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 orange heat for about twenty-four to thirty-six hours, and then covering it with hot sand or ashes in the furnace, and allowing about the same time for it to cool, it may be annealed pretty thoroughly so that it may be machined readily.

When annealed in this way and formed into cutters of irregular shape, or dies, it has been found so far not to be economical or well adapted to such work, so that up to the present time annealing is more of a scientific than a useful fact.

Self-hardened steel has the useful property of retaining its hardness when heated almost to redness; therefore it may be used as a lathe or similar cutter upon hard work, such as cutting cast iron and other metals, at a much higher speed than is possible with ordinary steel, which would be softened by the heat generated by the high speed. This property makes self-hardened steel very useful and economical for many purposes.

Self-hardened steel is an alloy of iron, carbon, tungsten, and manganese, and some brands contain chromium in addition to these, and it is claimed, and probably truly, that the chromium improves the quality of the steel.

It was supposed for a long time that tungsten was the hardener that gave to self-hardened steel its peculiar properties. By means of an open hearth, steel was produced containing about 3% tungsten and little carbon and manganese. This steel worked like any mild steel, except that it was hot-short and difficult to forge. It was not hard and had no hardening properties; that is, it did not harden in the ordinary sense when quenched in water. The addition of carbon to this steel, keeping the manganese low, produced a steel very difficult to work, which would harden

like ordinary steel when quenched, and which had no self-hardening properties whatever. The addition of 2½% to 3% of manganese to this steel produced self-hardening steel having the usual properties.

Manganese, then, is the metal that gives the self-hardening property, and this might have been anticipated by considering the properties of Hadfield's manganese steel, which, when it contains above 7% manganese, cannot be annealed so that it can be machined or drawn into wire. From this it might be inferred that tungsten is not a necessary constituent of self-hardened steel; that it performs an important function will be shown presently. Tests of the iron-tungsten alloy low in carbon gave only a small increase in strength above ordinary low cast steel containing little carbon; it was difficult and troublesome to work, and more expensive than the common steels, so that its production presented no advantages. When carbonized, it was fine-grained and could be made exceedingly hard; it was brittle, and compared to very ordinary cast steel comparatively worthless.

In self-hardened steel tungsten is the mordant that holds the carbon in solution and enables the steel to retain its hardness at comparatively high temperatures. That it does hold the carbon in solution may be proved in a moment by a beautiful test, first observed by Prof. John W. Langley.

When a piece of carbon steel is pressed against a rapidly running emery wheel, there is given off a shower of brilliant sparks which flash out in innumerable white, tiny stars of great beauty; it is accepted that this brilliancy is due to the explosive combustion of particles of carbon.

When a steel containing as much as three per cent of tungsten is pressed against the wheel, the entire absence of these brilliant flashes is at once noticeable, and if there be an occasional little flash it only serves to emphasize the absence of the myriads.

Instead there is an emission of a comparatively small number of dull particles, and there is clinging to the wheel closely a heavy band of a deep, rich red color. This red streak is distinctive of the presence of tungsten.

By testing various pieces it was soon observed that different quantities of tungsten gave different sizes of red streaks; as tungsten decreased the width of the band diminished and the number and brilliancy of carbon sparks increased. As little as .10 tungsten will show a fine red line amidst a brilliant display of sparks, and it soon became possible to determine so closely by the streak the quantity of tungsten present that the ordinary analyses for tungsten became unnecessary, except in occasional important cases where analysis was used merely to confirm the testimony of the wheel.

Self-hardening steel, then, is a steel which, owing to the presence of manganese and tungsten, hardens when quenched in quiet air, and which retains its hardness almost up to a red heat.

It may be forged between the temperatures from orange to bright orange; it cannot be worked safely outside of this range. The more quickly it is quenched the harder it will be; and it may be annealed so that it can be machined readily. Therefore it is not self-hardening; it simply has all of the properties of carbon steel modified profoundly by tungsten and manganese. If a piece of this steel will not harden sufficiently by cooling in the air quietly, that difficulty may be remedied by cooling it in an air-blast; if quenching in an air-blast will not give sufficient hardness, the steel had better be rejected, for quenching in oil or water means almost certain destruction.

As stated before, the range of temperature in which self-hardened steel can be forged safely is much smaller than for a high-carbon steel; it is harder at this heat than carbon steel and not so plastic, so that it requires more care and more heats in working it to tool-shapes.

This steel is so sensitive that it often occurs in redressing it that it will crumble at a heat that was all right in the first working. This difficulty may be remedied by first cutting off the shattered part with a sharp tool,—it must be cut hot,—then heating the piece up to nearly a lemon color, heating it through without soaking it in the fire, and then allowing it to cool slowly in a warm, dry place. After this treatment the steel may be heated and worked as at first. This treatment does not anneal the steel soft, because the heat is not continued long enough, and the cooling is not sufficiently slow; it does relieve the strains in the steel, so that it is plastic and malleable.

This treatment is good in any high steel which has become refractory from previous working.

Self-hardened steel is not as strong in the hardened condition as good high-carbon steel; it has not been used successfully for cutting chilled cast iron, for instance. If made hard enough to cut a chill, it is so brittle that the cutting-edge will crumble instead of cutting; if the temper be let down enough to stop the crumbling, the steel will be softer than the chill, and the edge will curl up instead of cutting.

Owing to the retention of hardness at a higher temperature than carbon steel will bear this steel is capable of doing a great amount of work at high speed, so that for much lathe-work it is cheap at almost any price.

Owing to its brittle, friable nature its use is limited to the simpler forms of tools, and to a narrower range of work than is possible with carbon steel.

CHROME STEEL.

An alloy of chromium with carbon steel has been before the public for many years, and greater claims have been made for it than experience seems to justify. Chrome teel is fine-grained and very hard in the hardened state, and it will do a large amount of work at the first dressing; upon redressing it deteriorates much more rapidly than carbon steel and becomes inferior; it is believed that this is due to a rapid oxidation of the chromium.

It is claimed for it that it will endure much higher heats without injury than carbon steels of the same temper. Intending purchasers will do well to satisfy themselves upon these points before investing too heavily.

SILICON STEEL.

Steel containing two to three per cent of silicon was put upon the markets, and great claims were made for it.

It is exceedingly fine-grained and hardens very hard; it is brittle, much more liable to crack in hardening than ordinary steel, and it is not nearly so strong as carbon steel.

It is made cheaply enough as far as melting goes, but it may not be melted dead, and therefore sound, because long-continued high heat will destroy it; therefore the ingots are more honeycombed than well-melted carbon-steel ingots. The steel will not bear what is known as a welding-heat in steel-working; it is hot-short; for this reason the bars are more seamy than is usual in carbon steel. Added to this the hot-shortness makes it so difficult to work that the labor cost is high. Altogether, then, silicon steel is expensive, and it presents no extra good qualities in compensation.

MANGANESE STEEL.

The glassy hardness, brittleness, and friability of ferro-manganese and of spiegel-eisen are well known; these are products of the blast-furnace, and the manganese ranges all the way from say 10% up to 80%.

Steel containing from 1% to 3% of manganese is about as brittle and almost as unworkable as spiegel-eisen, and a fair deduction would be that manganese above very small limits will not form any useful alloy with iron. Many a general law of nature has been based upon much more meagre data and has been announced with a great flourish of trumpets; such discoveries are usually heard of no more after the first blare has died away.

R. A. Hadfield, of Sheffield, England, is an inquirer who wants to know, and who is willing to travel the whole road in order to find out. Hadfield discovered that an alloy of iron and manganese containing from 7% to 20% of manganese was a compound possessing many remarkable properties. This alloy is now known as manganese steel.

Manganese steel is both hard and tough to a degree not found in any other metal or alloy.

It is so hard and strong that it cannot be machined with the best of tools made of the finest steel. Castings made of it may be battered into all sorts of shapes as completely as if they were made of the mildest dead-soft steel; still they are too hard to be machined.

The ordinary hardening process toughens this steel instead of hardening it to brittleness.

This steel is non-magnetic, and this property alone would give it exceedingly great value if the steel could only be worked into the required shapes.

Up to this time all attempts to anneal this steel have failed, and this persistent hardness is the best proof that manganese is the real hardener in self-hardened steel. So far carbon and manganese have not been separated in this steel or in any other. Persistent attempts have been made to produce manganese steel low in carbon, but all have been failures, because any operation that burned out the carbon took the manganese with it. The hope was that a non-magnetic alloy might be produced that would be soft enough to work. This may yet be accomplished, and if it should be another great step in the arts will have been taken.

Hard, tough, strong, non-magnetic—what great things may not come out of this when it has been worked out finally?

Since this was written carbonless manganese has been produced which is claimed to contain 98% + of manganese and no carbon, but at present it is sold at $1 per pound. If it can be produced more cheaply, it may lead to a workable non-magnetic alloy of iron and manganese which may prove to be of great value to electricians and to watchmakers.

The uses of manganese steel are large and growing, and it must be regarded as having an established and a prominent place.

It has been stated that in self-hardened steel and in manganese steel manganese is the hardener; it should be

borne in mind that carbon is always present, that it is the one great hardener, but its hardening property in the absence of manganese depends directly upon rapidity of cooling. By rapid cooling steel containing carbon is made harder than glass, and by slow cooling it may be made softer and more ductile than ordinary wrought iron.

Self-hardened steel may be annealed so that it can be machined, but it is by no means as soft and ductile as well-annealed carbon steel. Manganese steel has not been annealed at all; it cannot be annealed by any of the well-known annealing processes; some new way of doing it must be discovered. Therefore it is proper to say that the peculiar hardening properties of these two steels are due to manganese.

NICKEL STEEL.

The addition of a few per cent of nickel to mild steel adds greatly to its strength—so much so that nickel steel is now world-renowned as used in armor-plate for navy vessels, and for great guns. Recent reports from the ordnance bureaus indicate that it will also be of great use in the barrels of small arms, by means of which they may be made lighter, and still of sufficient strength. Nickel is so expensive and it adds so much to the cost of steel that its use for ordinary structural purposes, bridges, etc., has not been found to be economical.

Some years ago careful experiments were made with nickel alloy in a fine grade of high-carbon tool-steel to find out whether such steel would be improved as much as are the mild steels.

In such case the expense would not count, for if the best steel can be made better there are many users who would gladly pay a higher price for a better service.

The results were not encouraging. The high-carbon nickel steel was not as strong as the same quality of steel without nickel; the mixture seemed to be imperfect, containing little dark specks, supposed to be carbon thrown into the graphitic state. The steel did not refine as well and was not as strong as the carbon steel.

All of this applies to high-carbon tool-steel, hardened and tempered; no tests were made of the steel unhardened, for they would have been of no practical use.

ALUMINUM STEEL.

When a heat of steel is boiling violently, is wild, and unfit to be poured, the addition of a minute quantity of aluminum will have the effect of quieting it quickly. Half an ounce to an ounce of aluminum to a ton of steel will be enough usually, and for this purpose aluminum has become useful to steel-makers. If a little too much aluminum be added, the ingots will pipe from end to end; therefore the use of aluminum is restricted to small quantities. Experiments have shown that a considerable percentage of aluminum adds no good properties to steel; therefore aluminum steel so called may be treated later under a different heading.

IV.

CARBON.

Of all of the abundant elements of nature carbon is presented in the greatest variety of forms, and admits of the greatest number of useful applications.

In the form of the diamond it is the hardest of substances, and is the base used in determining the comparative hardness of all others.

In the form of graphite it is soft and smooth, and is one of the best and most durable of lubricants.

In the form of soot it is probably the softest of solids.

In the form of coal it is the one great and abundant fuel of the world, while as graphite again it is one of the best of refractory materials.

Hard, soft, highly combustible, almost infusible, refractory, it lends itself to the greatest variety of useful applications. To the iron- and steel-maker or worker it is simply indispensable; as charcoal or coke it is the fuel of the smelter; as gas, either carbon monoxide or as a hydrocarbon, it is the cheapest and most manageable fuel for melting and for all operations requiring heat.

As graphite, plumbago, mixed with a little fire-clay as a binder, it is the best material for crucibles in which to melt metals; as soot it forms the best coating for moulds into which metals are to be cast.

Durable beyond almost any other substance, it would