STEEL:

A MANUAL FOR STEEL USERS.

I.

GENERAL DESCRIPTION OF STEEL AND OF MODES OF ITS MANUFACTURE.

STEEL may be grouped under four general heads, each receiving its name from the mode of its manufacture; the general properties of the different kinds are the same, modified to some extent by the differences in the operations of making them; these differences are so slight, however, that after having mentioned them the discussion of various qualities and properties in the following pages will be general, and the facts given will apply to all kinds of steel, exceptions being pointed out when they occur.

The first general division of steel is cemented or converted steel, known to the trade as blister-steel, German, shear, and double-shear steel.

This is probably the oldest of all known kinds of steel, as there is no record of the beginning of its manufacture. This steel is based upon the fact that when iron not saturated with carbon is packed in carbon, with all air excluded, and subjected to a high temperature,—any temperature above a low red heat,—carbon will be absorbed by the iron converting it into steel, the steel being harder or milder, containing more or less carbon, determined by the temperature and the time of contact.

Experience and careful experiment have shown that at a bright orange heat carbon will penetrate iron at the rate of about *one eighth of an inch in twenty-four hours.* This applies to complete saturation, above 100 carbon; liquid steel will absorb carbon with great rapidity, becoming saturated in a few minutes, if enough carbon be added to cause saturation.

MANUFACTURE OF BLISTER-STEEL.

Bars of wrought iron are packed in layers, each bar surrounded by charcoal, and the whole hermetically sealed in a fire-brick vessel luted on top with clay; heat is then applied until the whole is brought up to a bright orange color, and this heat is maintained as evenly as possible until the whole mass of iron is penetrated by carbon; usually bars about three quarters of an inch thick are used, and the heat is required to be maintained for three days, the carbon, entering from both sides, requiring, three days to travel three eighths of an inch to the centre of the bar. If the furnace be running hot, the conversion may be complete in two days, or less. The furnace is then cooled and the bars are removed; they are found to be covered with numerous blisters, giving the steel its name.

The bars of tough wrought iron are found to be converted into highly crystalline, brittle steel. When blister-steel is heated and rolled directly into finished bars, it is known commercially as

GERMAN STEEL.

When blister-steel is heated to a high heat, welded under a hammer, and then finished under a hammer either at the same heat or after a slight re-heating, it is known as

SHEAR-STEEL, OR SINGLE-SHEAR.

When single-shear steel is broken into shorter lengths, piled, heated to a welding heat and hammered, and then hammered to a finish either at that heat or after a slight re-heating, it is known as

DOUBLE-SHEAR STEEL.

Seebohm gives another definition of single-shear, and double-shear; probably both are correct, being different shop designations.

Until within the last century the above steels were the only kinds known in commerce. There was a little steel made in India by a melting process, known as Wootz. It amounted to nothing in the commerce of the world, and is mentioned because it is the oldest of known melting processes.

Although converted steel is so old, and so few years ago was the only available kind of steel in the world, nothing more need be said of it here, as it has been almost superseded by cast steel, superior in quality and cheaper in cost, except in crucible-steel.

Inquiring readers will find in Percy, and many other works, such full and detailed accounts of the manufacture of these steels that it would be a waste of space and time to reprint them here, as they are of no more commercial importance.

In the last century Daniel Huntsman, of England, a maker of clocks, found great difficulty in getting reliable, durable, and uniform springs to run his clocks. It occurred to him that he might produce a better and more uniform article by fusing blister-steel in a crucible. He tried the experiment, and after the usual troubles of a pioneer he succeeded, and produced the article he required. This founded and established the great *Crucible-cast-steel* industry, whose benefits to the arts are almost incalculable; and none of the great inventions of the latter half of this nineteenth century have produced anything equal in quality to the finer grades of crucible-steel.

CRUCIBLE-CAST STEEL

is the second of the four general kinds of steel mentioned in the beginning of this chapter.

Although Huntsman succeeded so well that he is clearly entitled to the credit of having invented the crucible process, he met with many difficulties, from porosity of his ingots mainly; this trouble was corrected largely by Heath by the use of black oxide of manganese. Heath attempted to keep his process secret, but it was stolen from him, and he spent the rest of a troubled life in trying to get some compensation from the pilferers of his process. An interesting and pathetic account of his troubles will be found in Percy.

Heath's invention was not complete, and it was finished by the elder Mushet, who introduced in addition to the oxide of manganese a small quantity of ferro-manganese, an alloy of iron and manganese; and it was now possible, with care and skill, to make a quality of steel which for uni-

formity, strength, and general utility has never been equalled.

Crucible-steel was produced then by charging into a crucible broken blister-steel, a small quantity of oxide of manganese, and of ferro-manganese, or Spiegel-eisen, covering the crucible with a cap, and melting the contents in a coke-furnace, a simple furnace where the crucible was placed on a stand of refractory material, surrounded by coke, and fired until melted thoroughly.

The first crucibles used, and those still used largely in Sheffield, were made of fire-clay; a better, larger, and more durable crucible, used in the United States exclusively, and in Europe to some extent, is made of plumbago, cemented by enough of fire-clay to make it strong and tough. As the demands for steel increased and varied it was found that the carbon could be varied by mixing wrought iron and blister-bar, and so a great variety of tempers was produced, from steel containing not more than 0.10% of carbon up to steel containing 1.50% to 2% of carbon, and even higher in special cases.

It was soon found that the amount of carbon in steel could be determined by examining the fractures of cold ingots; the fracture due to a certain quantity of carbon is so distinct and so unchanging for that quantity that, once known, it cannot be mistaken for any other. The ingot is so sensitive to the quantity of carbon present that differences of .05% may be observed, and in everyday practice the skilled inspector will select fifteen different tempers of ingots in steels ranging from about 50 carbon to 150 carbon, the mean difference in carbon from one temper to another being only .07%. And this is no guess-work;—no chemical color determination will approach it in accuracy, and such work can only be checked by careful analysis by combustion.

This is the steel-maker's greatest stronghold, as it is possible by this means for a careful, skilful man to furnish to a consumer, year after year, hundreds or thousands of tons of steel, not one piece of which shall vary in carbon more than .05% above or below the mean for that temper.

The word "temper" used here refers to the quantity of carbon contained in the steel, it is the steel-maker's word; the question, What temper is it? answered, No. 3, No. 6, or any other designation, means a fixed, definite quantity of carbon.

When a steel-user hardens a piece of steel, and then lets down the temper by gentle heating, and he is asked, What temper is it? he will answer straw, light brown, brown, pigeon-wing, light blue, or blue, as the case may be, and he means a fixed, definite degree of softening of the hardened steel.

It is an unfortunate multiple meaning of a very common word, yet the uses have become so fixed that it seems to be impossible to change them, although they sometimes cause serious confusion.

The quantity of carbon contained in steel, and indeed of all ingredients, as a rule, is designated in one hundredths of one per cent; thus ten (.10) carbon means ten one hundredths of one per cent; nineteen (.19) carbon means nineteen one hundredths of one per cent; one hundred and thirty-five (1.35) carbon means one hundred and thirty-five one hundredths of one per cent, and so on. So also for contents of silicon, sulphur, phosphorus, manganese and other usual ingredients.

This enumeration will be used in this work, and care

will be taken to use the word "temper" in such a way as not to cause confusion.

It has been stated that crucible-cast steel is made from ten carbon up to two hundred carbon, and that its content of carbon can be determined by the eye, from fifty carbon upwards, by examining the fracture of the ingots. The limitation from fifty carbon upwards is not intended to mean that ingots containing less than fifty carbon have no distinctive structures due to the quantity of carbon; they have such distinctive structures, and the difficulty in observing them is merely physical.

Ingots containing fifty carbon are so tough that they can only be fractured by being nicked with a set deeply, and then broken off; below about fifty carbon the ingots are so tough that it is almost impossible to break open a large enough fracture to enable the inspector to determine accurately the quantity of carbon present; therefore it is usual in these milder steels, when accuracy is required, to resort to quick color analyses to determine the quantity of carbon present. Color analyses below fifty carbon may be fairly accurate, above fifty carbon they are worthless.

As the properties and reliability of crucible-steel became better known the demand increased, and the requirements varied and were met by skilful manufacturers, until, by the year 1860, ingots were produced weighing many tons by pouring the contents of many crucibles into one mould; in this way the more urgent demands were met, but the material was very expensive and the risks in manufacturing were great. About this time, stimulated by the desire of enlightened governments to increase their powers of destruction in war by the use of heavy guns of greater power than could be obtained by the use of cast iron, and for heavier ship-armor to be used in defence, Mr. Bessemer, of England, now Sir Henry Bessemer, reasoned that if melted cast iron was reduced to wrought iron by puddling, or boiling, by the mere oxidation, or burning out, of the excess of carbon and silicon from the cast iron, that the same cast iron might be reduced to steel in large masses by blowing air through a molten mass in a close vessel, retaining enough heat to keep the mass molten so that the resulting steel could be poured into ingots as large as might be desired. At about the same time, or a little earlier, Mr. Kelly, of the United States, devised and patented the same method. Both of these gentlemen demonstrated the potencies of their invention, and neither brought it to a successful issue.

To persistent and intelligent iron-masters of Sweden must be given the credit of bringing the process of Bessemer to a commercial success, and so they gave to the world pneumatic or Bessemer steel, the latter name holding, properly, as a just tribute to the inventor, and this inaugurated the third general division:

BESSEMER STEEL.

Bessemer steel is made by pouring into a bottle-shaped vessel lined with refractory material a mass of molten cast iron, and then blowing air through the iron until the carbon and silicon are burned out. The gases and flame resulting escape from the mouth of the vessel.

The combustion of carbon and silicon produce a temperature sufficient to keep the mass thoroughly melted, so

that the steel may be poured into moulds making ingots of any desired size.

In the beginning, and for many years, the lining of the vessel was of silicious or acid material, and it was found that all of the phosphorus and sulphur contained in the cast iron remained in the resulting steel, so that it was necessary to have no more of these elements in the cast iron than was allowable in the steel. The higher limit for phosphorus was fixed at ten points (.10%), and that is the recognized limit the world over. When Bessemer pig is quoted, or sold and bought, it means always a cast iron containing not more than ten phosphorus.

In regard to sulphur, it was found that if too much were present the material would be red-short, so that it could not be worked conveniently in the rolls or under the hammer, and that when the amount of sulphur present was not enough to produce red-shortness it was not sufficient to hurt the steel.

As red-short material is costly and troublesome to the manufacturer, it was not found necessary to fix any limit for sulphur, because the makers could be depended upon to keep it within working limits.

Later investigations prove this to be a fallacy, as much as ten or even more sulphur has been found in broken rails and shafts, the steel having made workable by a percentage of manganese. (See the results of Andrews's investigation given in Chap. X.)

During the operation of blowing Bessemer steel the flame issuing from the vessel is indicative of the elimination of the elements, and it is found that while the combustion is partially simultaneous the silicon is all removed before the carbon, and the characteristic white flame towards the end of the blow is known as the carbon flame; when the carbon is burned out, this flame drops suddenly and the operator knows that the blow is completed. Any subsequent blowing would result in burning iron only. During the blow the steel is charged heavily with oxygen, and if this were left in the steel it would be rotten, red-short, and worthless. This oxygen is removed largely by the addition of a predetermined quantity of ferro-manganese, usually melted previously and then poured into the steel.

The manganese takes up the greater part of the oxygen, leaving the steel free from red shortness and easily worked.

The fact that the phosphorus of the iron remained in the steel notwithstanding the active combustion and high temperature led to the dictum that at high temperatures phosphorus could not be eliminated from iron. This conclusion was credited because in some of the so-called direct processes of making iron where the temperature was never high enough to melt steel all, or nearly all, of the phosphorus was removed from the iron.

For many years steel-makers the world over worked upon this basis, and devoted themselves to procuring for their work iron containing not more than ten (.10) phosphorus, now universally known and quoted as Bessemer iron.

Two young English chemists, Sidney Gilchrist Thomas and Percy C. Gilchrist, being careful thinkers, concluded that the question was one of chemistry and not one of temperature; accordingly they set to work to obtain a basic lining for the vessel and to produce a basic slag from the blow which should retain in it the phosphorus of the

iron. After the usual routine of experiment, and against the doubtings of the experienced, they succeeded, and produced a steel practically free from phosphorus. For the practical working of their process it was found better, or necessary, to use iron low in silicon and high in phosphorus, using the phosphorus as a fuel to produce the high temperature that is necessary instead of the silicon of the acid process. In the acid process it is found necessary to have high silicon—two per cent or more—to produce the temperature necessary to keep the steel liquid; in the Thomas-Gilchrist process phosphorus takes the place of silicon for this purpose.

In this way the basic Bessemer process was worked out and became prominent.

The basic Bessemer process is of great value to England and to the continent of Europe by enabling manufacturers to use their native ores, which are usually too high in phosphorus for the acid process, so that before this invention nearly all of the ores for making Bessemer steel were imported from Sweden, Spain, and Africa.

The basic process has found little development in the United States, because the great abundance of pure ore keeps the acid process the cheaper, except in one or two special localities. Where the basic process is profitable in the United States, it is worked successfully.

At about the time that Bessemer made his invention William Siemens, afterward Sir William, invented the well-known regenerative gas-furnace. A Frenchman named Martin utilized this furnace to melt steel in bulk in the hearth of the furnace, developing what was known for some years as Siemens-Martin steel, or open-hearth steel; the latter name has prevailed, and open-hearth steel is the fourth of the general kinds of steel mentioned in the beginning of this chapter.

At first open-hearth steel was made upon a specially prepared sand bottom, by first melting a bath of cast iron and then adding wrought iron to the bath until by the additions of wrought iron and the action of the flame the carbon and silicon of the cast iron were reduced until the whole became a mass of molten steel. Sometimes iron ore is used instead of wrought iron as the reducing agent; this is called the pig and ore process. Now in general practice wrought iron, steel scrap, and iron ore are used, sometimes alone and sometimes together, as economy or special requirements make it convenient.

It was found as in the Bessemer, so in the open-hearth, the sulphur and the phosphorus of the charge remained in the steel, making it necessary to see that in the charge there was no more of these elements than the steel would bear.

This is known now as the acid open-hearth process.

After the success of the basic Bessemer process was assured the same principle was tried in the open-hearth; a basic bottom of dolomite or of magnesite was substituted for the acid sand bottom, and care was taken to secure a basic slag in the bath.

Success was greater than in the Bessemer; phosphorus was eliminated and a better article in every way was made by this process, now used extensively over the whole civilized world.

This is the basic open-hearth process.

Neither the basic Bessemer process nor the basic open-hearth removed sulphur, so that this element must still be

kept low in the original charge, until some way shall be found for its sure and economical elimination.

The four general divisions, then, are:

Converted or Cemented Steel.

Crucible-cast Steel.

Bessemer { Acid / Basic } Cast Steel.

Open-hearth { Acid / Basic } Cast Steel.

Little or nothing more will be said of the first kind, as it has been so thoroughly superseded by the cast steels. After a statement of the most patent applications and uses of the different cast steels the discussions which follow will apply to all, because practically they are all governed by the same general laws.