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IRON & STEEL

There is nothing more fundamental to the man-made physical world than the materials of which its elements are composed, and, likewise, nothing more basic to the smaller world of industrial archeology than the ferrous metals. Other than the static structures of masonry and timber, more industrial-archeological remains are formed of cast iron, wrought, or steel than of any other single material. Looked at another way, the ferrous metals constitute the greatest bulk of that part of our industrial heritage composed of "man-made" or "man-manipulated" material, even including concrete in that category.

Even the 'pure' masonry, timber, or concrete structures almost invariably incorporate ferrous elements in the form of fastenings, hardware, reinforcement, or sheathing. Despite their ubiquitousness, and the broad importance of the ferrous metals to industrial archeology, there exists within the IA community considerable misundertstanding of the nature of the various members of the ferrous family: their physical characteristics and the means by which they are produced (itself an important aspect of industrial archeology).

It must have been his awareness of this same void--although obviously with a more down-to-earth audience in mind--that led George Schuhmann nearly eighty years ago to set down in plain, non-metallurgical language descriptions of the most commercially important of the irons and steels as they related to the operations of a large corporation that dealt extensively with coal, metal, railroads, and the world of heavy industry in general. The fact that Schuhmann's little essay--which is reproduced below--appeared in the Philadelphia & Reading Railway's YMCA organ indicates that it was aimed squarely at the firm's working population, clearly intended to advance its understanding of its work, for the certain benefit of both capital and labor.

Regardless of the author's motive, his account sets forth with such clarity, in such straight-forward terms the essentials of this critical subject, that it was seen to provide ready-made answers to those iron and steel questions that have for so long been so plaguing to so many.

Somewhat more detail, with a historical perspective, will be found in the following:

1) W. K. V. Gale, IRON AND STEEL. Museum Booklet No. 20.04. Ironbridge Gorge Museum (Ironbridge, Telford, Shropshire TF8 7AW, England), 1979. 32 pages, illustrated.
2) _____________, IRONWORKING. Shire Album 64. Shire Publications (Cromwell House, Church St., Princes Risborough, Aylesbury, Bucks HP17 9AK, England), 1981. 32 pages.
3) W. David Lewis, IRON AND STEEL IN AMERICA. The Hagley Museum (Box 3630, Wilmington, DE 19807), 1976. 64 pages, illustrated.

Of additional interest may be:

4) THE MAKING, SHAPING, AND TREATING OF STEEL. This valuable work has been published since 1920 by the United States Steel Co. It treats in full technical detail all the aspects of steel making, including many of the basic bulk finished products such as rails and rolled shapes. The evolution of the elemental processes are covered in an introductory, essentially historical chapter. Chapter bibliographies enhance the usefulness of this outstanding publication. The latest edition (the 10th, 1971) is out of print but should be available in the larger libraries. A new edition is due in early 1985, available from: the Association of Iron & Steel Engineers, 3 Gateway Center, Pittsburgh, PA 15222.
5) The American Iron & Steel Institute (1000 16th St. NW, Washington, DC 20036) has an extensive publications list. Most deal with current technology and affairs but a number touch on historical matters. Request: PUBLICATIONS, FILMS, AND FILMSTRIPS.

IRON AND STEEL*

By GEORGE SCHUHMANN

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COMMERCIAL Iron and Steel are metallic mixtures, the chief ingredient of which is the element "Iron," that is, pure iron, of which they contain from 93% to over 99%. The difference between iron and steel is principally due to the composition and proportion of the remaining ingredients.

Iron Ore is an oxide of iron (iron rust) containing from 35% to 65% of iron; the balance is oxygen, phosphorus, sulphur, silica (sand), and other impurities. The ore is charged in a blast furnace, mixed with limestone as a flux, and melted down with either charcoal, coke, or anthracite coal as fuel; the resulting metal is what is commercially known as **Pig Iron,** containing about 93% of pure iron, 3 to 5% of carbon (pure coal), some silicon, phosphorus, sulphur, etc. When only charcoal has been used as fuel, the product is known as **charcoal pig iron.** Pig iron is used in foundries for the manufacture of **iron castings,** by simply remelting it in a cupola without materially changing its chemical composition; the only result is a closer grain and somewhat increased strength. Charcoal pig iron has the peculiarity of producing a hard, chilled surface when cast into a metal mold and is therefore largely used in the manufacture of car wheels, chilled rolls, etc.

In the manufacture of **wrought iron** the pig iron is remelted in so-called puddling furnaces, by charging about ½ ton in a furnace, and, while in a molten state, it is stirred up with large iron hooks by the puddler and his helper, kept boiling, so as to expose every part of the iron bath to the action of the flame in order to burn out the carbon. The other impurities will separate from the iron, forming the puddle cinder.

The purer the iron the higher is its melting point. Pig iron melts at about 2100 degrees F., steel at about 2500 degrees, and wrought iron at about 2800 degrees. The temperature in the puddling furnace is high enough to melt pig iron, but not high enough to keep wrought iron in a liquid state; therefore, as soon as the small particles of iron become purified, they partly congeal (come to nature), forming a spongy mass in which small globules of iron are in a semi-plastic state, feebly cohering, with fluid cinder filling the cavities between them. This sponge is divided by the puddler into lumps of about 200 lbs. each; these lumps or balls are taken to a steam hammer or squeezer, where they are hammered or squeezed into elongated blocks (blooms), and, while still hot, rolled out between the puddle rolls into bars 3 to 6 inches wide, about ¾-inch thick, 15 to 30 ft. long. These bars are called puddle bars or muck bars, and, owing to the large amount of cinder still contained therein, they have rather rough surfaces. The muck bars are cut up into pieces from 2 to 4 ft. long and piled on top of each other in so-called "piles," varying from 100 to 2000 lbs. according to the size product desired. These piles are heated in heating furnaces, and when white hot are taken to the rolls to be welded together and rolled out into merchant iron in the shape of either sheets, plates, bars, or structural shapes as desired. When cold this material is sheared and straightened, and is then ready for the market.

Charcoal wrought iron, commonly called **charcoal iron,** is made by remelting charcoal pig iron in a finery or run-out fire, in which the molten metal is exposed to a strong blast, which partly refines the metal by burning out some of the carbon, silicon, etc. The metal is then allowed to run out on the floor, forming a plate about two inches thick, which, after solidifying, is broken up into smaller pieces, and these pieces are then charged into so-called knobbling fires or sinking fires, using charcoal as fuel, where the metal is slowly melted again, the forgeman keeping the mass of charcoal and iron stirred up so as to bring every portion in contact with a strong blast blown in through tuyeres on the sides. This completes the purification of the iron, which forms a lump similar to the sponge in the puddling furnace. This lump of about 200 pounds is then taken out of the fire and forged under a steam hammer into elongated blocks commonly known as **charcoal blooms.** A plant of knobbling fires with their accessories is known as a **charcoal bloomery.** The blooms are afterwards rolled into bars (charcoal bars) similar to muck bars, and then cut up and piled for further rerolling into the shape of sheets, plates, bars, etc.

The process above described is still extensively used in Sweden, from which country large quantities of blooms are imported, but in this country very few, if any, run-out fires are in use at the present time. The common practice here is to melt down (sink) wrought iron or soft steel scrap direct in knobbling fires, using charcoal as fuel. The resulting metal, while much purer and softer than ordinary puddled iron, is usually not as pure and ductile as the Swedish iron, but it is claimed that, owing to its higher cinder contents, it will resist corrosion better than the Swedish iron.

In the manufacture of certain grades of boiler tubes, it is customary to use domestic charcoal iron in the center of the pile and Swedish iron for covers, that is, on the outside. This increases the ductility of the iron and yet maintains a greater resistance against pitting.

After leaving the puddle furnace, or knobbling fire, wrought iron does not undergo any material change in its chemical composition, and the only physical change is an expulsion of a large portion of the cinder; the small cinder-coated globules of iron are welded together, and the subsequent rolling back and forth will elongate these globules, giving the iron a fibrous structure.

Double Refined Iron is made by cutting up the finished bars, repiling the pieces on top of each other, then reheating these piles to a welding heat and rolling them out again, which drives the fibres closer together, thus increasing the strength and ductility of the metal.

The word **Steel,** nowadays, covers a multitude of mixtures which are very different from each other in their chemical as well as physical qualities. The ingredient that exerts most influence on these variations is carbon. High grade razor steel contains about 1¼ per cent. of carbon, springs 1 per cent., steel rails from ½ to ¾ per cent., and soft steel boiler plate may go as low as 1-16 per cent. of carbon. Steel which is very low in carbon can easily be welded, but it cannot be tempered; when carbon is above 1-3 per cent. welding is more difficult and can only be done by the use of borax or some other flux or by electric or thermit welding. Steel with carbon above ¾ per cent. can be tempered, that is, when heated to red heat and then quenched in water or other liquid, it becomes very hard and can be used for tools of various kinds, such as saws, files, drills, chisels, cutlery, etc. In tool steel other ingredients are sometimes used to influence its hardness, such as nickel, manganese, chrome, tungsten, etc., the last named playing an important part in so-called "high speed steels," that is, steel tools that will cut metal at a high speed without losing their temper or hardness.

As stated above, pig iron and cast iron contain about 4 per

* Reprinted from The Pilot, official publication of the P. & R. Ry. Dept. Y. M. C. A., Reading, Pa., April, 1906. The chapter referring to charcoal iron has been added since.

cent. of carbon, and wrought iron only a trace of it, while steel is between these two extremes. The manufacture of steel, therefore, refers principally to getting the right proportion of carbon. One method is to take pig iron and burn the carbon out of it, as in the Bessemer and open hearth processes, and the other method is to take wrought iron and add carbon to it, as in the cementation and crucible processes.

In the **Bessemer Process** the molten pig iron is put into a large pear-shaped vessel called the "Converter," the bottom of which is double, the inner one being perforated with numerous holes called "tuyeres" to admit air to be forced in under pressure. The molten iron (from 10 to 15 tons at a time) is poured into the converter while the latter is lying on its side, then the compressed air is turned into the double bottom as the converter rises to a vertical position. The air has sufficient pressure (about 20 lbs. per sq. inch) to prevent the molten metal from entering the tuyeres. The air streams pass up through the molten metal (piercing it like as many needles), burning out the carbon, silicon, etc., accompanied by a brilliant display of sparks and a flame shooting out of the mouth of the converter. The 15 tons of molten pig iron contain nearly ¾ of a ton of carbon, and since this carbon is all burned out in less than ten minutes, this rapid rate of combustion increases the heat of the metal very much; it does not cool it, as one would suppose at first thought. The flame, therefore, at first red, becomes brighter and brighter until it is finally so white that it can scarcely be looked at with the naked eye. A "blow" generally lasts about nine to ten minutes, when the sudden dropping of the flame gives notice that the carbon is all burned out. The metal in the converter is then practically liquid wrought iron. The converter is then laid on its side again, the blast shut off and a certain amount of spiegeleisen or ferromanganese is added in a liquid form so as to give the steel the proper amount of carbon and manganese to make it suitable for the purpose desired. The liquid steel is then poured out into so-called "ingot moulds" and the resulting "ingots" while still hot, but no longer liquid, are rolled out into blooms, billets, or rails without any additional reheating except a short sojourn in so-called "soaking pits." In some steel works where the molten pig iron is taken in large ladle cars direct from the blast furnace to the converter, it is possible to produce rails without adding any fuel to that contained in the molten pig iron, so that the red-hot rail just finished still contains some of the heat given it by the coke in the blast furnace.

The **Open Hearth Process,** sometimes called "the Siemens-Martin process," is similar to the puddling process, but on a much larger scale. The furnaces generally have a capacity of from 40 to 50 tons of molten metal (in some exceptional cases as high as 200 tons); they are heated by gas made from bituminous coal (oil and natural gas have also been used). The gas and the air needed for its combustion are heated to a high temperature (over 1000 degrees) before entering the combustion chamber by passing them through so-called regenerative chambers. Owing to this preheating of the gas and the air, a very high temperature can be maintained in the furnace, so as to keep the iron liquid even after it has parted with its carbon. The stirring up of the molten metal is not done by hooks as in the puddling furnace, but by adding to the charge a certain proportion of ore, iron scale, or other oxides, the chemical reaction of which keeps the molten iron in a state of agitation. While in the Bessemer process only pig iron is used, in the open hearth furnace it is practicable to use also scrap of wrought iron or steel, as the high temperature in the furnace will readily melt same. When the pig iron or scrap contains too much phosphorus, burnt lime is added to the charge; the resulting slag will absorb the phosphorus, thus taking it out of the metal. This dephosphorization by means of burnt lime is called the **basic process** in contradistinction to the **acid process,** where no lime is used, but where care must be taken that the metal charged is low in phosphorus. In this country the basic process is at present used only in connection with open hearth furnaces, while in Europe it is also used in many Bessemer plants, producing the so-called "Basic Bessemer steel."

Crucible Steel or **Tool Steel,** formerly called **Cast Steel,** is made by using high grade, low phosphorus wrought iron and adding carbon to it. The oldest method is the so-called "cementation process," in which the iron bars are packed in air-tight retorts, with powdered charcoal between the bars. The filled retorts are put into a cementation furnace, where they are heated to a red heat and kept at that temperature for several days, during which time the iron will absorb about 1½ per cent. of its own weight of carbon. (The process is similar to the case-hardening process familiar to many blacksmiths.) The carbonized bars, called "blister steel," are then cut into small pieces, remelted in a crucible, and from there poured into moulds, forming small billets, which are afterwards hammered or rolled into the desired shapes. The newer method is to put the small pieces of wrought iron direct into an air-tight crucible, mixed with the proper amount of powdered charcoal, and melted down; the iron will absorb the carbon much quicker while in a molten state than when only red-hot as in the cementation furnace. The other ingredients, such as chrome, tungsten, etc., are also added in the crucible.

Malleable Castings are produced in the reverse way from the blister steel referred to above, that is, instead of taking wrought iron and adding carbon, castings made of cast iron are made malleable by extracting the carbon. The castings are packed into retorts similar to the cementation retorts, but, instead of charcoal, an oxide of iron, generally in the shape of hematite ore, is packed with them, and kept in a red-hot state for several days. The oxygen of the ore will absorb the carbon in the iron, giving the latter a somewhat steely nature.

Steel Castings used to be produced in the same manner, but now steel castings are cast direct from the ladle containing molten steel, which is generally melted in an open hearth furnace, although small Bessemer converters are also sometimes used for this purpose.

While chemically there is not much difference between wrought iron and low carbon steel, there is considerable difference in their physical structures. Owing to the globules of pure iron being coated with cinder in the puddling furnace, the subsequent rolling and reworking, while expelling a large portion of this cinder, always leaves traces of it behind, which gives wrought iron the fibre. Steel having been produced in a liquid form, where the cinder all floated to the top and was removed, the metal is homogeneous, that is, without any grain or fibre. When subjected to many vibrations, or strains due to frequent expansion and contraction, wrought iron will generally yield gradually and give warning to the inspector, while steel is more liable to snap off suddenly. Wrought iron being composed of many fibres, the fibres can break one at a time without directly affecting their neighbors (like the strings in a rope), while a rupture once started in steel will extend more rapidly. Wrought iron will also resist corrosion and pitting longer than steel, no doubt due to higher resisting power of the enclosed cinder, which also causes the corrosive fluid to deflect endwise, thus weakening its action by diffusing it over a larger area and preventing deep pitting. Stay bolts and boiler tubes for locomotives have proven more satisfactory when made of charcoal iron than of steel. Thin sheets, tin plate, corrugated iron covering, wire fencing, pipes, oil well casings, etc., have also proven much more durable when made of wrought iron than when made of steel. On the other hand, in rails, tires, guns, armor plate, etc., steel has proven far superior to iron, owing to its greater strength and hardness, and where corrosion is of minor importance, owing to the rails, etc., generally being worn out long before corrosion has a chance to affect them seriously. When structural steel or iron is used for bridges, etc., it is necessary to protect the metal from serious corrosion by frequent and careful painting, and in the skeletons of high office buildings and other skyscrapers, when completely covered with concrete, etc., so as to thoroughly exclude air or moisture, steel as well as iron will last indefinitely.

Where material is buried in the ground, or exposed to the weather without the careful protection of paint, or where moisture has access to it by other channels, the interior of pipes, for instance, wrought iron will outlast steel by a good margin.

Fagoted Iron, Busheled Iron, and Knobbled Charcoal Iron.

1. Fagoted Iron.

This is produced by piling up pieces of wrought iron scrap, such as bolts, bars, structural material, etc., in a box-like shape, using either old boiler plate or new muck bar as sides and covers. These so-called "box-piles" are then put into a heating furnace, heated to a welding heat, and then either rolled into the shape of the product desired direct, or rolled first into billets and then reheated and rerolled into the finished product. When the scrap used is strictly wrought iron, the finished bars so made are of a good quality, showing a higher ductility than those made from ordinary muck bars, but, unfortunately, it is a difficult matter to get strictly wrought iron scrap without an admixture of steel scrap, and, while the mixed-in soft steel does not reduce the strength or ductility of the metal, it reduces its resistance against corrosion, and therefore it should never be used in the manufacture of material exposed to corrosive influences, such as corrugated iron sheets, pipes, etc.

2. Busheled Iron.

Busheled iron is made by taking miscellaneous junk-yard scrap (generally small pieces), sometimes mixed with iron and steel turnings, swarf, etc., and heating same to a welding heat in a furnace similar to a puddling furnace, then forming it into lumps similar to a puddle ball, running same through a squeezer to form an elongated round bloom, which is then rolled out into muck bars, which are afterwards cut up, piled on top of one another, heated to a welding heat, and then rolled out into the desired finished product. Owing to the irregular composition of the scrap, which is often mixed with high carbon and other alloy steels, the material so produced is very unreliable as to its physical qualities and should never be used where either strength or longevity is an object.

3. Knobbled Charcoal Iron.

As explained in the chapter on "Charcoal Iron," in the enclosed monograph "Iron and Steel," there are two grades of charcoal wrought iron. The first is made from charcoal pig iron, and the other from wrought iron or soft steel scrap. (Practically all the charcoal wrought iron made in this country is made by the last-named method.) While both steel and wrought iron are used in the latter process, the subsequent manipulation is entirely different from the fagoting or busheling processes described above, in which cases the different pieces of scrap retain their individuality in the pile and are stretched out in rolling, while in the knobbling fire the scrap is melted down drop by drop so that each drop as it sinks into the mass of cinder at the bottom of the fire is coated with cinder similar to the coating of cinder on the iron globules in the puddling furnace. In other words, the metal returns to its original state and forms an entirely different structure from the iron that has been produced by simply heating the scrap to a welding heat and then rolling it out. Because busheled iron is of such an unreliable quality and is the cheapest rolled iron that can be produced at the present time, its shortcomings have been used by the champions of steel as an argument against charcoal iron, by claiming that both processes are practically the same. Busheled wrought iron is a conglomerate of small pieces of iron and steel of different grades, while the iron produced in the knobbling fire is resolved into its original state, so as to cover each drop of iron with its coating of cinder. The lumps produced in the knobbling fire are forged under a steam hammer, then rolled into bars which are repiled, reheated, and rerolled, thus producing a metal of high ductility and uniformity, and at the same time retaining the rust-resisting cinder films, the same as wrought iron made from puddled pig iron.

READING IRON COMPANY.

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