightly different function in that it replaces the iron in the slag. In that although blast furnace slags melt at higher temperatures (c. 1400°C) than bloomery slags (1050-1150°C) the amount of iron trapped in a blast furnace slag (2-5%) is far less than a bloomery slag (50-70%) making the process more efficient.

Folding - iron

Forge - hearth

Forge - metal-forming

Forging

Founder

Foundry

Free-running temperature

Pure metals have sharply defined melting and freezing temperatures; glasses and slags, on the other hand, do not. They soften gradually as the temperature is increased until their viscosity is low enough to permit them to be worked or poured. The temperature at which this may be said to occur is the free-running temperature.

Fuel

Fuel Ash Slag

A low density slag-like material - often of a light colour externally with a high silica content. Complete pieces may have rounded exteriors with no obvious points of contact with a surface on which it cooled. Although, the exact origin of much Fuel Ash slag is uncertain, they often contain, partially fused or sintered quartz grains and other rock or soil debris. It is likely that this material is the result of a high temperature process which results in the sintering and partial melting of the non-combustible fragments in the fuel, together with material from the surrounds of the fire. There are a number of processes that could generate this type of material:- metal-working (all forms), pottery making, burning of daub during a building fire, glass-working, salt-making, cremation, or simply the burning of a fuel with a very high silica content such as bracken.

Related terms Cinder, Clinker

Furnace

A structure in which material can be heated to high temperatures. In general, the term furnace applies to a structure with a refractory superstructure which restricts air access to the charge. Thus, allowing the operator to control the reducing condition of the atmosphere the charge experiences. This is in contrast to a hearth which is open to the air. This is in contrast to a hearth

which is open to the air. However, the term hearth is used for parts of furnaces in which air and fuel first react.
The most important distinguishing feature for furnaces is whether the charge is separated from the source of combustion or not. The introduction of the reverberatory and muffle furnaces, in which the fuel is burnt separate from the charge, marked major technological changes as this prevents contamination of metal by elements such as sulphur from the fuel.

Furnace - types

Blast

Furnace - Cupola

Induced draught

Muffle

Natural Draught

Reverberatory

Shaft

Wind-powered

Furnace parts

Dam

Dam Plate

Tapping Arch

Throat

Tymp

Furnace - Temperature

Fusion gilding

See Gilding - Fusion

G

Gad(d)

An archaic term for a piece of iron or steel - usually a short length of broken rod or strip
Also the name of a type of a small pick used to break rock and ore.

Galena

The mineral lead sulphide, PbS, also was known as lead glance or blue lead. This mineral was the principal ore of both lead and silver, as some argentiferous ores may contain an appreciable amount of silver.

Galvanised Iron

In 1837 H.V. Crauford was granted an English patent for dipping in a bath of molten zinc protected from volatilisation by a layer of sal ammoniac, (ammonium chloride, NH_4Cl). This appears to be derived from the work, in the previous year, of the French chemist Sorel. In the 1840s the process was used to produce agricultural and industrial goods and corrugated iron sheet for building purposes. (Dickinson, 1943-4). There had been earlier attempts in France, starting around 1740, to use zinc to replace tin to protect iron goods. The last of these early attempts to use zinc plating seems to have been to produce iron hammered saucepans in Rouen, France, which was abandoned shortly before 1786.

Gama-hada

Japanese decorative technique making use of immiscible metals, such as silver or silver-copper alloy droplets on iron.

Gamma iron

Another term for the face centred cubic, non-magnetic alliotrope of iron, austenite.

Gangue
The unwanted part of the ore that has been removed or cannot be removed by mineral dressing. During smelting this combines with any fluxing material that may be added to form slag.
Gassed
Some molten metals will dissolve gases, which are released upon solidification and which give rise to porosity in the casting. The term ‘gassed’ or ‘gassy’ describes the result. It can sometimes be avoided by suitable pre-treatment such as adding a small amount of cuprous oxide to a hydrogen-containing (over-poled) copper.
Gate
The narrow channels through which molten metal enters the casting (sometimes referred to as ‘jets’). These are situated between the funnel-shaped runner-bush, which receives the metal from the crucible, and the casting itself. The term may combine the gates and the runner-bush all in a ‘running and gating’ system.
Gehlenite
A mineral, $Ca_2[Al_2SiO_7]$, of the melilite group that may be found in slags.
German Silver
Alloys of copper, nickel, and zinc usually comprising about 52-80% copper, 5-35% nickel, and 10-35% zinc. This alloy was formerly used for many decorative purposes as a cheap substitute for silver, since it does not readily tarnish and is of silvery hue.
Gilding
The technique of covering the surface of a cheaper material with thin layer of gold. There are a number of different ways of gilding metal and non-metallic objects (see below)

> **Acid**
> **Cold Mercury Gilding**
> **Depletion Gilding**
> **Diffusion bonding**
> **Electrochemical**
> **Fire**
> Also known as mercury gilding
> **Foil gilding**
> **Fusion**
> A process used in ancient South America, especially Ecquador, for the gilding of copper alloys by dipping or fusion of molten gold alloys to the surface, resulting in thick gold alloy coatings. May also be used to create silver alloy coatings over copper.
> This is the precious metal version of hot-dip plating which has a wider range of applications.
> **Lacquer**
> **Leaf gilding**
> **Mercury or fire gilding**
> **Non-acid**
> To remove the silver a combination of salt, alum and ferrous sulphate (and possible other components) had long been used to enhance the colour of gold by surface enrichment depletion gilding.

Goethite
An iron oxide, alpha-FeOOH. Commonly found as a weathering product of iron bearing minerals, and forms in oxidizing conditions. It is often the main constituent of the so called ‘limonitic’ and bog ores. The mineral is a yellowish brown to red colour, but has a yellow streak,

and dehydrates to haematite, unlike lepidocrocite (the other yellow iron ‘oxide’) which dehydrates to maghemite.
Related terms: Magnetite, Haematite, Maghemite, Lepidocrocite, Limonite, Pyrite, Pyrrhotite

Gold

Element with atomic number 79, symbol Au, atomic weight 196.96, mp 1063°C, specific gravity 18.88. Native gold usually contains some copper and silver. Typical gold concentrations are 85% to 95% with the remainder being mostly silver. Gold is bright yellow, but with increasing silver content the colour is white, while copper provides red tints to the colour. With a platinum content of between 20 and 25% and nickel gold alloys become white.

Gold foil

A thin sheet of gold thick enough to be handled easily and support its own weight. Further hammering will reduce the thickness still further to produce gold leaf. (Oddy A. 2000, 15)

Gold leaf

Gold leaf is so thin that it has to be handled using special techniques. (Oddy A. 2000, 15)

Gossan

The upper part of a metalliferous deposit (vein) from which the wanted metal has been leached down into the zone of secondary enrichment. This part of the vein is rich in iron, hence Cornish term Iron Hat. In regions subject to glaciation the original gossan may have been removed and not had time to reform

Grain

Most metal artefacts are poly-crystalline, that is they consist of a large number of small regions (crystals) in which the atoms are arranged in regular aligned repeating 3-dimensional arrays of atoms (unit cell). A grain is a volume in which the unit cells are all arranged parallel to each other.

Graduation

Grain boundary

Grain boundary is the interface between two or more grains. The unit cells in two adjacent grains will not be orientated in the same directions in 3 dimensions. In such regions, the mismatch between the atom lattices means that there will a lower density of atoms, thus grain boundaries act as paths for rapid diffusion, and sites for the nucleation and growth of new phases.

Grain boundary segregation

The precipitation of a phase or inclusion at the grain boundaries of a polycrystalline solid.

Grain growth

The mismatch of the atomic lattices across the grain boundary means that the grain boundaries have a higher energy than the bulk of the grain. Thus, there is a tendency for the system to try to reduce this energy by the reduction of the total grain boundary area. When the temperature of the metal is high enough to allow grain boundary migration, the larger grains will tend to grow at the expense of the smaller grains.

Grain Growth - Abnormal

Grain size

Grain size, control of

Granulation

When referring to cast iron, slag and other metals as well as gold, the term means the production of small solid droplets of the material. Usually this was done by pouring a thin stream of the molten material into a water bath.
This term more usually refers to the process by which small gold grains (produced by granulation or by simply melting small pieces of gold and allowing surface tension to pull the metal into a

ball) were soldered (by reaction soldering or diffusion bonding) to the surface of the workpiece. Common in Etruscan goldwork.

Graphite

One of the alliotropes of carbon, in which the carbon atoms form sheets of strongly bonded atoms in a hexagonal arrange, but with relatively weak bonding between the sheets, giving graphite its lubricant properties.

> **Graphite Crucible**
>
> The inclusion of graphite into the body of a crucible helps to protect the melt from oxidization. Graphite was used as part of crucible fabric in Germany/Austria during the Iron Age. Later the use graphite crucibles was reintroduced as both as part of the fabric and as pure graphite crucibles when more extensive graphite deposits became available.
>
> **Graphite, Kisch**

Graver

A fine tool for cutting / shaving metal used by an engraver. (Also see burin)

Grey cast iron

A cast iron in which the majority of the carbon present is in the form of flakes of graphite. The presence of the graphite gives the fracture surface a characteristic grey colour - hence the name. Related terms: White cast iron, Mottled cast iron, Ccast iron

Gunmetal

A ternary alloy of copper, zinc, and tin; modern gunmetals usually contain less zinc than tin, but some contain equal proportions together with lead, and have a composition such as 85-5-5-5.

H

HV

Hardness on the Vickers or Diamond Pyramid Number (DPN) scale.

Hadfield Manganese Steel

In 1887 Hadfield patented his manganese steel, which could not be hardened by quenching although it contained 1.2% carbon, but was tough and work-hardened rapidly.

Hammer scale

The scale removed from iron during forging. This consists of metal which has reacted with air and which has thereby been converted mainly into oxides of iron. The oxide may be shed in to the hearth and help form smithing slag, but most is formed and shed around the anvil.
There are two major forms -

> **Flake hammerscale** formed by the oxidisation of the surface of the metal, hence has follows the form of the surfaces of the artefact. The thickness of the scale tend to be a function of the temperature of the metal and amount of forging. Higher temperatures result in the formation of thicker, and bubbled scale. Whereas, when the temperature of the metal drops the scale forms less quickly, and thus, thinner scales form before being disrupted and dislodged from the surface during forging. Flat scale is usually magnetic.
>
> **Spherical hammerscale** forms as a result of hammer spray. Liquid iron oxide from the surface of the metal or between two surfaces to be welded will be sprayed out when the welding hammer blow is struck. The molten oxide then freezes whilst travelling though the air in the form of spheres. They may or may not be magnetic depending on the iron oxide content.

Hammer Weld

Hammer or fire welding is carried out at full welding heat, at which the metal is white hot, but not molten. The method relies on the ability of two oxide-free metal surfaces to weld to each other when brought together. For this to happen with iron, the iron oxide layer on the surface must be molten and free running so that it can be swept away when the surfaces are forced together by the hammer blow.

Hard Pan iron ores.

These are chemically formed iron ores which occur where a change in Eh/pH conditions cause the iron that was either in solution as ferrous ions, or was in suspension as colloid particles, are deposited as insoluble iron oxides in the soil. They can form relatively rapidly under suitable conditions (in a few decades). They often contain high concentrations of other elements, phosphorus being the most common, but may also accumulate copper and arsenic.

They can form extensive deposits in sandy iron rich soil at the level of the water table - often found in England developing on or adjacent to the Cretaceous Lower and Upper Greensands, the Tertiary sands (East Berkshire; Hengistbury Head, Hampshire), but also in sandy soils on or adjacent to the Jurassic ironstones.

Hard soldering

An alternative term for the use of a brazing alloy or a copper-silver alloy for joining, as opposed to the use of lead-tin alloys (soft solders).

Hardness

The measure of the resistance of a material to plastic deformation when indented. There are a number of different measures of hardness

Brinell

Knoop

Rockwell

Vickers

Hearth

Heat-Treatment

Types - Austenising, Homogenising, Soak, Maraging

Hematite/Haematite

The iron oxide Fe_2O_3 a dense purple-black mineral with a characteristic cherry streak. Often found a dense massive or reniform formations which make it a more difficult ore to smelt by the direct process than bog/hard pan or sideritic ores.

Related terms: Goethite, Magnetite, Maghemite, Lepidocrocite, Limonite, Pyrite, Pyrrhotite

Hercynite

The iron aluminium spinel $FeAl_2O_4$, a minor mineral in many metal working slags. Shows as a slightly pink colour when compared with fayalitic under the reflected light microscope, particularly noticeable when slightly out of focus due to its different birefringence. The transition elements chromium, vanadium and titanium tend to segregate to this mineral

High bloomery (Stückofen)

A developed shaft furnace capable of producing cast iron as well as a bloom.

Hollowing

Homogenization

A thermal or thermo-mechanical process designed to even out the cast-in inhomogenities in composition or micro-structure. Usually, a combination of both annealing and mild coldworking is required to remove gross chemical segregation.

Hone

A fined-grained stone (often a siltstone or a metamorphosed siltstone) used to polish and give a final sharpening to a cutting edge.

Hot Blast

Hot-working

Deformation of the metal or alloy above the temperature necessary for the recovery processes to be fast enough to counteract work-hardening during plastic deformation. This temperature is usually about 0.3 of the melting temperature in degrees Kelvin for pure metals and 0.5 of melting temperature for alloys, if not higher for some steels.

Hushing

A method of hydraulic mining in which the barren over burden was removed by directing a stream of water down the hillside. (Expand)

HV

The units of hardness on the Vickers (VPN) or Diamond Pyramid Number (DPN) scale.

Hydraulic Mining

Mining using water to remove the over-burden, and often to perform the initial ore beneficiation.
Related terms: Hushing, Tin stream-works, Tinning

Hypereutectoid

An alloy containing more of the alloying element than that required to form the eutectoid structure. In steels this would require more than 0.8% carbon, the amount needed to create a completely pearlitic structure, but less than about 2% C as above 2% the composition enters the range for cast irons.

Hypoeutectoid

An alloy containing less of an alloying elements than that required to form the eutectoid structure (0.8% carbon for steels). Most ancient steels are hypoeutectoid, except for Wootz steels made in a crucible, or later historical products, such as cut steel beads from France, and England.
Glossary of terms used in the study of ancient metal-working

I

In-gate

Indirect Process - iron smelting

The production of malleable iron/steel by a two stage process in which the in is first reduced in a Blast Furnace to cast iron. Cast iron is hard, brittle and unworkable due to its high carbon content. Thus, the carbon content has to be reduced by some form of refining process (using the finery hearth, puddling hearth, Bessemer converter, open hearth furnace etc.) until a workable alloy results.

Induced draught furnace

Furnace operated by means of a draught created by the chimney effect of hot air rising, due to the difference in density between the surrounding cold air and the heated air. Many African iron smelting furnaces used the technique, as do reverberatory furnaces. Such furnaces are characterized by their height (around 2 metres and taller), and a relatively large air in-let area (many tuyères or large grated fire boxes).

Ingot

A cast block of metal which may be intended for further working (i.e. into a billet) or merely reused on some future occasion. Some authors use billet and ingot interchangeably which is not technically correct.

Intaglio

The process of engraving or removing metal to create a design. The depression so formed may be filled with niello or enamel. The term is also used to describe small engraved semi-precious gem stones (typical of the Roman period).

Intergranular

A process, or a phase that occurs or forms at the grain boundaries. For example intergrannular corrosion, which specifically attacks the grain boundaries causing the metal to fall apart.
Related terms: Intragranular, Transgranular

Intermetallic compound

An intermetallic phase formed by the reaction between a metal and a non-metal (eg Fe and C forming cementite, Fe_3C) or between metals (CuSn). Such phases have relatively well defined compositions (limited solid solubility), and have properties intermediate between those of metals and non-metals. They tend to be conductive but with low ductility, and to be hard and brittle.

Interstitial

An element whose size is relatively small may occupy lattice spaces without causing too great a distortion of the original lattice structure. An example is carbon in iron. The carbon is small enough fit into the spaces of the cubic iron lattice of the austenite phase.

Intragranular

A feature or an effect crossing the grains rather going along the grain boundaries.

Investment

A method of forming moulds for casting, in which the moulding material is wrapped, pressed or cast around the pattern. The pattern material must be capable of being converted into a liquid so as to remove it from inside the mould. Suitable pattern materials are waxes, plastics or the low melting-point metals (mercury, tin or lead). The best known is the lost-wax or ciré perdue process.

Iron

An element with atomic number 26, symbol Fe, atomic weight 55.85, mp 1528ºC, specific gravity 7.87. A heavy whitish metal and one of the most abundant and widely distributed. Iron was probably first known in the form of meteoric iron, which usually contains some nickel. Extraction by the bloomery process became established in Asia Minor in the late 2nd millennium BC, and the technology seems to have spread out from this centre, reaching Britain in the west by the 7th century BC, and China in the East by the 8th century BC. In China the blast furnace process (or indirect process) was developed some time in the 5th century BC.

Iron - bloomery

The product of the bloomery or direct process. Usually, the product is a low carbon iron, but the bloomery process is capable of producing steel.

Iron - phosphoritic

Metallic iron with sufficiently high phosphorus content to appreciably harden the metal. Phosphorus will increase the rate of work hardening, making the metal more brittle. Thus high phosphorus iron is more difficult to work than a low carbon bloomery iron, especially at low temperature. However, high phosphorus irons have been used selected for specific uses in a number of periods - during the Iron Age it seems to have been used for larger edge tools as a alternative to carbon steel. During the Anglo-Saxon period when many of the pattern-welded sections of composed of alternating bands of high and low phosphorus iron. In the 18th century, high phosphorus iron wires were used for harpiscord and early piano wires.

Iron - wrought iron

The term ‘wrought iron’ tends to be used some authors for all ancient iron. However, before the introduction of the indirect process, such use is a tautology in that all iron was wrought (wrought means forged). Also the mechanical properties of bloomery iron and wrought iron are different in that bloomery iron tends to contain variable but higher amounts of carbon than refined cast iron. Whereas, wrought iron tends to have a much higher volume of slag inclusions. Therefore, the term wrought iron should be restricted to forged refined cast iron.

J

Joining

There are a large number of different way in which two pieces of metal can be joined together. See links for more details :

> **Brazing**
> Higher temperature version of soldering
> **Riveting**
> **Soldering**
> **Welding**

Jominy Test

K

Kish graphite

A characteristic type of large curving flakes of graphite seen in the microstructure of cast iron.

L

Latten

Copper-zinc-tin alloy (sometimes with lead as well) used in the medieval period for cheap decorative and functional metalwork. The term should not be used for the largely unreported antimony leaded bronzes used for the same purpose in the medieval period.

Leaching

The removal of elements from the soil or a metal deposit by aqueous solutions.

Lead

Element with atomic number 82, element symbol Pb, atomic weight 207.19, mp 327.4°C, specific gravity 11.35. Pure lead recrystallizes at room temperature when deformed. The metal can readily be extruded into pipes or rod but lacks the strength to be drawn into wire. Lead was commonly extracted from galena, lead sulphide, and was often a by-product of the extraction of silver from galena, since many of these lead ores are argentiferous. Lead is a useful addition to bronzes and brasses, especially for making castings and is used as an alloy with tin as a soft solder. The relative abundance of its various isotopes may give an indication as to the source of the metal.

Leaded bronzes

Copper-tin alloys containing lead. Small amounts of lead may have a beneficial effect, in particular by improving its casting properties. However, when present in large amounts it weakens the metal as it will tend to segregate into weak lead-rich inclusions

Leaf gilding

See Gilding – Leaf

Ledeburite

Ledeburite is the name applied to the cementite-austenite eutectic at 4.3% carbon which solidifies at 1130 ºC. During cooling the austenite in the eutectic may transform into a mixture of cementite and ferrite (which may be pearlitic).

Lepidocrocite

A hydrated iron oxide gamma-FeO.OH. It has the same composition as goethite but a different crystal structure and physical properties. Like goethite, lepidocrocite forms under oxidizing conditions by the weathering of iron-bearing minerals. It has a brown streak.

Related terms: Bog ore, Goethite

Leucite
A potassium aluminium silicate ($KAlSi_2O_8$)
Limonite
A term to cover a mixture of hydrated and other oxides of iron, e.g. lepidocrocite (gamma-FeO.OH), goethite (alpha-FeO.OH) and hematite(Fe_3O_4). Colour
Liquate
Liquation
Liquidus
The boundary on a phase diagram that shows the temperature at which solidification begins upon cooling from the melt. In a ternary diagram the liquidus is a surface, not a line.
Litharge
The lead oxide a PbO, typically white to yellow in colour, but often reddish due to cuprous oxide. Formed as a result of cupellation to recover silver from argentiferous lead.
Lost-wax
Casting from a wax model. The object to be made is shaped in wax (either solid or hollow) and is covered (invested) in a clay mould. The mould was then heated to melt and burn out the wax. The resulting space is then filled with molten metal.
Loup
The pasty mass of iron formed in the slag bath of the finery.
Lute
A mixture of clay and graphite or charcoal used to stop up and fill cracks in furnaces, or to seal lids to crucibles. Also used as a verb to describe those actions.

M

Mf
The temperature at which the at least 99% of the microstructure has transformed to martensite.
Ms
The temperature at which the martensitic transformation starts.
Magnetite
The mineral name for the iron oxide Fe_3O_4 , a member of the spinel group of minerals which includes the minerals chromite ($FeCr_2O_4$) and hercynite ($FeAl_2O_4$) as well as spinel (*sensu stricto*, $MgAl_2O_4$). Magnetite is a high quality iron ore, but generally, the most difficult to smelt in a bloomery due to its compact dense nature, which makes gas exchange slow.
Manganese
Element with atomic number 25, symbol Mn, atomic weight 54.938. Manganese is a strongly electronegative element and hence difficult to reduce.
Related Spiegeleisen
Marcasite
Iron sulphide (FeS). Also used to describe jewellery decorated by polished steel studs
Martensite
A diffusionless transformation of one phase to another. The transformation takes place by the atomic lattice of the original grains being strained to a different crystal structure.
In steels: An extremely hard product is produced by rapidly quenching iron containing carbon from the austenitic structure to a low temperature before pearlite, or other intermediate structure can form. The body-centred-cubic structure of austenite converts to a body-centred-tetragonal structure. The hardness depends on the carbon content. In order to produce a structure containing only martensite, the temperature at the start of the quench must be above a certain figure,

depending on the carbon content, and the rate of quenching must be extremely high. Suitable rates are obtained by quenching into cold water or brine.
The structure may be revealed by etching with nital (2% or 4%), but some martensites etch very rapidly (in a few seconds) whereas other etch very slowly (1 to 2 minute may be required) and have been missed during examination of iron artefacts by some authors. However, hardness testing in combination with metallography should identify the structure due to the high hardness associated with it.
The term may be used more generally for any needle-like, transformation product of a quenched alloy which occur without any atomic diffusion e.g. martensite in beta-quenched bronzes.

Matrix

Casting

Metallographic

Master-Alloy

Matte

A liquid or solid mixture of sulphides, usually FeS_x and Cu_2S, but other sulphides may dissolve in the mixture. Usually present at some stage in the production of copper from sulphide minerals.
Related terms - White metal, black metal

Maul

A stone hammer, used in prehistoric mining.

Mechanical twinning

Twinned crystals produced by mechanical strain alone, as in zinc.

Melilite

Mineral $(Ca,Na)_2[(Mg,Fe^{2+}),Al,Si)_3O_7]$

Mercury

Element with atomic number 80, symbol Hg, atomic weight 200.59, mp -38.84 ºC, specific gravity 13.55. A silvery white metal which is liquid at room temperature. The earliest extractions were carried out by roasting cinnabar, mercury sulphide, in an oxidizing atmosphere and collecting the mercury by distillation.

Metallographic Analysis

A technique used to determine the microstructure of a metal, including the history of working of a metal

Metallography

The examination of prepared (polished and etched usually) metal samples by reflected light microscopy.

Meteoric iron

Iron from outer space. Usually an alloy of iron and nickel. Small amounts of cobalt and manganese are typical. Some early iron artefacts were made using meteoric iron.

Microhardness testing

An indentation hardness test at low loads and high magnifications such that individual phases within the structure can be investigated.

Micron

Shorten form of micrometre. One thousandth of a millimetre.

Mild steel

Low carbon iron. The modern equivalent of wrought iron but without the slag which gives the latter its fibrous structure. However, some mild steel compositions can form banded structures following certain thermo-mechanical treatments.

Mint

Mise-en-coleur

Mokumé
Monotectic
An alloy in which at certain temperature and compositions one liquid forms two distinct immiscible liquids, and at the monotectic point a liquid (L1) of a given composition will result in the solidification of a metal and the production of a liquid (L2) of the other composition. The most common monotectic alloy seen in the archaeological record are the leaded copper alloys.
Mood
A blank for a sword or a partially finished sword.
Mosaic Gold
A gold coloured tin sulphide SnS_2 used as gold pigment. Also called porporino, aurum mosaicum, aurum musivum. Made as early as the 9th century in Europe. Its manufacture was described by Ko Hung in China by AD300. Thornton, J. 2000, 313
Mould
Muntz Metal

N
Nail Iron
Tool to produce the head of nails.
Natural Draught
Neumann lines or bands
Markings on ferrite which occur as a result of shock loading at low temperatures, i.e. below about 500ºC. In terrestrial iron they indicate severe cold-hammering; in meteorites they are probably caused by shock on entering the earth's atmosphere. They disappear when the metal is heated above about 600ºC.
Nickel
An element with atomic number 28, symbol Ni, atomic weight 58.71, mp 1453ºC, specific gravity 8.9. A heavy whitish metal not known as a pure element until its discovery was announced to the Swedish Academy of Sciences in 1751 by Axel Cronstedt.
Nickel-brass
Nickel-silver
Niello
A mixture of sulphides, usually copper and silver, used as a black decorative inlay on silver and some other metals.
Nital
An etchant of steels consisting of nitric acid (2-4%) in alcohol. It will reveal grain boundaries and carbon containing phases. It will also reveal phosphorus ghosting to a lesser extent.
Nitride Needles
Apparently acicular precipitates seen in ferrite. Originally assumed to be due to nitrides, although evidence suggests some may be carbides (Liu et al. 1984). The true shape of the phase is also likely to be plate-like, the needle morphology resulting only from the two dimensional section.
Nitriding
Nodular pearlite
See Troostite
Normalize
Nucleation and growth

O

Off-cut
A fragment of metal cut from the main body of an artefact during manufacturing. Often fragments of sheet, rod or bar with visible cut marks. This type of material may be important evidence for the raw metal used, the type(s) of artefact produced, and/or the manufacturing process. As well being preserved in non-ferrous metal working debris, these marks can often be seen in the small fragments of iron associated with iron smithing sites.

Open Hearth Furnace
A furnace of a reverberatory type fired by producer gas and used air preheated using a pair of regenerative heaters. The use of open hearth furnaces was first patented for the melting of glass and metals by Frederick Siemens in 1856, based on the principles set out in Stirling's patent of 1812, and Nielson's use of hot blast in the coke fire blast furnace.

The 1856 patent outlined the use of two sets of checkerwork firebrick heat exchangers through which the air flowing into, or out of, the furnace passed. One set was heated by the waste gas from the furnace, while the other (hot from a previous heating phase) was used to heat the air going into the furnace. Periodically, the control valves were changed so that the air flow through the furnace and heat exchangers was reversed, the checkerwork that had been cooled by the incoming air now being heated by the exhaust gas, and vice versa.

Initially the furnaces were fuelled by coke, or other solid fuel, but the ash carried over by the air eventually blocked the checkerwork. This problem was eliminated if producer gas was used as the fuel instead of a solid fuel. A further patent in 1861 by both William and Frederick improved the furnace temperature by having a separate pair of checkerworks to preheat the gas as well as the air. Such furnaces were capable of reaching temperatures as high as 1600°C, and thus steel could be melted in them.

Open Hearth Steelmaking
In general, the term covers all methods of making steel using the Siemens Open Hearth. Following the considerable savings in fuel costs by application of the Siemens regenerative heating method in glassmaking, steelmakers tried to apply the same method to their industry. Initially, open hearths were simply used as more efficient melting furnaces for the production of crucible steel.

In 1864, as a result of their work at Sireuil, Pierre & Emile Martin issued a British patent, through R.A. Brooman, on the melting of cast iron (pig iron) and puddled iron or steel in a Siemens open hearth. This patent described a semi-continuous method with an initial melt of cast iron, to which additional scrap steel and puddled iron or cast iron was added as required to obtain the required composition. In following the year, another patent improving on the method was issued. This outlined a batch process consisting of a single melt that resulted in the steel maker having better control of the composition of the steel. This Siemens-Martin method of steelmaking was widely used through Europe for the next 15 years. Siemens described the Siemens-Martin process as the pig and scrap process. In Britain, from 1865 to 1869 Siemens experimented and developed a method of steelmaking using the open hearth. By 1869 this had progressed to the extend that Siemens was making 75 tons of steel a week at his Landoe works, near Swansea. The method, which Siemens described as the pig and ore method, involved melting cast iron, then adding iron oxide in the form of iron ore, together with some lime and other fluxes. The iron oxide acted as a source of oxygen to decarburize the cast iron. Then as a final step before casting, -spiegeleisen was added to the molten metal it was poured into ladle to be taken to the foundry. In Britain, this was method was known as the "Siemens Open Hearth Process" (or the Acid Open Hearth Process). For further information on this topic see Barraclough 1990.

Related Terms: Basic Steelmaking, Bessemer Steelmaking, Puddling, Refining (cast iron), Steelmaking

Open mould
A form of mould for flat or long object of relatively simple shape in which the top is left open to the air. Examples of the type of object that were cast in open moulds are Bronze Age flat axes, ingot moulds of all periods, cast-iron pigs and fire-backs and probably Roman mirrors.
Order Hardening
A process which hardening of the metal occurs as result of an order-disorder reaction. It is not widely used, but may be important in some noble metals, where the effect can be used to advantage, but may also be detrimental if the metal needs to retain its flexibility.
Ordering
In binary alloys there is a preference for dissimilar atoms to surround each other. Consequently certain alloys, when slowly cooled below a critical ordering temperature, may undergo a transformation in which the atoms organize themselves into regular arrays of alternating atoms over large regions (also called superlattice).
In the gold-copper alloy system there are three ordered alloys corresponding to the compositions Au_3Cu, AuCu, and $AuCu_3$. The ordered phases are, in general, harder than the normal or equivalent disordered alloy. Therefore, quenching gold alloys of these compositions from above the critical ordering temperature will keep these alloys in the soft state, rather than harden them. However, the formation of ordered structures over time may lead to embrittlement.
Ordered alloys differ from most intermetallic phases, in that they have a greater composition range and that range tends to increase with decreasing temperature. This gives their phase range in the equilibrium phase diagram a characteristic inverted U-shape.
Ore hearth
A bellows-blown low open-fronted hearth used for lead smelting, in a water-powered smeltmill. Dressed ore (galena, lead sulphide) was mixed with fuel in the hearth, and raked out intermittently onto a sloping 'work-stone' in front of the hearth to partially oxidise the ore; the lead produced in the hearth ran out though channel across the workstone into an iron pot, from which it was ladled into pig moulds. The chemistry was complex, but can be summarised as a double-decomposition between oxidised ore (lead oxide and sulphate) and unoxidised sulphide, producing metallic lead and sulphur dioxide vapour. The ‘grey slag’ produced was often resmelted in a separate slag hearth. The ore hearth was developed in the mid 16th century; it was partially replaced by the reverberatory furnace in the early 18th century, but remained in use in some areas till the late 19th century -later 19th century examples developed into enclosed shaft furnaces, blown by pipes from blowing machines. The fuel was initially charcoal, but by the 18th century a mixture of peat and low-grade coal was normally used.
Orthoclase
The potassium rich end member of the alkali feldspars ($KAlSi_3O_8$) group of minerals.
Overheating
Heating a metal or alloy to such a high temperature that its properties are impaired.
Oxidation (or Oxidization)
Chemical reaction in which a metal is converted to its oxide, or from one oxidization state to a higher state (that is the equivalent of an increase in the number of oxygen atoms for each metal atom. For example, in the reactions -

$2Fe + O_2 = 2FeO$	Metallic Iron to Wüstite
$6FeO + O_2 = 2Fe_3O_4$	Wüstite to Magnetite
$4Fe_3O_4 + O_2 = 6Fe_2O_3$	Magnetite to Haematite

iron is progressively oxidized from the metal to its highest oxide, haematite. Another way of looking at these reactions is that oxidation occurs every time the cation (the metallic ion) gains a

unit of charge, e.g. Fe^{2+} goes to Fe^{3+}, or alternative that the cation loses an electron (the charge on an electron is negative - e^-)
e.g. Fe^{3+} e^- = Fe^{2+}
Related terms: Reduction, Valency

P

PGE
Platinum Group Elements;

Paktong
Corruption of Chinese 'Paitung' used for alloys containing zinc. The other elements are usually copper and nickel; this alloy is synonymous with a nickel silver or German silver.

Panning
A mineral washing process in which the lighter unwanted mineral is removed from the wanted mineral in a shallow vessel (or pan). Panning was used as a prospecting method, and for small-scale ore processing of gold deposits.

Part mould
A semi-permanent mould made of several pieces so that objects with recesses can be cast without destroying the mould each time.

Parkes' Process
The Parkes' process was a cheaper method of extracting silver from lead. An appropriate amount of metallic zinc was added to the molten impure lead. The zinc formed an alloy with the silver, which crystallized out of the melt and floated to the surface where it was skimmed off. The silver was then recovered by heating the alloy in a zinc retort where the zinc evaporated leaving the silver behind, or by dissolving the zinc in acid. The archaeology and archaeometallurgy of this process have not yet been investigated.
Related terms: Pattinson process, Zinc smelting

Parting
Noble metals can be separated from base metals by liquidation of the metal with lead, then cupellation of the lead, however, this does not separate silver from gold. To remove silver from gold a method of parting has to be used. This was by either acid parting, or the salt cementation process, and later by sulphur parting. For full discussion of the history of parting see Rampage and Craddock 2000.

Acid parting
Although weak organic acids could improve the colour of gold containing copper, these would not remove silver, so that silver-rich gold would remain a pale colour. The removal of silver required the use of strong acids (hydrochloric and nitric in particular). Acid parting only became possible when strong mineral acids became generally available. The distillation is thought to have been first used during the eleventh or twelfth centuries in Europe, although it is some evidence that they were used by the 10th century in the Islamic world.
The method is not mentioned by Theophilus, but various 16th century European metallurgical treatises and handbooks describe the method in some detail; they suggest that it was not a cost effective alternative to salt parting. However, it seems likely that it became more widely used by the end of the 16th century and during the 17th century.

Antimony Parting
See sulphur and sulphide parting.

Salt Cementation Parting

Until the discovery of strong mineral acids salt cementation parting was the main method used to refine gold. The literature would suggest that there were a number of different variations on the process, but the essentials were the use of common salt cement and the presence of alumino-silicate ceramics preferably with an appreciable iron oxide content (in the form of an earthenware container, and possibly the addition of crushed brick or earthenware powder to the salt cement).

The impure gold was beaten into thin sheets, or was granulated to produce fine grains, or was naturally in the form as an ore. The gold was interleaved with layers of 'cement' formed of either salt or a mixture of slightly moistened ground up alumino-silicate material (burnt clay - old pot or tile) and salt (NaCl) in a sealed clay vessel. On heating the salt would react with the alumino-silicates of the burnt clay together with the water or urine, used to moisten the cement, to liberate volatile hydrogen chloride or chlorine gas. This gas, in turn, reacts with the silver at the surface of gold to form volatile silver chloride (AgCl), which was absorbed by the alumino-silicate in the ‘cement’.

The process had to be carried out at as high as a temperature possible to speed the diffusion process. But the temperature was limited by either the melting points of either the alloy, or of the active reagents if no carrier medium was used. If the gold alloy melted, or the temperature rose very close to its melting point, the foil would ball up. This would reduce the surface area available for attack and increase the diffusion distances, thus slowing the reaction. If no carrier material (brick or pottery dust) was used, the gold would sink through a simple salt cement if the temperature rose too close to the melting point of salt (804°C).

At the end of the process the gold would be melted into small ingots that could be tested for purity and if found to be of low purity these could be forged into foils so that the parting process could be repeated. The spent cement would be smelted with lead, which would be cupelled to recover the silver.

Various versions of the process have been described in the ancient literature, with the addition of other salts such green vitriol (hydrated ferrous sulphate), saltpetre (potassium nitrate) in addition to common salt. However, the presence of large amounts of nitrates in the mixture would result in the loss of gold as the combination of hydrochloric and nitric acid will dissolve the gold as well as the silver.

Although widely used until the 18th century, the process was largely forgotten and the distinctive debris from the process is rarely identified, as the sherds do not have the vitrified internal surfaces typical of used crucibles. However, parting vessels do have a distinctive purple tinge due to the presence of silver chloride.

See Craddock 1995 216-219 and Bayley 2001, Rampage & Craddock 2000 for more information.

Related terms - Depletion Gilding

Sulphur and sulphide parting

Finely divided impure gold could be treated with elemental sulphur. All other metals would react with the sulphur to form sulphides. The process had to be carried out at a low temperature as sulphur is easily evaporated. The process could be carried out at higher temperatures if antimony sulphide (Sb_2S_3)was used. Parting using antimony sulphide was misleadingly known as the antimony process.

There is no evidence that either sulphur or sulphide parting was used in antiquity, although sulphur was reacted with a mixture of copper and silver to form niello. The advantage of sulphur parting was that it was much quicker than salt parting. It was also

believed to give much purer gold, but it was a more expensive process. In addition, it was more difficult to recover the silver - the sulphide had to be treated with iron filings.
The first definite European reference to the use of sulphur refining is in Theophilus. It was used either when refined gold was required quickly, or where gold of a higher purity than normal was required, i.e. to form hollow-ware vessels.
Surprising, the first definite Islamic reference appears as late as the 14th century. Care has to taken with some translations, as some authors seem to have translated terms for sulphate compounds as sulphides (Rampage and Craddock p 36).

Patina

The surface layer formed by reaction with environment over time. However, a patina may be formed artificially by chemical means for artistic effects, or to fake an ancient appearance.

Pattern

Pattern Welding

The technique of producing a pattern on a blade or other ferrous artefact by the welding together of two or more types of iron or steel.
From the second century AD some Roman swords were made with a patterned core fabricated by twisting and welding together several rods of low carbon iron and phosphoritic iron. Steel cutting edges were then welded on to this complex composite core. The resulting complete blade would be etched to reveal the complex pattern of welds. It is likely that these blades were regarded as high status objects, considering it would have taken about 70 hours to manufacture a sword (Anstee & Biek), and that they were recorded as being given as gifts. Even so, it is likely that they were mechanically inferior to a weapon made with a plain low-carbon iron core as examination of the swords has revealed that the welds were often poorly executed, with many slag inclusions, and even voids, at the welds between the various decorative components (Tylecote & Gilmour 1986, Gilmour and Salter 1998).
In the early period the cutting edges do not appear to have been hardened, but later the cutting edges were quenched. By the tenth century the number of pattern-welded swords decreased, as swords forged from more uniform steel replaced them. Pattern welded inserts were also used in seaxs (large single edged knives) and spearheads
The technique of pattern welding reappeared much later as European craftsmen tried to imitate the patterns seen in watered-steel (Damascus Steel) artefacts made from a single piece of crucible steel. The technique was thus described as damascening, in reference to the steel swords and artefacts sold through Damascus. The technique is still used to this day to produce the intricate patterns of very high quality shotguns.
In Asia two traditions of forming patterned blades arose by development of the piling technique using dissimilar types of iron. In Japan, low and high carbon steel components were welded together, then forged out, folded and welded back on itself repeatedly, to form finely layered steel. On quenching this produced alternate layers of pearlite and martensite, which were revealed by etching and polishing. In Southeast Asia, a similar technique developed in Malaysia and Bali but in this case the patterns were formed due to the use of steel containing a little nickel (pamur). This could be from meteoritic iron from the Prambana meteorite (now in the Kraton Gardens, Surakarta), or smelted from nickel rich iron ore, possibly from Sulawesi, in the Celebes Isles, (Craddock 1995, 273)
Related terms: Damascened, Damascus Steel, Watered-Steel, Wootz

Pattinson Process

A 19th century development of the cupellation process for extracting silver from lead, depending on the principle that, when molten lead crystallises, the silver concentrates in the remaining liquid while the crystals are silver-poor. The process was conducted in a row of cast-iron pans, each holding 6-10 tons of molten lead, and heated by a coal fire. Lead was introduced to a pan at the centre of the row, melted, and allowed to cool to crystallisation point. The crystals were scooped out with a perforated ladle, and passed to the next pan in one direction, while the remaining liquid lead was ladled out to the next pan in the other direction. The process was repeated in each pan, the crystals being passed in the opposite direction to the remaining liquid, so that the silver content was progressively enriched in the liquid. The silver-rich lead from the end pan, containing up to 200-300 oz/ton, was then treated by cupellation.

The Pattinson process was gradually replaced by the Parkes' process after its introduction in 1852.

Pearlite

A constituent structure that can be found in iron containing more than 0.15% carbon consisting of alternating parallel lamellae of ferrite (Fe) and cementite (Fe_3C). It forms by the eutectoid decomposition of austenite. It is a product of slow to moderate rate cooling but may appear in conjunction with martensite and troostite, or bainite and troostite when the rate of quenching is not high enough to form the fully quenched morphology, or in regions of lower carbon content in inhomogeneous steels. Often in more slowly cooled, or reheated steels the pearlitic structure has degenerated or spheroidised to some extent.

Related term: Sorbite

Peritectic

An isothermal reaction in which one solid phase reacts with a liquid of a different composition to form a new solid phase. The new phase may consume all of the liquid to form a totally new solid. The formation of the beta phase in the bronze system is an example.

Peritectoid

A peritectoid is the solid-state version of the peritectic reaction. It is an isothermal process in which two solid phases react to form a new solid phase. For example, a peritectoid reaction occurs in the copper-tin (bronze) system, at 65% copper. On cooling from above about 580ºC. the intermetallic Cu_3Sn, and solid solution gamma, react producing a new phase, Cu_4Sn.

As such solid-state reactions are largely diffusion controlled they often only occur to a limited extent, or may be completely suppressed by rapid cooling.

Pewter

Ancient pewter is an alloy of tin and lead, much used in Roman times, and from the Medieval to the 18th century. The poisonous nature of lead has resulted in the replacement of lead with antimony, although antimony is also inadvisable in high amounts for cooking utensils. Roman pewter appears to have included three different binary tin lead alloys, the groups covering the range 30 to 50%, 69% to 80% and greater than 90% tin. The first group would seem to correspond to Pliny's 50-50 alloy, but the second has a higher tin content (nearer to 3 tin to 1 lead) than Pliny's second alloy of two tin to one lead. (Pollard 1983 and Hughes 1980)

Some Romano-British and medieval pewter has been found to contain an appreciable amount of copper.

Modern lead-free pewter is basically tin with variable amounts of copper and/or antimony to harden the metal or alter the casting characteristics. Such alloys may contain between 0.5-2.5% copper, and 0-10% antimony

Phase

A single component of the chemical assembly having a common physical and crystallographic state. For example - water, ice and steam are all different phases although they have the same chemical formula. Silver in solid solution with gold is also a single phase no matter what the composition, as there is complete solid solution between the two metals. On the other hand, copper will only dissolve to a limited extent in silver and vice versa. Thus most silver-copper alloys consist of two distinct finely dispersed phases - copper with a very little silver in solution, and silver with a little copper in solution.

Phase diagram (equilibrium)

A diagram with axes of temperature and composition describing the different phases that will be present in a chemical system or alloy at equilibrium at a given composition and temperature. A binary phase diagram consists of two elements. A ternary system consists of three elements; these are often plotted as a triangular diagram with temperature as contour lines.

Related Terms: Ternary diagram, TTT-curve

Phosphoric iron

Iron with sufficient phosphorus present to increase the hardness of the metal. As well as increasing the hardness, phosphorus also increases the rate of work hardening of the metal, and its brittleness. In 17th-18th century Britain, phosphoric iron was referred to as ‘cold-short’, since it tended to crack during cold forging, but was preferred for nailmaking due to its hardness. Phosphorus also increases the drawability of low-carbon wrought iron, phosphoric iron being used for the wires of musical instruments (Goodway 1999 [JHMS, 33.2, 104-5]

The presence of phosphoritic iron may be revealed under the microscope by excessive grain size (when little or no carbon is present) and/or ghost structures when some carbon is present in the metal.

Phosphorus ghosting

In metallography of iron artefacts, regions in which differential relief develops during polishing and etching due to phosphorus segregation in the ferrite. These bands, which can cross the grain structure, are often best observed by moving the sample slightly off focus.

Piece-mould

As part mould

Pig

In the earliest period of British cast iron production (16th century), one of the products of the blast furnace was a large central ingot with small ingots run off it. This was thought to look like a sow and sucking piglets. The smaller ingots were termed pigs. Now the term has been widened to apply to any similar shaped metal ingot destined to be broken up and remelted, although most commonly applied to iron and lead.

Pig boiling

See Puddling

Pig iron

Cast iron ingots: Pigs of cast iron - or more generally broken cast iron ready to be remelted. See above.

Piled (steel)

A method of improving the mechanical properties of iron and steel, in which the metal is forged out, folded back on itself and the resulting ‘pile’ of metal is welded together. This process may be repeated several times so that the final metal consists of many fine layers.

Piling was used to homogenise steel produced by carburising strips of iron. Because the carbon has to diffuse into the metal from the surface it is difficult to produce homogeneous steel of any great thickness. If carried out successfully the piling process reduces the final thickness of each original strip to a fine lamination, while migration of carbon at welding heat further homogenises the carbon content. Thus, although exactly the same methods are used as in damascening (forging, folding and welding) the results and aims are different. The aim was to produce a more uniform consistent structure, whereas, damascening through the use of two different types of iron or steel deliberately produces a decorative pattern. The aim of piling (although not always achieved) was to produce a macro- and microscopically homogeneous steel, whereas, the aim of

damascening was to produce a steel that behaved in a uniform manner in the bulk, but was patterned on the small scale. The production of 'shear steel', the highest-quality British product before the development of crucible steel, was essentially a large-scale version of piling, though given the thickness of the blister steel bar raw material, micro-homogeneity could not be achieved (Barraclough 1984, 45-6 and 65-7).
Although, it is absolutely clear that some artefacts have been made by this technique, it is likely that some that been identified as having been made by this technique are, in fact, the result of either fortuitous banding, or the side effect of other parts of the manufacturing process.

Pinchbeck

Gold coloured brass, invented by Christopher Pinchbeck, a watchmaker of Fleet Street, London, in 1725. Probably made by melting copper and imported spelter (zinc). Later the term was widely used for all gold coloured brasses, and became a synonym for any cheap imitation. Thornton, J. 2000, 311

Placer deposits

Placer deposits form by the release of dense minerals (or metals in case of gold) by weathering of a primary ore body, and concentration by the action of water. The most important placer deposits are of gold and tin (the latter in the form of cassiterite), although locally magnetite may be concentrated in black sands sufficiently for them to be used as an ore. Often, the deposits are associated with the rivers flowing over a newly exposed landscape, rather than the present river or beach systems. Thus, the alluvial 'stream' tin deposits of Devon and Cornwall were buried several metres below the river level. As well as alluvial deposits in river and stream valleys, placer deposits include eluvial deposits weathered out from primary ores but only moved downslope by weathering and soil creep processes.

Plating

The technique of applying a thin surface layer of one metal over another for decorative, aesthetic, or anti-corrosive purposes. Plating may be applied by a number of different means -

Diffusion bonded plating

Diffusion plating involves bringing the plating metal into intimate contact with the metal to be coated at elevated temperatures, by application of pressure or by mechanical working. The main use of this technique was for the production of Sheffield Plate - silver-covered copper sheet. Diffusion bonding was also used to produce the mokume multi-layer decorative metals used in Japan.

Dip or Hot Dip

In this technique the objects to be plated were dipped in a hot bath of the molten plating metal. This technique was used in the Iron Age to simultaneously plate and braze iron horse fittings rings; examples of this technique have been found at Gussage All Saints and Maiden Castle in Dorset, and Yarnton in Oxfordshire.
Other examples of hot dipping to protect iron sheet from corrosion are tin plating and zinc-coated galvanized iron

Electro-plating

Electroplating uses an electric current to deposit the metal from solution on to the object to be plated, which acts as the cathode of the cell. The process was invented by Weiner Siemens in Germany, in 1842. His brother, Karl Wilhelm, introduced the process to Britain in 1843, where he sold it to James Elkington. This new electro-plating industry rendered the Sheffield plate industry obsolete by the latter part of the 19th century

Gilding

A method of putting a thin layer of high carat gold on a less expensive substrate. This includes a number of methods that are given in more detail in the section on gilding - Depletion gilding, Foil gilding, Leaf gilding, Mercury or fire gilding.

Vapour deposition

A modern technique in which the object to be plated is put in a vacuum chamber and the metal is thermally vaporized and deposited on the surface as a thin film. Widely used to deposit aluminium on a wide variety of surfaces.

Wiping

In this technique the metal object to be coated was fluxed and heated. The rod of the plating metal was rubbed over the areas to be plated. This technique was typically used for the decorative application of low melting point ‘white’ metal alloys.

Platinum

Metallic element atomic number 78, atomic weight 195.09, mp 1772°C, specific gravity 21.45. First discovered by Western Science in South America by Ulloa in 1735, but had been used previously by the natives of Ecuador and Colombia. Finds are known particularly from La Tolita dating to the last centuries BC. The metal is malleable and ductile, however, its high melting point, well above the temperatures attainable in any medieval or earlier furnace, made it very difficult to consolidate the native metal. Hence, the early South American artefacts were of platinum sintered with gold.

In the 19th century AD an attempt was made to establish a Russian coinage based on platinum coming from the Urals. In this case, the metal was consolidated by sintering the metal at high temperature and pressure. This early attempt at powder metallurgy was soon abandoned due to technical difficulties.

Native platinum is usually alloyed with some iron. Sometimes there is sufficient iron present for the metal to be magnetic. Platinum was used in early scientific instruments since its coefficient of expansion is very similar to soda-lime glass.

Related terms: Platinum Group Elements, PGE inclusions

Platinum Group Elements

The group of elements whose characteristics are similar to platinum, in that they have high densities and melting points, and are unreactive. These elements are iridium, osmium, palladium, rhodium, and ruthenium

Platinum Group Element Inclusions

Platinum group element inclusions occur as small silver-grey or steely coloured particles in alluvial gold. These were much harder than the surrounding gold and caused problems to jewellery makers. Osmium-iridium inclusions found in the California placer gold were used to make the hard-wearing Osmiroid pen tips until quite recently, due to their high hardness.

It has recently been realised that the classical term, adamas, must have been referring, in part, to PGE inclusions, as Pliny noted that -

‘Adamas was the name given to the auri nodus (literally knot of gold), found very occasionally in mines in association with gold and, so it seemed, only forming in gold.’ from Rampage and Craddock 2000, 240, referring to the interpretation of the text suggested independently by Ogden 1977 and Nicollini 1990.

Powder Metallurgy

Powder metallurgy is a set of methods used, initially, to produce metal components by sintering of pre-formed shaped powder compacts by the application of heat and pressure.

The technique was first developed to deal with refractory and reactive metals. More recently, the method has been applied to oxides and other ceramic materials. Also, it has been use to try to make alloys with finely divided and uniform microstructures which can now be produced by any other means.

Poling

A process designed to reduce the oxygen content of molten copper. This is carried out by plunging a pole of wood into a bath of molten copper. The distillation of volatiles in the wood results in the evolution of hydrogen and other reducing gases. These, in turn, reduce any copper oxide present in the molten metal.

Polycrystalline

Consisting of many individual crystalline grains. Most metals are polycrystalline solids.

Precipitation

The process by which a minor phase or component comes out of solution due to a chemical or physical change. For example - Iron carbo-nitrides may precipitate as small acicular particles in ferrite subject to prolonged heating in air.

Precipitate

A small particle of a specific metallurgical phase that has formed out of solution. For example - The aging of aluminium copper may harden the metal due to the formation of small coherent CuA_{l3} precipitates.

Prill

A small droplet of metal that has solidified from the melt. Prills are often the result of splashes of metal lost during casting operations, or are trapped in slag during a variety of metallurgical processes but in particular smelting or assaying.

According to the Shorter Oxford Dictionary, the word originally was used in Cornwall to describe the richer pieces of copper ore remaining after the leaner ore had been removed by cobbing. Later it was used to describe the globule of metal obtained on assaying the ore by cupellation. Hence, its present wider use to describe small metallic droplets.

Proeutectoid

For an alloy with a composition away from the eutectoid composition a phase will precipitate before the eutectoid component can be described as the proeutectoid phase or component. In the case of a hypoeutectoid steel, ferrite will start to form on the austenite grain boundaries at temperature above the eutectoid temperature. This grain boundary ferrite can be described as proeutectoid ferrite to distinguish it from the eutectoid ferrite of the eutectoid pearlite.

Pseudomorph

One phase copying the morphology characteristic of another phase. Typically, as a result of corrosion, one material or phase mimics the form of the replaced original. Pseudomorphic replacement of organic materials is common on iron artefacts and can occur on copper alloys and silver/copper alloys as well.

Proeutectoid

When an alloy of composition away from the exact eutectoid composition is cooled, particles of the first phase to precipitate are described as proeutectoid. For example, on cooling a 0.6 % carbon steel from a temperature where the structure is fully austenitic proeutectoid ferrite will start growing before the eutectoid reaction produces pearlite.

Puddling

As the production of coke pig for forge use took off from the 1740s onwards, there were increasing attempts to find a cast-to-wrought iron conversion process that was larger-scale and less labour-intensive than the finery, and that obviated dependence on charcoal and water-power and the craft skill of the finers. Many of these involved attempts to use the coal-fuelled reverberatory furnace, either in conjunction with or as replacement for the finery, although, the most successful process until the late 1780s, 'stamping and potting', involved heating granulated iron (broken up by stamping) in sealed pots with decarburising fluxes. In the late 1780s, however, Henry Cort's puddling process was developed, and rapidly took over complete dominance; Cort's main innovation was the use of grooved rolls to form the decarburised iron into bars. In this process a charge of cold cast iron was melted in a reverberatory puddling furnace with a sand bed. The air draught into the furnace was then controlled to produce oxidising conditions, while the molten iron was stirred with iron tools through the furnace door. As the carbon content dropped, the iron became increasingly 'pasty', and was manipulated into large balls. These were removed from the furnace, hammered and passed through grooved rollers to consolidate the metal and form it rapidly into bars of uniform section. The mechanical working of the iron at the various stages was an important aspect of the process.

In Cort's process the cast iron reacted with silica in the sand bottom to form a fayalitic slag. This resulted in a considerable loss of metal. This so-called 'dry' puddling was later replaced by 'wet' puddling. In the wet process, the floor of the furnace incorporated iron oxide in the form of iron scale or roasted slag rich in iron oxides; also material rich in iron oxides was added as part of the charge. The effect of this was to reduce the losses of iron caused by slag formation and more importantly to aid the decarburisation as the iron oxide reacted with the carbon in the molten cast iron to form carbon monoxide. The wet process was also known as 'pig boiling' from the strength of the reaction. (Tylecote 1992, 126-129)

Puddling furnace

A reverberatory furnace used for converting cast iron into wrought iron, using a stirring or 'puddling' action in the later stages when the iron becomes pasty.

Related terms: Cast Iron, Puddling, Refining, Wrought Iron

Q

Quartation

Quartation is a stage in the parting process in which additional copper or silver is added to gold to be refined. The method does not seem to be extensively used until acid parting became the main method of refining silver from gold, although it use is mentioned by 16th century writers. The process is also known as graduation.

In the early accounts gold was refined by parting in the normal way, then a large amount of copper was added, and the metal parted again. Later, it became standard to add silver rather than copper.

Although, it seems counter-intuitive that the addition of extra impurities should help in refining gold, it became the standard method for acid parting. It is doubtful whether the method was particularly beneficial when used in conjunction with salt cementation, as in that case the reaction proceeded as a gas/solid phase interaction, and transport through the narrow pores formed in relatively pure gold alloys would be rapid at the temperatures involved. However, the method was helpful when salt cementation was replaced by acid parting. Because acid parting was carried out at low temperatures, it was necessary to have larger pores and shorter diffusion distances for the method to be effective. The addition of extra silver, which was subsequently dissolved by the acid, resulted in a more open and reactive structure.

Quench

The act of quickly cooling a metal or alloy by plunging it into cold water, brine or oil. In some alloy systems the effect of quenching is to form non-equilibrium meta-stable phases with very different properties from those of a more slowly cooled alloy. This is particularly important for formation of martensite in steels, but also in high tin bronzes.

In other alloy systems quenching has little effect other than preventing grain growth and additional surface oxidisation during cooling. However, in some gold alloys it can prevent embrittlement associated with the formation of ordered alloys.

The martensitic transformation occurs by a shear transform rather than a diffusion-controlled transformation, therefore, the metal is left in a highly stressed condition after a simple quench. It is normal in modern metallurgical practise to gently heat or temper steel after quenching to relieve these stresses, and adjust the metals properties to those required for its intended function.

The rate at which heat is removed from the metal is critical to the resultant properties; see Quench agitation, critical diameter, media, and severity (below) for further discussion of the topic.

Quench, agitation

The more vigorously the work piece is agitated in the quench bath, the more severe the quench will be. See Quench severity.

Quench, critical diameter

It takes longer for the temperature to drop in the centre of an object than near the surface due to the time it takes for the heat to be conducted to the surface. Considering a steel bar with uniform composition, the quench rate may be sufficient for the surface to be fully martensitic, but because the centre of the bar has cooled more slowly it may be only partially martensitic, or possibly totally pearlitic steel, depending on the diameter of the bar. The critical diameter for a given alloy is given as the diameter of a bar so that the centre of the bar has a structure of 50/50% martensite and pearlite when given an ideal quench. In practice, the critical diameter is determined by the Jominy test.

The importance of the critical diameter is that it is a measure of the hardenability of a steel. The larger the critical diameter, the easier it would be to form martensite, to greater depth, with a less severe quench. Most early steels were of low hardenability.

Quench hardening

The hardening of steel by plunging it at a red heat (the austenite field) into cold liquid such as water, brine, or oil. The structure is converted to martensite, or bainite, depending a combination of the composition of the steel and the quench rate. At lower quench rates, combinations of martensite, bainite, troostite and pearlite may form, and the relative proportion of these components that are likely to form is described by the TTT curve.

Hardenability DI

Hardenability is one of the most important properties of a steel. It is a measure of how easy it is to convert austenite to martensite on quenching. The ease of this conversion is controlled by a number of factors, the most of important of which is composition. The shape of the object in terms of the thickness of section and the grain size of the metal will also determine if the metal can be fully transformed to martensite.

Composition - the effects of

Carbon:

In ancient European steels the only element that has an appreciable effect on the hardenability of steel is carbon. At low carbon contents it is impossible to cool the metal rapidly enough for avoid the formation of pearlite (the pearlite curve on the TTT diagram is well to the left). With increasing carbon content the TTT curve is pushed to the right, so that it is possible to cool the metal without passing through a regime in which pearlite would be formed.

An additional effect of increasing the carbon content of a steel is to drop the temperature of Ms and Mf, the start and finish of the martensitic transformation. With sufficient carbon the Mf is less than room temperature, so that not all the austenite will transform on quenching. This is termed retained austenite. On tempering, this retained austenite will transform to martensite or bainite depending on the temperature. These changes can start at the same sort of temperatures required to set hot mounting thermo-resins; for this reason only cold setting resins should be used to mount samples from artefacts that may contain quenched steels.

Other elements:

Manganese (Mn), silicon (Si), nickel (Ni), chromium (Cr) and molybdenum (Mo) will all move the pearlite curve of the TTT diagram to the right, thus, making it easier to avoid the formation of pearlite before reaching the start of the martensite transformation. However, none of these elements occur in any appreciable quantity in most early western steels, although, nickel may be concentrated at weld lines up to levels of 1% or more. Some crucible steels and associated material from the Middle East and South Asia can contain low but appreciable amounts of manganese (up to 0.3%). However, this is insufficient to aid the reliable formation of martensite.

As with carbon, the addition of manganese will drop the Ms temperature. With a 1.0% carbon steel the effect of the addition of 6% manganese is to drop the Ms far below room temperature, so that the austenitic structure is effectively stable. This effect was only discovered and used in the second half of the 19th century with the discovery and production of spiegeleisen (1848). Tylecote 1992, 165.

Section thickness

For a given severity of quench, the rate at which the temperature can be reduced is a function of the thickness of the section. A thick-sectioned blade will cool more slowly than a thin one, as it will take longer for the heat of the metal at the centre to be conducted to the surface.

Grain Size

Austenite grain size has an important effect on the hardenability of steel, in that it controls the number of potential nucleation sites for pearlite. Pearlite prefers to nucleate on the austenite grain boundaries and grow out into the centre of the austenite grain. Steel with a small grain size will have a much greater area of austenite grain boundary per unit volume than one with a larger grain size. Thus, the probability of pearlite formation and growth in the time it takes to cool the steel to the Ms temperature is much higher for a fine-grained steel than one with a larger grain size. That is, it is more difficult to harden a fine-grained steel than a coarse grained one.

Related terms: Grain size, Control of grain size

Quench, Media

Brine

Brine will give a more severe quench than pure water as the additions of salt will increase the boiling point of the liquid thus preventing the thermal insulating effect of a layer of steam for longer. However, when boiling does occur it is as a series of small explosions in the liquid close to the metal, resulting in the violent agitation of the liquid

Oil

Oil is more viscous than either brine or water, therefore, the surface bubbles formed at the surface of the hot metal are much more difficult to remove. With a slower cooling rate the quench is likely to be more even than in the case of pure water.

Water

Water was widely used to quench metals as it is widely available and has a very good thermal capacity (the ability of a given weight of the material to absorb heat). However, when a piece of steel is plunged into water, the water at the surface boils generating a layer of poorly conducting steam. As some areas will act as nucleation centres for steam bubbles, these will cool more slowly than other adjacent regions, resulting in an uneven microstructure. (Reed-Hill, 1973. 708-709)

Quench, severity

The medium in which an object is quenched, and the degree of the movement of the metal in the medium control the rate of cooling. The rate of cooling, the H value is given by the table below. By measuring the critical diameter of test piece, the H value and using charts it is possible to calculate the ideal critical diameter for that material - that is a measure of its hardenability.

H Value	Quench conditions	Agitation
0.20	Poor Oil Quench	None
0.35	Good Oil Quench	Moderate
0.50	Very Good Oil Quench	Good
0.70	Strong Oil Quench	Violent
1.00	Poor Water Quench	None
1.50	Very Good Water Quench	Strong
2.00	Brine Quench	None
5.00	Brine Quench	Violent
Infinity	Ideal Quench	

Quench, Slack

A slack quench is one in which not all the structure was converted to the quenched microstructure. In the case of steel, this means that the quenched structure was not fully martensitic, but there may be some ferrite or pearlite present.

A slack quenched structure may be deliberately produced by the use of a delayed or interrupted quench. On the other hand, a piece of steel may have been accidentally slack quenched due to the carbon content being lower than anticipated, and hence it becomes impossible to quench the metal in that particular thickness of section quickly enough to produce a fully hardened structure.

Not all non-fully martensitic structures are slack quenched as in very high carbon steels, where Mf can drop to well below room temperature, resulting in even fully water quenched micro-structures retaining some austenite.

Quenched structures

Non-equilibrium metastable structures or phases formed by quenching in water or oil. The most common quenched products are martensite and bainite in steels and martensite in high-tin bronzes. Quenching may also be used to suppress ordering reactions, especially in gold alloys, and some ancient texts refer to this practice to avoid embrittlement.

Quern stones

In archaeometallurgy, stones used for grinding ore preparatory to dressing or smelting, or for grinding slag to release trapped prills of metal.

R

Rabble

An iron rod bent at the end used to stir the molten cast iron during puddling, to ball up the refined iron produced in the process into blooms. The blooms would then be forged and rolled into bars of wrought iron.
Probably, the term originally came from the French word - râble , meaning rake. It was first used to describe the shovel used by charcoal burners to tend the covering of the burning charcoal clamp, and was later applied to puddling.
Related Terms: Puddling, Refining (cast iron)

Raising

The method of producing hollow-ware (dishes and bowls etc) by hammering an initially flat sheet of metal over a curved stake. In raising the metal is struck on the convex side of the form with a curved faced-hammer compressing and thickening the walls of the vessel as the overall diameter of the vessel is reduced and the edges are 'raised' above the centre. The diameter of the initial blank is much larger than the diameter of the finished article; typically the starting blank has a diameter equivalent to the combined dimensions of the average diameter and the height of the finished form and is of relatively thin sheet. The thickening of the metal at the rim is often increased further by caulking the edge. So that, starting with a 0.9 mm thick blank the rim may end up 2 to 3 mm thick, and the vessel is less likely to distort during use.
The raising process is usually preceded by a ‘blocking out’ or ‘hollowing’ process in which the sheet is forged into a shallow dish-shaped form by hammering from what will become the inside of the vessel against a concave depression in a wooden block.
Related Terms: blocking, caulking, dishing, hollowing, sinking

Reaction Solder

A method of soldering gold in which the joint was covered with a mixture consisting of powdered copper compound, such as azurite, malachite or chrysocolla, and an organic compound, then heated. The carbon rich compound reduced the copper in the mixture to metallic copper. This copper dissolved in the gold forming a small region on the surface of the join with a lower melting point. If the temperature was high enough a solder (metal-liquid-metal) joint would form. Prolonged heating would result in the copper diffusing into the body of the gold, leaving little or no external evidence of the use of solder. The technique was extensively used to produce Anglo-Saxon gold jewellery.
Sometimes the technique is misleadingly called diffusion soldering - the solid-state diffusion of copper away from the join is a secondary effect.
Related Term - brazing, diffusion bonding, solder

Reamer

A tool for cleaning out a hole bored by a drill, auger, or cast-in, in the case of hollow-cast objects. Iron cannon were cast hollow until the 18th century, and finished by reaming the bore; a reamer with steel-edged cutters has been recovered from Stream furnace, Sussex

Recovery

The mechanical deformation (cold working) of a metal will increase its strength, hardness, and electrical resistance, and will decrease its ductility. Recovery is the term used to describe the tendency for these properties to recover to the original values without any obvious change to the deformed crystal grain structure. This may occur slowly at room temperature, or more quickly as the temperature is increased.
Recovery is the first stage of the annealing cycle after cold working. It occurs before recrystallization and grain growth. It occurs, largely, through the elimination or rearrangement of the vacancies and dislocations introduced into the crystal lattice of the metal during working. Many of these processes follow an Arrhenius type law. That is, they are time-temperature dependent with the rate of recovery increasing with temperature in an exponential manner.

Related terms: Annealing, Arrhenius, Cold working, Dislocation, Ductility, Dynamic Recovery, Grain Growth, Hot Working, Recrystallization, Vacancy

Dynamic Recovery

Dynamic recovery occurs when a recovery type process occurs during deformation. It is often strongly temperature dependent and may extend the deformation possible with some metals. But recrystallization, which occurs at higher temperatures, is the main process that occurs during hot working.

Recrystallization

Generally, a change from one grain structure to another with a lower overall energy, without a change in crystal type. Recrystallization normally occurs during an anneal after cold work, as it softens the metal so that further working mechanical deformation can occur in the next cycle of cold work. It is also the main mechanism by which the mechanical properties of the metal recover during deformation in hot working.

Recrystallization is a nucleation and growth process, that is, it is temperature controlled. In pure metals the rate of recrystallization may become measurable at temperatures as low as a third of the absolute melting point of the metal (0.3Tm). The presence of small quantities of solute atoms can have a marked effect on the recrystallization temperature; for example the addition of 0.01 atomic percent tin to high purity copper will raise the recrystallization temperature by 180°C. With alloys the recrystallization temperature is typically 0.5Tm

The final recrystallized grain size, for a given temperature, is a function of the number of nucleation centres and the length of time that recrystallization and grain growth has been possible, and the density of pinning features such as second phase precipitates or inclusions.

Nucleation occurs in the regions of high lattice strain. These are near slip-line intersections, deformation twin intersections, and the original grain boundaries. The number of these features will increase with increasing deformation, but at low strain there will be very few sites with sufficiently high dislocation density to form nuclei for new grains. Thus the recrystallized grain size tends to decrease with increasing deformation as nucleation predominates over growth, whereas at low strains with few nucleation centres grain growth predominates.

The aim of a recrystallization anneal is to complete primary recrystallization but to keep the grain size as small as possible, as large grain sizes are detrimental to the mechanical properties of metals.

Recrystallization - critical strain

Below a critical strain, no or very few nucleation centres will be created. Annealing metal that has not been deformed beyond the critical strain will result in detrimental secondary recrystallization.

Recrystallization - Primary

Primary recrystallization is the term used to describe the replacement of the original deformed grains with new grains. It is complete when all the deformed original grains have been replace by new strain-free grains.

Recrystallization - Secondary

Once primary recrystallization is completed continued annealing, or annealing at higher temperature than intended, will result in a second wave of grain growth with some of the grains with favourable orientations growing at the expense of others. In general, large grains will grow at the expense of smaller. It is possible that boundaries of these grains will not stopped by inclusions and second phases in the way that grains are during primary recrystallization resulting in abnormally large grains.

Recrystallization - Temperature

As recrystallization is a thermally activated process, the rate of recrystallization roughly doubles with every 10oC. So there is not, in fact, a fixed temperature at which recrystallization starts, but because the process is so strongly temperature controlled, below a certain temperature primary recrystallization is never completed. The recrystallization temperature is usually defined as the lowest temperature at which primary recrystallization is completed in a reasonable time (typically 1 hour).
Related terms: Annealing, Grain Growth, Grain Size, Recovery, Strain

Red Heat

See Heat - red

Reduction

Chemical reaction in which a metal is transformed from its oxide or sulphide to the metallic form, or from one oxide to another with a lower number of oxygen atoms for each metal atom. For example the series of transformations -

$6Fe_2O_3 = 4Fe_3O_4 + O_2$ Haematite to Magnetite
$2Fe_3O_4 = 6FeO + O_2$ Magnetite to Wüstite
$2FeO = Fe + O_2$ Wüstite to Metallic Iron

the oxides of iron (going left to right) are successively reduced through to metallic iron. Each individual stage is still a reduction, eg Magnetite to Wüstite even when both reactant and the products are oxides.
Another way of looking at reduction is that it occurs when a cation (the metallic ion) loses a unit of charge, e.g. Fe^{3+} goes to Fe^{2+}, or alternatively that the Fe ion gains an electron (the charge on an electron is negative - e^-)
$Fe^{3+}\ e^- = Fe^{2+}$
Related terms: Oxidization, Valency

Refining

Refining is the separation of a metal from its impurities. As such it is applied to a wide range of different processes for the different metals.

Copper

The copper that was produced by the last stage of the smelting process was, in general, rather impure (black copper with copper content as low as 90%). This had a high iron content, which would have to be reduced by two stage refining process if the copper was to be useable for most purposes. This was done by first an oxidizing process to convert the metallic iron in the metal to iron oxide (usually magnetite), and then a reducing process (poling) to remove the excessive amount of oxygen introduced by the iron removal stage.

Refining black copper

The magnetite would float on top of the metal where it could either be slagged by the addition of silica and tapped off, or the pasty magnetite could be physically scrapped off the top of the liquid metal to form a high magnetite smithing hearth bottom type slag. Unfortunately, the tapped refining slag would be difficult to distinguish from other of copper smelting slags, or even iron smelting slag - however the presence of a significant amount of partially digested crushed quartz fragments is often an indicator of a copper smelting or refining slag.
The high magnetite smithing hearth bottoms, or skulls, have been recorded rarely from archaeological contexts. This is almost certainly because the number of sites on which refining occurs would be limited as -

- Either the slag would be produced on the original smelting site, where the small amount of such slag produced would be swamped by the much large amount of 'normal' smelting slag. Thus not easily recovered and recorded.
- Or the refining occurred away from the smelting site, that is, the copper was traded as black copper ingots. In this case, the slag might be mistaken as a slightly unusual iron smithing slag.

Poling

This was the final stage of the refining process designed to reduce the oxygen content of copper to a reasonable level. It was carried out by plunging a pole of wood into a bath of molten copper this produces hydrogen and other reducing gases by the distillation of the wood. These in turn reduce any copper oxide present.

Alloying copper with tin or zinc would also deoxidise the metal but at the expense of loss of expensive alloying element to slag or vapour. It is, therefore, more economical to pole the metal before alloying.

Silver

The main method of separating silver from the majority of its impurities was by cupellation of the impure metal with lead. However, cupellation would not separate gold from silver.

Gold

Cupellation

Cupellation was used to separate gold from those alloys containing copper but as silver is not oxidized during the cupellation process, it would not separate gold from silver. Thus, if high purity gold was required for jewellery, or coinage the metal would have to be further refined by parting.

Mercury amalgam refining

In the classical period mercury amalgamation refining was used to recover and refine gold from worn out gold embroideries and gold leaf gilding. Gold dissolves in the mercury to form a pasty amalgam. The majority of the mercury was remove by squeezing the mixture chamois leather leaving the amalgam behind. The gold was then recovered by heating amalgam so that the remaining mercury was lost by evaporation.

The same technique was later used to recover finely divided gold from crushed ore.

Parting

To get rid of silver from gold it was necessary to use a parting technique. The earliest of the heated the impure gold with salt in combination with other chemicals to convert the silver to silver chloride which diffused out of the metal. This method appears to be first used to produce the gold for the Lydian coinage produced at Sardis in the 6th century BC (Rampage and Craddock 2000).

Later other parting methods were used to treat impure gold alloys; these included acid, and the antimony or sulphide parting.

Related term: <u>Parting</u>

Iron

Bloomery iron and steel did not undergo a specific refining process other than by forging and possibly folding and welding to break up the slag inclusions and homogenize the metal.

However, as the major use of iron was in the malleable form, the majority of cast iron was (re)fined to wrought iron by oxidizing carbon, and when present the silicon, out of the metal. Initially in Britain, this was carried out in the finery forge using the Walloon process where both a finery and chafery hearth were used. After Henry Cort’s use of the reverberatory furnace to convert the iron and grooved rolls to convert the resultant bloom to bar, the puddling process generally replaced the finery forge.

Refinery

The refinery was a separate hearth used to convert grey cast iron into white cast iron prior to its conversion to wrought iron in the finery and chafery.

With the introduction of the coke fired blast furnace the silicon content of cast iron increased. This resulted in the production of grey cast iron rather than white, as was normally the case with the charcoal-fired blast furnace. Grey cast iron was more difficult to refine, because the silicon had to be oxidized before the carbon could be removed. The carbon in grey cast iron was in the form of graphite was more difficult to oxidize than when it was combined with iron in the form of cementite, as in white cast iron. To solve this problem, an additional step in the fining process was added, in which the grey cast iron was heated under oxidizing conditions until the silicon was removed and the metal was converted to white cast iron.

Related term - Chafery, Finery, Puddling, Running-out fire

Refractory

The term either describes the heat resisting properties of a material, or the heat resistant objects such as tuyères, crucibles, and furnace and hearth linings. A refractory material must have the following properties.

A high melting point

It is likely that much of the history of metallurgy has been controlled by the improvement of the properties of refractories. Although most copper alloy metallurgy can be carried out in the temperature range in which common clay-base refractories are adequate, the same is not true for the production of steel and cast iron.

Chemically inert with respect to the charge

At high temperatures the slag produced can attack some furnace linings extremely aggressively. This was particularly true in the 19th and 20th centuries with the development of the basic steel making. The normal silica refractories were attacked and destroyed rapidly by the basic (calcium-rich) slag needed to reduce the phosphorus content of the steel.

Mechanical strength and dimensional stability at high temperatures.

In the case of crucibles, the material must be able to support the weight of the molten metal and be able to be picked up without excess deformation at the pouring temperature. In the case of furnace linings they must be able to support the weight of the material above them without slumping.

Thermal shock resistance

Crucibles, in particular, have to with stand large thermal shocks when the crucible is removed from the furnace for pouring. Furnace linings have to withstand thermal stresses imposed by thermal gradients within the furnace lining.

Thermal conductivity

Ideally crucibles and muffles should have high conductivity, whereas, furnace linings should have low conductivity. However, conductivity of crucible refractory was not factor that would have been considered important until recently, the other factors being much more important. Similarly, for furnace linings the requirement for low thermal conductivity was not an overriding factor, although reducing the overall thermal losses through the furnace walls would have been important.

The difference between the thermal conductivity of modern refractories and those used in the past has not always been considered in some experimental reconstructions of early smelting processes. The use of different refractory materials can have a major effect on the thermal losses and thus on the blowing and rate of fuel use required to run a smelt. The earliest refractories were made from local clays. These may have been modified to improve their properties usually by the addition of quartz rich sand, but where available graphite was used. Eventually, some clays (high kaolin fire-clays) were discovered to make particularly good refractories. So that production became centralized in a few centres and the crucible exported over large distances as is shown by the import of large number of Hessian crucibles, manufactured in what is now Germany, into England during the 17th and 18th centuries. The introduction of the blast furnace required the use of refractories with high silica content to withstand the higher temperatures involved. These were either in the form of natural high purity sandstones with low iron content, or later silica bricks that contain more than 96% silica. To deal with basic slag or higher temperatures refractories based on magnesite MgO or dolomite $(Ca,Mg)CO_3$ were used.

Regenerative Heating

A regenerative heater was a fuel saving device fitted to a furnace, consisting of two sets of chambers filled with a checker-work of firebricks. One chamber is heated by the hot waste gas from the furnace, while the other, heated in the preceding cycle, is used to heat the incoming cold air and gas(fuel). After a period the air flow through the furnace and chambers is reversed, so that the chambers change their roles. The idea was based on the idea patented by Stirling in 1812, and fully developed by Frederick Siemens between 1856 and 1861. The earlier versions used coal and other solid fuels, but there was a tendency for the ash carried over by the airflow to block the firebrick checkers. The use of producer gas as a fuel eliminated this problem. The use of regenerative heaters allowed the furnaces, both to run using less fuel, and at higher temperatures. William Siemens applied the use of the regenerative heater to steel making and developed the Open Hearth method of steel making, which was used extensively in Britain

Related term: Hot blast

Relief Polishing

During sample preparation for metallography, there is a tendency for the softer phases in a sample to be preferentially removed by the abrasive paste. Normally this effect is not wanted, but may be helpful in revealing phosphorus ghost structures in phosphoritic irons.

Repoussé

A design is raised on the front side of the metal by hammering from the back surface. The front side is supported with a soft material such as pitch during the repoussé stage, so that large areas of metal compared with the thickness of the sheet was deformed (unlike chasing).

Related terms: Chasing, Tracer.

Retained Austenite

With high-carbon steels the Mf temperature can be reduced to well below ambient temperatures. If such a material is not tempered after quenching, some of the structure will remain as austenite. Retained austenite is rarely seen in examples of archaeological or historical steels as most early steels are either not quenched sufficiently fast, or are tempered. However, retained austenite has been observed in a few Medieval Iranian ultra-high carbon steels.

Retort

A vessel with a long turned down neck used to distil materials by volatilisation. Originally, applied to chemical apparatus, but also furnaces in which metals were purified or smelted by volatilisation - mercury and zinc. The term was also applied to the oven in which coal gas was heated to produce coal gas and coke.

Reverberatory furnace

The name comes from the verb, to reverberate - to beat back or reflect, thus, a reverberatory furnace is one in which the flame or heat is reflected back on to the charge.
This has the effect that fuel is separated from the charge as the heat is reflected down onto the charge from the roof. The furnace is of the induced draught type with a tall chimney at one end and a firebox at the other. It needs a long-flame fuel such as coal or wood (not charcoal or coke) to transfer the heat towards the near-horizontal roof. Used for remelting cast iron, bronze and bell metal. Often known as an 'air furnace' and latterly used for puddling, steel-making and non-ferrous smelting.

Riser

When metal is poured into a mould air has to be displaced. A riser is a vent that lets out any trapped air, and thus, allows the metal to enter the mould more easily. Generally, situated on the opposite side of the mould from the feeder. When the metal is seen in the riser, pouring is stopped. The use of risers appears to be a late development in casting technology as the is no evidence for the use of risers with early stone and metal moulds, or clay investment or part-moulds.
The introduction of the use of risers must have been associated with the development of large castings requiring the use of casting pits. However, although the feeder arrangement of moulds is often discussed in the archaeometallurgical literature, the use of risers is rarely discussed or illustrated.

Riveting

The method of joining metal sheets by metal pegs passing through aligned holes previously cut in the sheets and hammering down the ends. Riveting can be performed hot or cold. The term hot or cold referring to the temperature of the rivet when it is closed. The advantage of hot riveting being that the joint is tightened further by the thermal contraction of the rivet on cooling.

Rolling

The hand-powdered rolls were first used to emboss narrow strips for coins and to flatten and thin soft metals like gold and lead. But the development of the machinery capable of thinning work hardening metals and alloys required the improvement of the materials for the rolls and the their supporting structures as well as the increased power available in the post-medieval period.
It is likely that the early rolling mill technology came from the slitting mill, and Tylecote 1990 (249) quotes C.S. Smith's reference to the earliest description of a rolling mill of 1568 for the preparation lead window 'cames'. Clearly the use of rolls to form metal was of interest at this period, as in 1496 Leonardo da Vinci drew a design for a rolling mill.
Related terms**:** Slitting

Roasting

Another term used for the heating of materials either in open heaps or simple kilns. Ores may be roasted either under oxidising conditions, or very limited reducing conditions. Roasting was used to drive off water (both any chemically combined water, as well as any general dampness), decompose carbonates, and break up the ore to make it more permeable to gases. Roasting may be used to partially convert sulphides to oxides prior to forming a matte.
Related terms: Calcine, Dead Roast.

Rockwell Hardness Test

The Rockwell hardness testing method uses either a steel ball (Rockwell B) or a diamond cone having an angle of 120° (Rockwell C). It is used for rapid testing but the results are not directly comparable to Vickers Pyramid numbers. A disadvantage of the Rockwell test is single test-head cannot be used over the whole range of materials from soft copper and brass to very hard materials such as nitrided surfaces.
Related Terms - Brinell Hardness, Vickers Pyramid Number

Runner
In a casting the runner is a passage connecting the sprue to the ingate of the mould. A runner is normally horizontal or near horizontal, and helps control the flow of the metal into the mould.
Related terms: Cope, Drag, Feeder, Gate, Riser, Sand Casting, Sprue
Running-out fire
The introduction of coke-fired blast furnace meant that the iron produced had a higher silicon content than was the case with the charcoal-fire blast furnace. As silicon is more reactive than carbon, it protects the carbon from oxidization until most of the silicon has been removed, and thus extending the time required to complete the refining process. In addition, high silicon cast irons tend solidify as grey cast iron rather than white. Grey cast iron is more difficult to convert than white iron. The running-out fire was a method of overcoming these problems. It was a hearth into which the liquid iron from the blast furnace could be tapped. It had a series of tuyères that blew air down on to the surface of the pool of metal oxidizing the silicon to slag; the resulting low silicon could then be converted as before.
Related terms**:** Finery, Puddling, Refinery.
Rutile
Titanium dioxide. TiO_2. A common accessory mineral in many rocks, in particular it is associated with placer magnetite iron ores.

S

Safidruy
Islamic term for high tin bronzes, often white in colour.
Sand Casting
A method of casting in which the mould is made of sand and a binder rather than clay, metal or stone. Simple shapes may be cast directly into impressions made in the sand using a pattern. But for more complex objects, sand castings are two part mouldings, with pattern first being impressed into the lower part of the mould. A parting agent is applied to both the surface of the sand and the pattern. Then a box to contain the upper part of the mould is put down around the pattern, and sand is rammed into the box around the pattern to fill the box. The upper part of the resulting mould is lifted off the lower, and the pattern removed. The upper part of the mould is then lowered back on to the lower ready to received the molten metal.
Green sand
Silica(te)? sand
Scoria
Scoria is an old name for slag, probably of late Middle English origin, but not often used now. Care needs to be taken with old documents referring to scoria as from the late 18th century, the term scoria was also applied to the rough, broken, cinder-like surface of some types of lava flows, and occasionally the term ‘slag’ was used to describe lava.
Segregation
The non-uniform distribution of alloying elements, impurities or phases. Normally, used to describe compositional inhomogeneity developing during the solidification of a metal from a melt. Normally, when a metal or other multi-component systems solidify the composition of the solid that first freezes will be different from that of the liquid; it will have a lower concentration of the lower melting point component. This result in the liquid composition becoming slightly enriched in the lower melting point component. Because solid-state diffusion is much slower that liquid-state diffusion it is rare for the whole system (solid and liquid) to come to equilibrium

before more metal freezes over the first metal at normal cooling rates. This can lead to a number of different types of chemical segregation in cast alloy

1. Normal segregation. The term applies to the overall distribution of elements in the casting. In a ‘normal’ casting the metal freezes from the outside to the centre. Thus, the local composition metal on the outside of the casting will have a higher melting point than the centre. The centre of the casting will collect all the low melting point components.
2. Inverse segregation.. Again, term applies to the overall distribution of elements in the casting. However, in this case, the lower melting point constituents, such as the phases rich in tin or arsenic in bronzes are concentrated toward the surface of the cast due to contraction of the casting forcing the remaining low melting point liquid from the centre to the edge of the casting.
3. Dendritic segregation. Dendritic segregation, describes local differences in composition in which fern-like dendrite growth occurs from local compositional gradients. In this case, the core of the dendrite will have a local high melting point composition, compared with the inter-dendritic material. Castings showing either normal or inverse segregation are likely to have dendritic segregation on the small-scale.

Related terms: Dendrite

Set

Smithing tool, a chisel with handle mainly for cutting hot metal.

Shaft furnace

1. In the classification of archaeological furnaces, a furnace in which the main reaction chamber is taller than it is wide and the width of the chamber does not vary significantly with height, is thought to be a shaft furnace.
   There does not seem to be a generally accepted definition for the height to width ratio to determines the limits of a shaft furnace - but anything with a height to width ratio greater than 1.5 seems to be thought to be a shaft furnace.
2. The term shaft furnace can be more generally used to describe all furnaces in which the reactants (ore and fuel) move down through the furnace chamber while the combustion products flow up through the furnace. Thus they differ in the manner in which they work to hearths and reverberatory furnaces

Related terms - Furnace, Furnace Types, Hearth, Reverberatory furnace

Shear steel

Shear Steel was formed by taking several pieces of blister steel and welding them together. This has the effect of reducing the inherent inhomogenity across each individual bar of blister steel. The process is well described by Percy (1864 Vol II.3, 859) -

Bars of blister-steel are broken into pieces about 16in. long (400 mm), and drawn out at a red heat under the hammer to the width of about 1 1/2 in. (38mm) and the thickness of about 1/2in (13mm). Several bars are thus obtained are piled on one another, and the end of the pile is firmly wedged into an iron hoop with an handle attached to it. The free end of the pile is raised to welding heat in a hollow coke fire, during the process being dusted over with finely-pounded clay, welded under the hammer and reduced to about 2 in. (50mm) square. The hoop is now detached from the other end of the bar, and this end is treated in exactly the same manner as the first end.

Double shear-steel is formed by taking a bar of shear steel, breaking it in half (or bending it back on itself) and welding the two pieces together.

Related terms: Blister steel, Piled Steel, Steel

Sheffield Plate

A plating technique to plate copper with silver developed by Boulsover during the 1740s in Sheffield. Silver was diffusion bonded over thick copper sheet by heating a sandwich of carefully prepared sheets of silver, copper, and silver protected by iron sheets to red heat. The silver and copper was relative thick, but could be rolled or forged down as the copper and silver retained their relative thickness. With the introduction of electroplating to Britain in 1843 by Karl Wilhelm Siemens and its development by James Elkington, the use of Sheffield plate to dwindled and stopped in the second half of the 19th century. (Day & Tylecote, 1991, 29 & 177)

Short

A metal is described as short when it tends to crack after a relatively small amount of mechanical deformation. The term tends to be applied to steels with reduced workability. Steels may be described as cold short or hot short.

Cold Short

Metals that have limited ductility at low temperatures. Steels containing phosphorus are particularly prone to cold shortness - hence the British steel makers preference for Swedish low phosphorus iron rather than British iron many of which contained significant quantities of phosphorus. Although, phosphoritic iron with low carbon contents can be drawn to form wires. Goodway

Hot Short

A hot short metal will have a tendency to crack during hot-working. This is usually due to the presence of a low melting point phase at the grain boundaries. In the case of steel, sulphur is particularly detrimental as iron sulphide will wet the grain boundaries with the rest the steel will fall apart if forged at high temperature. The addition of manganese to form manganese sulphide rather than iron sulphide prevents this.

Silica

The oxide of the element silicon, with the chemical formula SiO_2. Pure (or nearly pure silica) can occur in several mineral forms: quartz, tridymite, and cristobalite, depending on temperature and pressure. Silica combined with other metal oxide comprise a large part of many rock-forming minerals, and hence silica is a major gangue component or many ores. Hence, silica is a major component of many smelting slags, although occasionally some copper smelting slags can have very low silica content as there is a low melting point region in calcium-ferrite system.

Silver

A white-coloured metallic element that is very ductile and malleable. Silver is one of the noble elements as it does not oxidize when heated in air. Silver was usually obtained by cupellation of lead ores, although it may also be extracted directly from silver sulphide deposits. Pure silver is often stated to be 1000 fine and alloys are based on this nomenclature. For example, sterling silver is 925 fine (contains more than 92.5 % by weight silver). The atomic number of silver is 47, and its atomic weight 107.87, with a melting point of 960ºC, and specific gravity 10.50.

Sinking

A forming technique in which a vessel is formed from a sheet by hammering from the inside (the concave side). The sheet metal is hammered into a shallow concave depression in the anvil. Also called blocking, dishing or hollowing.

Related term: <u>Blocking</u>, <u>Caulking</u>, <u>Dishing</u>, <u>Raising</u>

Sinter

To render a pressed powder solid by heating without melting.

Originally this term was applied to describe hard mineral encrustations found on rock, especially those around mineral springs (18th century). From the late 19th century used in a material science context to describe the process and products of high temperature solid state consolidation of powders and granular material.

Slack quenching
The term 'slack' indicates something done without due diligence, hence the term slack-quenching implies a structure that has not been fully quenched. That is, the structure is not fully martenistic and that this was due to the quench having been done into a less severely quenching medium such as oil, or molten lead, or the quench was deliberately interrupted or delayed.
However, the fact that an early piece of quenched steel does not show a fully tempered structure does not necessarily mean that it was deliberately 'slack' quenched, as the composition of many of these steels were such that it would be nearly impossible to quench the metal fast enough to avoid getting some nodular pearlite (troostite) or bainite. Modern steels contain significant quantities of manganese which moves the Continuous Cooling Curve to the right (to slower quench rates) compared with most ancient and historic steels. Without this manganese, or a very high carbon content, the steel would have to be cooled to from above the eutectoid temperature to room temperature in a fraction of a second to achieve a fully martensitic structure, which would have been very difficult if not impossible for many artefacts.
In some cases structures have been described as having been 'slack quenched', it is clear that the steel had not been fully transformed to austenite but had been cooled from a temperature in which both ferrite and austenite were still present.
Without knowing the full composition of a steel it is probably best not to use the term 'slack' quench with its implications of deliberate action.
Related terms: Manganese, Spiegeleisen, Troostite
Slag
A general term for a variety of non metallic, usually oxide waste products formed during smelting, refining, and the hot-working of metals. Although slags are often considered as a mere nuisance waste product, they are a vital component of the production and working of many metals. The formation of a molten slag at a suitable temperature makes possible the separation of the metal from it ore, and protects the metal being re-oxidised. Thus, the use of the term slag implies that the material has been molten or very nearly molten as result of metal production or refining, but the term is more widely used to cover any non-metallic semi-vitreous material produced during any pyrotechnic process.
Many early smelting slag were composed mainly of iron oxide and silica, so that the majority of the microstructure is in the form of the silicate mineral fayalite ($2FeO.SiO_2$), with the excess iron in the form of its oxides. The other minor elements present forming a glassy or pseudo-glassy component of the microstructure. This was true of both iron and copper smelting slags. However, in some regions and periods low melting point slags of non-fayalite-iron-oxide compositions are know to produced during both copper and iron smelting, probably due to the fortuitous local ore composition giving a low melting point.
Later in the history of smelting, when higher furnace temperatures were possible in the blast furnace, lime was added to the charge during iron smelting to replace the iron in the slag, increasing the efficiency of the furnace.
Slag can be classified on the basis of its physical morphology and chemical composition. A morphological study of the complete suite of debris from a site will often be sufficient to identify the type of metal-working being carried out on that site. However, care needs to be taken with such identification when there is only a very limited amount of slag recovered. Some very different metallurgical processes can produce slags of very similar appearance, for instance, some copper smelting tap slags can easily be mistaken for those from iron smelting. Sometimes the forging of iron will produce a number of different slag types, some of which could be easily mistaken for small flows of tap slag, produced during smelting.

Slag - Blast furnace

These are glassy or partially glassy massive tap slags. In the case of iron blast furnace slag they have much lower iron contents than bloomery slag. This was because the higher furnace temperatures possible in the blast furnace allowed the replacement of most of the iron in the slag by calcium from a lime flux.

Charcoal blast furnace slag tend to be of a dark olive-green colour, whereas, early coke-fired blast furnaces, in Britain, produced slag that was of an opaque blue-green, often showing banded and mottled colours. The slag from the later hot-fired blast furnaces tends to be a more uniform black glass although some areas of mottled opacity may occur.

Slag - Cinder

A term used to describe the type of slag that is angular and without obvious flow forms, but often takes the impression of the burnt-fuel around which it had formed.

Slag - Fuel Ash

A low density slag-like material - often of a light colour externally with a high silica content. Complete pieces may have rounded exteriors with no obvious points of contact with a surface on which it cooled. Although, the exact origin of much Fuel Ash slag is uncertain, they often contain, partially fused or sintered quartz grains and other rock or soil debris. It is likely that this material is the result of a high temperature process which results in the sintering and partial melting of the non-combustible fragments in the fuel, together with material from the surrounds of the fire. There are a number of processes that could generate this type of material:- metal-working (all forms), pottery making, burning of daub during a building fire, glass-working, salt-making, cremation, or simply the burning of a fuel with a very high silica content such as bracken. References

Related terms: Cinder, Clinker

Slag - Furnace bottom

A furnace bottom is the large block of slag left at the bottom of a furnaces at the end of a smelting run. Both slag-tapping and non-slag tapping furnaces can produce this type of slag. In the case of non-slag tapping furnaces, most of the slag produced during the smelting will be in this form. The block of slag would either have to be removed from the furnace before the furnace could be reused, as was probably the case for the smaller shaft furnaces see Peter Crew's experimental reconstructions of the prehistoric iron furnaces of North Wales, or the furnace was effectively used only once, as was probably the case with slag-pit furnaces. In the case of slag-tapping furnaces, the furnace bottom represents a much smaller proportion of the slag produced by the furnace with a high proportion being tapped out of the furnace. In this case, the furnace bottom only represents the last of the slag that had drained to the bottom of the furnace and solidified there because the build up of the bloom caused the temperature of the bottom of the furnace to fall below that where it was possible to tap the last of slag.

There is a great variation in the size of furnace bottoms from as low as a kilogram, or so, to hundreds of kilograms, depending on furnace design and operation. At the smaller end of the scale it can be difficult, if not impossible, to distinguish large smithing hearth bottoms from small furnace bottoms. It such cases, the relative proportions of other slag types is the best indicator of the type of activity taking place.

Slag - Refining

Slag produced as a result of a refining process. This term usually is applied to slag produced as the result of refining non-ferrous metals. Some copper refining slags have a very high iron oxide (magnetite) content, and thus can easily be mistaken for iron-working slags.

Slag - Smithing

Slag - Smithing Hearth bottom

Slag - Tap

Tap slag is slag that is tapped out of the furnace and allowed to cool and solidify as flows, or as more massive pooled lumps. The upper surface of tap slag usually has distinctive ropy flow patterns. Often large pieces of tap slag will consist of layers of smaller flows on top of each other. On sites from before the Industrial Revolution the presence of large amounts of tap slag is indicative of smelting activity. Care needs to be taken when identifying tap slag when only a small amount of slag is present or has been sampled, as small flows and drips produced by smithing activity can look similar to small broken up tap slag flows.

Related term: Tap Slag

Slag - Undiagnostic

Small-scale slag

Hammer-scale

Hammer-scale are usually small thin scales of metal oxide. These are formed by the shedding of the oxide layer formed at high temperatures on the surface of metals when they are heated. Iron hammer-scale is highly diagnostic of forging activity, as the surface scale may be shed several times during one cycle of hot forging. Hammer-scale made be formed during the working of copper or even base-silver alloys during annealing or homogenization treatments - most falls from the metal during quenching or pickling prior to the next cycle of forging.

Spherical Hammer Scale

These are drops of molten slag that have cooled and solidified whilst in the air. When hot enough the hammer scale layer will melt, and when struck by a hammer the molten liquid is ejected as a spray (the sparks flying away from the blacksmith's hammer during welding are these droplets).

They varying is size from a few tens of microns to several millimetres, they are often hollow. They may or may not be magnetic, depending on their iron content. The non-magnetic spheres are the result of the silica from the slag already present in the metal or any flux added during welding, reducing the iron content to below that required to allow magnetite to form.

Spherical Hammer Scale is indicative of high temperature forging as the temperature required to produce molten iron-oxide (or possibly molten iron-oxide-silicate) is much higher than that required to produce a solid layer of iron oxide. Thus a blacksmithing site, on which a high proportion of spherical hammer-scale to normal flat hammer scale is found, would suggest that the blacksmithing involved a lot of welding activity.

Slag spheres

Slag spheres are of normal slag (smelting or smithing) and are larger than most spherical hammer-scale, typically, 5mm to 15mm.

Related terms: Hammer scale, Scoria

Slag Hearth

Slag Hearth - Spanish

Slag inclusion

Slag Smelting - Lead smelting process

Slag stringer

Small pieces of slag (inclusions) that have become incorporated into the metal and are then strung out as small elongated ribbons as a result of working the metal to shape it.

Slip planes

Face centred cubic metals may show slip planes, a fine series of lines in two intersecting directions upon heavy deformation of the metal.

Slitting

Slush casting

A method of casting in which metal is often spun or agitated in the mould so that a thin shell is formed. The excess liquid is poured out before it freezes. More common in ancient and historic metalwork is slush wax work in which wax is slush cast over a piece mould interior before investment.

Smelting

Smelting is the process of extracting the metal from its ore. This involves a chemical reaction between the ore and the fuel, or between the heated ore and a reducing atmosphere. Most smelting processes are carried out above the melting point of the metal concerned. So that both the metal and waste products (slag) are liquid and can be separated using gravity. The main exception being iron smelting, before the introduction of the blast furnace process, where the iron remained solid or at least in a pasty state, but the waste products formed a molten slag.

Smith - black

Smith - white

Smithing

Soak

A prolonged heat treatment.

Solder

Is a term to describe alloys that can be used to join two pieces of metal. These alloys have lower melting points than the metal, or metals, they are joining, and wet them. Typical solders are classified as soft or hard solders depending on their melting points.

Soft solders

A term applied to lead-tin alloys used in soldering. The upper limit of the melting range is about 300ºC, and many alloys melt at about 130-180ºC. Lead-tin solders are now being replaced by other low melting point alloys due to the toxicity of lead.

Hard solders

Solid Solution

A single solid crystalline phase containing two or more chemical species in concentrations that may vary between limits imposed by phase equilibrium.

Solidus

The line in the phase diagram that describes the temperature at which an alloy of given composition is completely solid. This line forms a boundary on the phase diagram between those regions which are completely solid and those where there is a mixture of solid and liquid. At specific temperatures and compositions, the liquidus and solidus lines may meet (the eutectic and peritectic points, and at the melting point of a pure phase).

Sorbite

This term refers to a spheriodized granular cementite structure produced as the result of an annealing or tempering process.

Sow

Speculum

Spiegel(eisen)

Speiss

Spelter

?Spheroidal Graphite

Spheroidal pearlite

A metallographic structure in which the action of prolonged temperature (below the critical temperature) has degraded the usual lamellar form of pearlite to the extent that cementite forms globular particles within a ferrite matrix.

Spheroidised - structure

Spheroidizing - heat treatment

Spiegeleisen

Spinning

Sprue

Stamp - Ore

Stamping

Stamping mill

Stamping & Potting

The term cover a number of methods used to refine cast iron using coal or coke as a fuel, before the development of puddling. In these methods, involved decarburising the cast iron to some extent in a coal-fired finery. The resulting metal was then broken up or granulated. The broken metal was then melted in crucibles together with a basic flux to absorb the sulphur introduced by the use of coal. Such a method was described in a patent granted to John Wood in 1761, in which the broken metal from the finery was melted in crucibles together with a flux made from kelp* and other alkali fluxes using a reverberatory furnace.

*Kelp is a brown seaweed which has high content of alkali metals.

Related Terms: Refining (cast iron)

Stannite

Steadite

Stearite

A soft silicate which carves easily; also called soapstone.

Steel

Plain steels are alloys of iron and carbon in which the carbon content does not exceed about 2.1%. The carbon is present as cementite, usually as a component of pearlite. Low-carbon steels contain from 0.09% carbon to 0.2% and are soft - the same composition range as bloomery iron. Medium carbon steels contain 0.2-0.4% carbon and high carbon steels more than 0.4%. Modern alloy steels do not necessarily contain carbon in more than trace amounts, but are alloys of iron and some other elements.

Steel - Alloy

Steel - Bloomery

Steel directly produced in the bloomery furnace. By control of the furnace conditions - rate of blowing, ore-charcoal ratio, charcoal type, size of ore and charcoal particle size it is possible to produce a bloom with a considerable amount of steel (carbon content > 0.3 wt %).

Steel - Crucible

Steel that has been formed in a crucible. The problem with steel production is that pure metallic iron only melts at a temperature in excess of 1500°C. Therefore, unlike copper alloys it was not possible form steel by mixing in the liquid state until the discovery of refractories capable of withstanding these sorts of temperatures were discovered. Once that happened, there were a number of different ways in which this could be done using different ingredients but they basically fall into three classes

1. Melting a mixture of cast iron and low carbon in the crucible and heating the mixture until the charge completely mixed and melted.

2. Putting a charge of low carbon iron or steel in crucible with a supply of carbon rich material which would result in the carburisation of the metal and bringing the melting point down into the operating temperature range.
3. To simply melt a steel of suitable composition in a crucible.

Related terms: Wootz, Huntsman

Steel - Damascus
Steel - High carbon
Steel - Making
Steel - Manganese
Steel - Medium carbon
Steel - Mild
Steel - Ultra-high carbon
Steel - Watered-silk
Steel - Wootz

Sterling Silver

Stiffness

Stope; stoping

Strain

Strain hardening

A synonym for work hardening.

Strain lines

Same as slip planes. Often seen in FCC metals after heavy working due to slip of planes of atoms past each other.

Streak

Stream tin

Stream tin is another term for alluvial tin ore. These occur where tin eroded from its host rock has been concentrate at the base old river beds. These are often cover by considerable thicknesses of gravel and detritus. In order to get at this ore it was necessary to dig down through the bed with the aid of shafts not unlike well-shafts, or use hydraulic mining to remove the overburden. Evidence of both these types of mining are particularly well preserved on Dartmoor, Devon, UK.

Stress

A measure of the force applied to a metal. It is measured as a force (Newtons) per square metre (formerly tonnes per square inch).

Related term: Strain

Strickle board

Wooden board used to form the mould of a circular component; its edge is shaped to the profile of the object and rotated around it.

Striking

A method of making coins and medals. The impression is cut in negative in a very hard material and this die is then placed over the coin blank and given a single heavy blow thus compressing the metal of the blank into the recesses of the die. Before the introduction of steel, bronze coins could only have been struck using stone or bronze dies. Striking may cause stress-related features in the struck metal such as surface cracking or internal defects.

Stückofen

Swaging

T

TTT diagram
See Time Temperature Transformation diagram.
Tang
Tap slag
Slag that has been tapped out from the furnace. Usually has ropey flow form in the more viscous slags or forming close to the tapping hole, whereas slags of lower viscosity or solidifying in the collecting area may have a platey form. The ropey flows may have internal voids in which the slag flowed to feed flows further from the furnace and then drained - small-scale version of the lava tubes seen on Hawaii and Iceland.
Tap slags tend to have characteristic cooling internal morphology with chilled zone of very fine crystals on the lower surface, a zone of columnar dendritic growth, then a void or zone of equi-axed growth, then moving outwards the top surface columnar dendritic growth, and a thinner less severe chilled zone on the upper surface. The upper surface is also often marked with a layer of iron oxide similar to hammer scale as well as iron-oxide crystal growth.
A single piece of tap slag may be composed of several flows on top of each other, in which case these solidification patterns may be repeated.
Note: a single flow of slag with flattened or rounded section should not be classified as tap slag, as slag forming within the furnace can have this same morphology, and can be the result of smithing or non-slag tapping smelting. When it important to determine whether the slag is a slag on the basis of a few pieces it is necessary to make a polished section to determine the cooling history.
Related terms: Slag, furnace slag
Telluric Iron - native
Temper

Modern

In heat treatment, reheating hardened steel to some temperature below the A1 temperature for the purpose of decreasing hardness and/or increasing toughness.

Temper as quench

Temper as carbon content

Tennantite
Ternary
Pertaining to three. Usually refers to an alloy system with three elements or components.
Ternary Phase Diagram
Terrestrial Iron
Tetrahedrite
Time Temperature Transformation diagrams
Tin
Element with atomic number 50, symbol Sn, atomic weight 118.71, mp 231.8ºC, specific gravity (grey) 5.75, (white) 7.31. A soft white lustrous metal obtained mainly from the mineral cassiterite, SnO_2, but stannite (Cu_2SnFeS_4) occasionally occurs in ore grade concentrations. Tin is not affected on exposure to air at ordinary temperatures. At temperatures above 13.2ºC the white tetragonal allotropic form is stable and below this the grey cubic form may exist. Above 170ºC, tin is rhombic in crystal structure. The metal has low tensile strength and hardness but good ductility. Mechanical deformation of white tin makes a distinct sound - tin cry - due to the formation of deformation twins.
Tin stamping
Tinning

The application of a thin surface layer of tin for decoration (copper alloys), or corrosion protection (iron alloys)
Tin Plating
Toughness
The ability to withstand sudden impacts (One of the crucial measurements of a material's mechanical properties).
Related terms: Ductility
Trade bar
Tracer / Tracing
Troilite
Trompe
Troostite
In steels this nodular rapidly etching component was originally thought to be a separate phase. However, the introduction of the electron microscope proved that the material was finely divided radiating pearlite, which not resolvable in the optical microscope.
It is often found as characteristic nodules at the grain boundaries in slack quenched steels.
Troy weight
Trunnions
Tundish
Tumbaga
Tutenag
Tutty
Tuyère
Tuyère - Blocks
Tuyère - Eisenstein
Twins
Twins - annealing
Twins - deformation
Tymp

U
UTS
Ultimate tensile strength

V
VPN
See Vickers Pyramid Number
Valency
Vickers Pyramid Number
Related terms: Brinell, Hardness, Rockwell
Vacancy
Vickers Hardness Number
See Vickers Pyramid Number
Void

W
Walloon Process

Washing
Watered Steel
Watered Silk Steel
Weld
Joining two or more pieces of material by applying heat or pressure, or both, with or without filler metal, to provide a localized union through fusion or recrystallization across the interface. If a filler is used it is of similar metal type as the pieces to be joined with a similar melting point, unlike a solder joint.
Welding, Fire
Welding, Hammer
Welsh Process
The ‘Welsh Process’ is a copper smelting process in which the double decomposition of the matte provided some of the energy requirements of the process, and hence reduced fuel costs. Although this process replaced the industrial dead-roasting of matte, given the high sulphide inclusion density in ancient copper ingots it is likely that the double decomposition was used in antiquity. Related terms: Matte, black metal, blister copper
Whetstone
A stone used for sharpening metal edge-tools.
White Cast iron
Cast iron in which the carbon is present as cementite rather than flakes of graphite. The high cementite content of the metal makes the metal extremely hard and brittle with a white fracture (hence the name). Rapid cooling of molten cast iron tends to favour the formation of white cast iron against that of grey.
White Heat
White Metal
Cu_2S
White Smith
Widmanstätten Structure
A structure formed by the solid state decomposition of one phase into one or more other phases with the new phase developing along specific crystallographic planes of the original phase. The structure occurs in steels which have been cooled from high temperatures (~1000ºC) at a moderate rate. Ejection of ferrite, or cementite depending whether the steel is of hypo- or hyper-eutectic composition, takes place along certain crystallographic planes forming a mesh-like arrangement. Most commonly found as an incidental feature of low-carbon steels. The same type of structure occurs in the octahedrite meteorites which show a typical example of this structure, though on a much coarser scale than occurs with steels. Note: many archaeometallurgical texts incorrectly state that ferritic martensites form in rapidly cooled low carbon steels - as it is a diffusion controlled process this is incorrect. A rapid cooling would suppress the formation of ferrite before the eutectoid temperature is achieved, hence giving rise to a uniform pearlitic steel but with non-eutectoid ferrite-cementite distribution.
Wind-blown furnace
Wipe tinning
Wootz
Hyper-eutectoid crucible steel produced in India and elsewhere in South and Central Asia and Persia. Some Wootz steels, with suitable heating and forging, were capable of producing the much prized characteristic watered steel patterns. Although often called Damascus steel, there is no evidence that the metal was produced that far west, although articles made from this metal were decorated with gold designs and marketed there.

Work Hardening
Metals, when hammered at low temperatures, become hardened and stronger. If the temperature of working is increased, a point is reached at which hardening no longer occurs, i.e. the hot-working temperature is reached. The dividing line between hot and cold working for lead is about room temperature; for pure iron it is about 600ºC.
Workability
Wrought
Simply meaning forged - shaped by hammering, or more recently, by pressing or stamping.
Wrought Iron
A problematic term. Before the introduction of cast steel and iron, all iron alloys had to be forged into shape, therefore the use of the term is tautological when applied to the products of the direct or bloomery process. The term only came into use with the development of the finery and the related succeeding methods of refining cast iron, therefore, it would be best if the use of term was confined to post-medieval refined cast iron.
Characteristics - puddled wrought iron - high slag content, low carbon content, fibrous nature due to rolling
Wüstite
Wüstite is the iron oxide with a composition close to a stoichiometric composition FeO (but is generally deficient in iron $Fe_{1-x}O$ rather than FeO). The presence of wüstite is indicative of moderately reducing conditions. It is often present in iron slag in dendritic or globular forms. The dendrite arms of wüstite tend to be rounded, whereas, those of magnetite dendrites are more facetted. Intergrowths and overgrowths of magnetite on wüstite, or the other way round are indicative of a change in the furnace/hearth conditions during slag form.

X

Y
Yield Point
Yield stress
The stress at which the metal first deforms by plastic deformation rather stretching elastically. Below the yield stress the metal will return to its original shape once the load is removed. If a load is applied such that the metal is subjected to a stress greater than the yield stress, the dislocations in the metal move irreversibly resulting in a permanent change in shape.
Young's Modulus
The measure of the extent to which a metal will elastically deform when loaded.

Z
Zinc
Element of atomic number 30, symbol Zn, atomic weight 65.37, mp 419.58ºC, specific gravity 7.13. Zinc ores were used for making brass by cementation long before the metal was used in its pure form. The limit of zinc that can enter into solid solution in copper by this process is 28%. The Romans made extensive use of brass and, in India, zinc was being made by distillation in retorts during the 13th century A.D. The metal was not known in Europe until rediscovered in 1746. Zinc is a bluish-white, lustrous metal, brittle at ordinary temperatures but malleable at 100-150ºC.
Zinc Smelting