II.

APPLICATIONS AND USES OF THE DIFFERENT KINDS OF STEEL.

WHERE exact uniformity of composition is not a necessity, and where welding is required, cemented or converted steel may be preferred to cast steel, because the converted bar retains the occluded layers of slag which give to wrought iron its peculiar welding properties, and for this reason blister- or shear-steel may be welded more easily and surely than cast steel. For tires, composite dies, and many compound articles this steel will do very well, and it may be worked with good results by almost any smith of ordinary skill; however, owing to the more uniform structure and the greater durability of the cast steels, they have, even for these purposes, almost entirely displaced the more easily worked, but less durable, cemented steels.

CRUCIBLE-CAST STEEL.

For all purposes crucible-steel has proved to be superior to all others; it is well known to all experienced and observing workers in steel that, given an equal composition, crucible is stronger and more reliable in every way than any of the other kinds of steel.

This may read like a mere dictum, and it might be asked properly, What are the proofs?

The proofs are wanting for two reasons: first, because

crucible-steel is so expensive that except for gun parts, armor, and such uses where expense could be ignored, crucible-steel never came into extensive use for structural purposes; second, that while thousands upon thousands of tests of the cheaper steels are recorded and available to engineers very few of such tests have been made on crucible-steel, simply because it has not been used for structural purposes.

On the other hand, intelligent makers of crucible-steel have for self-preservation made careful study of the relative properties of the different steels in order that they might know what to expect from the cheaper processes. In this way they have surrendered boiler-steel, spring-steel, machinery-steel, battering-tool steel, cheap die-steel, and many smaller applications; not because they could not produce a better article, but because the cheaper steels met the requirements of consumers satisfactorily, and therefore they could not be expected to pay a higher price for an article whose superiority was not a necessity in their requirements.

Still this stated superiority is proven best by the fact that many careful consumers who have special reasons for studying durability as against first cost adhere to the higher priced crucible-steel for such uses as, for instance, parts of mining- and quarrying-drills, high-speed spindles, in cotton-mills, and in expensive lathes and machines of that kind.

This sort of testimony should be more conclusive than that of interested steel-makers, because these men pay their own money for the higher priced material, and because men who are most careful of the quality of their produce and of their reputation are the most clear-headed and most sensible men of their class; they have the best business and the greatest success. Such men are not fools; they may be depended upon to try everything of promise with the greatest care, and to use only that thing which pays them best. In fact such men do use the cheaper steels freely wherever they can do so safely.

A good car-spring, carriage-spring, or wagon-spring is made from Bessemer or open-hearth steel, a spring that will wear out the car or carriage; it would be stupid then to buy more expensive steel for such purposes, for even if crucible-steel would wear out two cars or two wagons the owner never expects to take the springs out of an old wagon to put them under a new one.

On the other hand, the watch-spring maker or the clock-spring maker will find a great advantage in using the very best crucible-steel that can be made.

A sledge, a maul, or a hammer can be made of such excellent quality from properly selected Bessemer or open-hearth steel that it would be foolish for makers of such tools to continue to buy crucible-steel, even though they knew it to be superior, for lower first cost in such cases outweighs superiority that cannot be shown for a number of years.

Locomotive-boilers, crank-pins, slide-rods, connecting-rods, and springs can be made of such good quality of Bessemer or open-hearth steel that, like the "one-horse shay," the whole machine will wear out at the same time practically, and that a good long time; there would be no reason in this case for using crucible-steel for one or more of these parts, although twenty-five years ago it was by means of crucible-steel that engineers learned to use steel for these purposes.

A good cam for an ordinary machine, such as a shear or

punch, may be made of Bessemer or open-hearth steel where greater strength and endurance are required than can be had in cast iron; on the other hand, makers of cams for delicately adjusted high-speed machines where intricacy and accuracy are necessary will touch nothing but the very best crucible-steel of fine-tool quality for their work. It is of no use to suggest the greater cheapness of the other steels; they have tried them thoroughly, and they know that in their case the highest priced is the cheapest.

This superiority of crucible-steel has been doubted, because the claim appeared to rest solely upon the statements of steel-makers, and not to have any scientific basis; there is, however, a scientific basis for the fact. Given three samples of steel of say the following composition:

	Crucible.	Open-hearth.	Bessemer.
Carbon................	1.00	1.00	1.00
Silicon................	.10	.10	.10
Phosphorus	.05	.05	.05
Sulphur...............	.02	.02	.02
Copper, arsenic, etc.....	traces		

Why should there be any difference in the strength of the three? In mere tensile strength in an untempered bar the difference might not be very great, although all experienced persons would expect the crucible to show the highest; but it is not necessary to make the claim, because we have not enough tests of crucible-steel to enable us to establish a mean, and one or two tests are insufficient to establish a rule in any case.

There have been made, however, hundreds of tests of hardened and tempered samples by the most expert persons, with one invariable result: the crucible-steel is incomparably finer and stronger than the others, and the open-hearth is almost invariably stronger and finer than the Bessemer.

Unfortunately for the argument these tests cannot be recorded so as to be intelligible to the non-expert, because we cannot tabulate the result of the touch of the expert hand or the observation of the experienced eye.

For a time it was popular to call these differences mysteries, and so let them pass; this, however, was not satisfactory, and the question was studied carefully for the physical reasons which must exist.

Much thought led to the conclusion that the reason lay with the three elements oxygen, nitrogen, and hydrogen; they are known to exist in greater or less quantity in all iron and steel.

It is known that the presence of oxygen beyond certain small limits produces red-shortness and general weakness; it is probably a much more hurtful element than phosphorus or sulphur, but no quantitative method for its determination has been worked out; there is an effort now being made to develop a simple and expeditious oxygen determination, and it is to be hoped that it will be successful.

In the crucible no more oxygen, hydrogen, or nitrogen can get into the steel than is contained in the material charged and in the atmosphere of the crucible, or than may penetrate the walls of the crucible during melting. In the open hearth the process is an oxidizing one, and besides the charge is swept continuously by hot flames containing all of these elements.

In the Bessemer process the conditions are worse still,

as these elements are all blown through the whole mass of the steel.

We know the effect of oxygen and how to eliminate it practically.

Percy gives the effects of nitrogen as causing hardness and extreme brittleness, and giving to iron or steel a brassy lustre. Such a brassy lustre may be seen frequently in open-hearth or Bessemer steel, and occasionally in crucible-steel. When seen in crucible-steel it is known to be due to the fact that the cap of the crucible became displaced, exposing the contents to the direct action of the flame. Of the effect of hydrogen we know less; there is no reason apparent why it may not be as potent as the others.

Ammonia in sufficient quantity to be detected by the nose has often been observed in open-hearth and Bessemer steel.

To settle the nitrogen question Prof. John W. Langley developed some years ago a very delicate and accurate process for the determination of nitrogen even in minute quantities; the process was tedious and expensive, so that it was not adapted for daily use; it involved the careful elimination of nitrogen from all of the reagents to be used, requiring several days' work, in each case to prepare for only a few nitrogen determinations.

By this process it was found, in every one of many trials, that crucible-steel contained the least amount of nitrogen, open-hearth steel the next greater quantity, and Bessemer steel the greatest amount. He found no exceptions to this. For many years great efforts had been made both in Europe and in the United States to make by the Bessemer or the open-hearth process a cheap melting-product to be used in the crucible instead of the expensive irons which so far have proved to be necessary to give the best results.

There appeared to be no difficulty in making a material as pure chemically, or purer, than the most famous irons in the world, and this material was urged upon the crucible-steel makers. Careful tests of such material failed to produce the required article; in fact it was demonstrated over and over again that an inferior wrought iron would produce a stronger steel than this very pure steel melting-material, and crucible-steel makers were compelled to adhere to the more costly irons to produce their finer grades.

Prof. Langley determined the nitrogen in a given quantity of open-hearth and Bessemer steel; this same material was then melted in a crucible, and it was found that the resulting ingots contained nearly as much nitrogen as the original charge. The quantity was reduced slightly; still this steel contained more nitrogen than any other sample of crucible-steel that he had tested. The physical test of this trial steel showed the usual weakness of the Bessemer or open-hearth steel, as compared to crucible-steel.

The next step was to try to get rid of nitrogen by the use of some affinity, as oxygen is removed by manganese. Boron and titanium seemed to be the most feasible elements; boron appeared to offer less chance of success, and titanium was selected. A ferro-titanium containing six per cent of titanium was imported from Europe at some expense. As the most careful and exacting analyses of this material failed to reveal a trace of titanium, it was not used.

After many futile efforts Langley succeeded, by means of

electric heat, in reducing rutile and producing a small quantity of an alloy of iron and titanium. A trial of this alloy, although not conclusive, led to the belief that such an alloy could be used successfully to eliminate nitrogen; but as its cost, about two dollars a pound, was prohibitory of any commercial use, the subject was not pursued farther.

Although we know these elements only as gases, there is no reason to suppose that their atoms may not be as potent, when added to steel, as atoms of carbon, silicon, phosphorus, or any other substance.

Such are the facts for crucible-steel as far as they are known; it is vastly more expensive than any other kind of steel, yet for the present it holds its own unique and valuable place in the arts.

For all tools requiring a fine edge for cutting purposes, such as lathe-tools, drills, taps, reamers, milling cutters, axes, razors, pocket-knives, needles, graving-tools, etc.; for fine dies where sharp outline and great endurance are required; for fine springs and fine machinery parts and fine files and saws, and for a hundred similar uses, crucible-cast steel still stands pre-eminent, and must remain so until some genius shall remove from the cheaper steels the elements that unfit them for these purposes.

As stated before, crucible-steel is divided into fifteen or more different tempers, ranging in carbon from .50 to 1.50. Each of these tempers has its specific uses, and a few will be pointed out in a general way.

.50 to .60 carbon is best adapted for hot work and for battering-tools.

.60 to .70 carbon for hot work, battering-tools, and tools of dull edge.

.70 to .80 carbon for battering-tools, cold-sets, and some forms of reamers and taps.

.80 to .90 carbon for cold-sets, hand-chisels, drills, taps, reamers, and dies.

.90 to 1.00 carbon for chisels, drills, dies, axes, knives, and many similar purposes.

1.00 to 1.10 carbon for axes, hatchets, knives, large lathe-tools, and many kinds of dies and drills if care be used in tempering them.

1.10 to 1.50 carbon for lathe-tools, graving-tools, scribers, scrapers, little drills, and many similar purposes.

The best all-around tool-steel is found between .90 and 1.10 carbon; steel that can be adapted safely and successfully to more uses than any other temper.

At somewhere from .90 to 1.00 carbon, iron appears to be saturated with carbon, giving the highest efficiency in tools and the highest results in the testing-machine except for compressive strains. More will be said upon this point in treating of the carbon-line.

Much more could be said about the uses for the different tempers of steel; it would be easy to write out in great detail the exact carbon which experience has shown to be best adapted to any one of hundreds of different uses, but it would only be confusing and misleading to a great many people.

It is within the experience of every steel-maker that men are just as variable as steel, and the successful steel-maker must familiarize himself with the personal equations of his patrons. One man on the sunny side of a street may be making an excellent kind of tool from a certain grade and temper of steel, and be perfectly happy and prosperous in its use. His competitor on the shady side of the street

may fail in trying to use the same steel for the same purpose and condemn it utterly.

The know it all agent will condemn the latter man with an intimation that his ears are too long, and so lose his trade. The tactful agent will supply him with steel a temper higher or a temper lower, until he hits upon the right one, and so will retain both men on his list; and both men will turn out equally good products.

Few men know their own personal equations, and the best way for a steel-user to do is to tell the steel-maker what he wants to accomplish, and put upon him the responsibility of selecting the best temper.

It costs no more to make and to provide one temper than another; therefore the one inducement of the steel-maker is to give his patron that which is best adapted to his use. This plan puts all of the responsibility upon the steel-maker, just where it ought to be, because he should know more about the adaptability of his steel than any other person.

BESSEMER STEEL.

Bessemer steel is probably the cheapest of all grades of steel; that is to say, it can be made so rapidly, so continuously, and in such enormous quantities that a greater output per dollar invested can be made than by either of the other processes. Again, the work is controlled and operated by machinery to a much greater extent than in the other processes; therefore the cost of labor per ton of product both for skilled and unskilled labor is less than in the crucible or the open-hearth method.

This being the case, it might be inferred that the result would be the eventual driving out of all other steels by this, the cheapest. This would be the inevitable result if Bessemer steel were as well adapted to all purposes as either of the other kinds of steel; there are limitations which prevent this.

The source of heat in the Bessemer process is in the combustion of the elements of the charge, there is no extraneous source of heat; therefore, if the heat be too cold, there is no way to remedy it unless it be by the addition of ferro-silicon and more blowing; if it be too hot, it may be allowed to stand a few minutes to cool. Still in either case the remedy is somewhat doubtful. This limitation must not be taken as being fatal to good work, for in skilful hands such cases are rare, and the product is generally fully up to the standard of good work.

As there is no known sure way of stopping the blow at a given point in the operation to produce a steel of required carbon, it is usual to blow clear down, that is, to burn out all of the carbon practically and then to re-carbonize by the addition of spiegel-eisen or ferro-manganese. It is necessary, also, to add the manganese in one of these forms to remove the oxygen introduced during the blow; this must be done quickly, and all accomplished before the metal becomes too cold for pouring into ingots.

So little time for reactions is available that it is doubtful if the material is ever quite as homogeneous as it can be made by either of the other processes.

Notwithstanding these limitations, which are not mentioned to throw doubt upon the process, but merely to inform readers fully so as to enable them to judge rightly as to what may be expected, enormous quantities of good, reliable Bessemer steel are made to meet many requirements.

For good, serviceable, cheap rails Bessemer steel stands

pre-eminent, and if it found no other use it would be difficult to overestimate the benefit to the world of this one great success.

Bessemer steel is used largely for a great number of purposes, Bessemer billets being now as regular an article of commerce as pig iron.

For wire for all ordinary purposes; for skelp to be worked into butt-welded and lap-welded tubing; for wire nails, shafting, machinery-steel, tank-plates, and for many other uses, Bessemer steel has absorbed the markets almost entirely.

For common cutlery, files, shovels, picks, battering-tools, and many such uses it contests the market with open-hearth steel; and while many engineers now specify that their structural shapes, plates, beams, angles, etc., must be of open-hearth steel, there are many eminent engineers who see no need for this discrimination, they being satisfied that if their requirements are met the process by which they are met is a matter of indifference.

OPEN-HEARTH STEEL.

As in the Bessemer process, so in the open-hearth, carbon and silicon are burned out, phosphorus is removed on the basic hearth, and the sulphur of the charge remains in the steel. During the operation oxygen and nitrogen are absorbed by the steel, although not quite so largely as in the Bessemer process, so that practically the chemical limitations are the same in each.

The open-hearth reductions are much slower than in the Bessemer, each heat requiring from five to eight hours for its completion; the furnace must be operated by a skilled man of good judgment, so that more time and more skilled labor per ton of product are required than in the Bessemer, and the making of an equal quality as cheaply in the open-hearth is problematical. The open-hearth has extraneous sources of heat at the command and under the control of the operator, and there need be no cold heats, and no too hot heats.

The time for reactions is much longer, and for this reason they ought to be more complete, and they are so in good hands; yet it is a fact that, as the operation is a quiet one compared to the Bessemer, and not nearly so powerful and energetic, a careless or unskilful operator may produce in the open hearth an uneven result that is quite as bad as anything that can be brought out of a Bessemer converter. The process that eliminates the human factor has not yet been invented.

For fine boiler-plates, armor-plates, and gun parts open-hearth steel has won its place as completely as has the crucible for fine-tool steel or the Bessemer for rails.

For all intermediate products there is a continued race and keen competition, so that it is impossible to draw any hard and fast line between the products of the three processes where they approach each other; the only clear distinctions are at the other extremes.

Owing to the power to hold and manipulate a heat in the open-hearth it is safe to say that it is superior to the Bessemer in the manufacture of steel castings; and owing to its much greater cheapness it is difficult for the crucible to compete with it at all in this branch of manufacture.

In conclusion of this chapter it is safe to say that in good hands these processes are all good, and each has its own special function to perform.

III.

ALLOY STEELS AND THEIR USES.

In addition to the four general kinds of steel treated of in the last chapter there are a number of steels in the market which contain other metals, and which may be termed properly alloy steels, to distinguish them from carbon steel, or the regular steels of world-wide use which depend upon the quantity of carbon present for their properties. The most generally known of the alloy steels is the so-called Self-Hardening steel.

Self-hardening steel is so called because when it is heated to the right temperature,—about a medium orange color,—and is then allowed to cool in the air, it becomes very hard. This steel is so easily strained that it is impossible, as a rule, to quench it in water without cracking it. It may be quenched in a blast of air without cracking, and so be made much harder than if it be allowed to cool more slowly in a quiet atmosphere. If it be quenched in oil or water, it will become excessively hard, much harder than when quenched in air, and it will almost invariably be cracked, or if it be not cracked it will be so excessively brittle as to be of little use.

Self-hardened steel is so hard in what may be called its natural condition, that is, in ordinary bars, that it cannot be machined, drilled, planed, or turned in a lathe.

By keeping it in an annealing-furnace at about bright