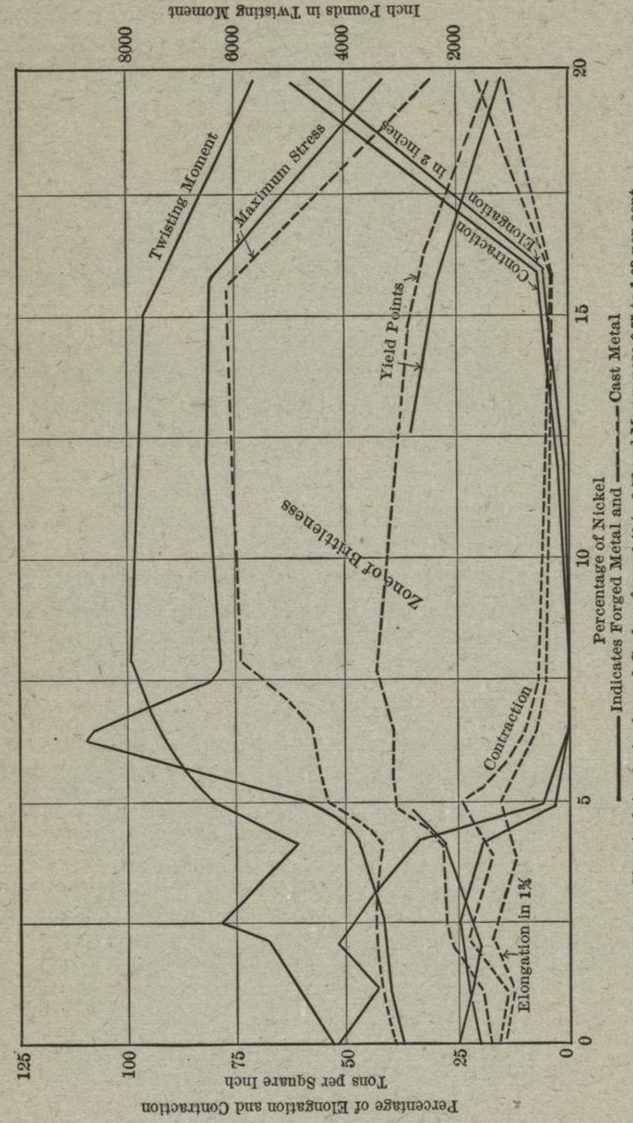
In the matter of cobalt-iron alloys, investigations up to a cobalt percentage of 60 have been made. The mechanical properties were but little modified in these, but the breaking strength and the elastic limit increase slowly, while the elongation and the reduction in cross-section are inversely modified. Notwithstanding its similarity to nickel the cobalt steels so far examined have no industrial interest and do not present any of the qualities of the nickel steels.



Note: Chemical Analysis showed Carbon from 0.40 to 0.52 and Manganese 0.75 to 1.08 per cent.

FIG. 49. — Strengths of nickel steel annealed at 1475° F.

In general, cobalt in steels enters into solution in the iron, and the carbon exists therein — at least in the range of the experiments made — in the shape of iron carbide. The mechanical properties of these steels do not seem to promise any industrial application; but they show very clearly the marked difference between tin, titanium, and silicon steels on the one hand, and nickel and cobalt steels on the other.

CHROMIUM

Chromium, tungsten, molybdenum, and uranium are in the same chemical group, and all show some resemblance to the elements in the sulphur group. Each forms a trioxide which is acid in character, and lower oxides which have little or no acid character.

Chromium forms three series of compounds. It occurs in nature principally in the mineral chromite, which is commonly called chrome iron ore, or chromic iron, with the composition $FeCr_2O_4$. It is a very hard metal and can be highly polished; has a bright metallic luster, and is difficult to fuse, its melting point being nearly that of pure iron. It burns brilliantly in oxygen, though it is not changed by exposure to the air at ordinary temperatures. In steel making it is used as a ferro-chromium, containing 60% chromium and 40% iron, which is made in an electric furnace from chrome iron ore.

Chromium gives to steel a mineral hardness, and refines the grain remarkably, owing to its tendency to prevent the development of the crystalline structure; but it gives no self-hardening properties, although it is the element used in combination with tungsten to produce the quality of "red-hardness" in high-speed steels.

Chromium added to steel in percentages up to 5 increases the tensile strength and elastic limit of hardened steel. In the annealed state the tensile strength is raised until 6.5% is reached and the elastic limit is raised up to 3%, and this does not lower to any great extent until 9% is reached. After these percentages are passed a decided reduction takes place. This is best shown in Fig. 50.

Extreme hardness may be obtained in chromium steels as the chromium intensifies the sensitiveness of the metal to quenching, and greatly reduces the liability of fracture that is found in carbon steels. This is due to the chromium making the critical changes of steel take place much more slowly. Chromium steel practically shows no grain or fiber and possesses a high power of resistance to shocks. This has made it almost universally used for armor plate.

When 2% of chromium is added to steel, it is very difficult to cut cold, and is quite brittle; with higher percentages than this it is impossible to finish it with machine tools except by grinding. When chromium is combined with nickel, it makes the strongest, toughest, and best wearing steel on the market, and it can be machined and forged more easily than when chromium alone is used. Small gears can be made with these alloying materials added to steel, that if properly heat-treated will be so tough and strong as to make it almost impossible to break out a tooth, even with a sledge hammer.

Some of the best grades of chrome-nickel or chrome-vanadium steel contain from 0.75 to 1.50% of chromium. If more than this is used the metal is too brittle and it is difficult to preserve the high strengths which are given by the lower percentages. The carbon content is also kept comparatively low, as a percentage of 0.45 of carbon makes the metal about as hard as can be cut with machine tools, even when thoroughly annealed. Many of these steels contain only 0.25% of carbon as the chromium gives the metal a hardness similar to that given by carbon, but one which makes the cohesion of the molecules greater. This makes the metal much more homogeneous, and gives it the ability to resist shock and torsional stresses. Thus, this alloy is one of the best steels for crankshafts of internal-combustion engines or other parts of machinery which have to withstand similar vibrational stresses.

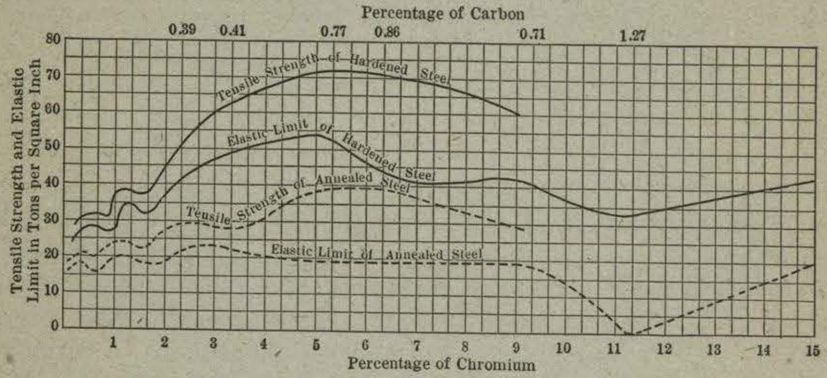


FIG. 50. — Effect of chromium on tensile strength and elastic limit.

The nickel-chrome steels are difficult to forge, as it is dangerous to hammer them after the temperature has dropped below that which makes the metal a bright yellow. It must be heated many times to forge pieces of any size or of intricate shapes. The chrome-vanadium steels, however, are no more difficult to forge or machine than the 0.40% carbon steels. Chrome steels for armor plate are made with the chromium content about 2%, while as high as 6% is used in some of the high-speed steels when the tungsten or molybdenum content is high.

TUNGSTEN

Tungsten forms a large variety of compounds, two of which are with oxygen, namely: the dioxide (WO_2) and the trioxide (WO_3). The trioxide forms salts with bases analogous to the molybdates. It occurs in nature as tungstates, the principal one of which is wolframite ($FeWO_4$), an iron salt that always contains some manganese. It is very hard, difficult to fuse, and forms lustrous steel-colored laminæ or a black powder.

The tungsten metal has recently been used quite extensively for incandescent lamp filaments but was extremely brittle and hence hard to work. This brittleness was considered an inherent property of the metal that could not be overcome. Recently, however (April, 1910), ductile tungsten has been produced at a cost that is not prohibitive. This promises to make a radical change, as when reduced several times in drawing it into fine wire, about .001 inch in diameter, a tensile strength of 610,000 pounds per square inch has been obtained. This is nearly double that of piano wire, the strongest metal known.

Tungsten as an ingredient of steel has been known and used for a long time, it having been used in the celebrated Damascus steel, but its actual effect was not known until Robert Mushet, after much experimenting, brought out the famous "Mushet steel." This caused some radical changes in treating crucible steels, and much progress and improvement has been made since that time.

The effect of tungsten on steel is to increase hardness, but it does this chiefly through its action on the carbon. In other words, it intensifies the hardening power of the carbon. If the percentage of tungsten is high with a proportionately high manganese content the steel will be very hard even when cooled in air, and thus is made possible "air-hardening" tool steel.

As the principal use of tungsten is in high-speed tool steel, and as a high percentage of manganese makes steel that is liable to fire-crack, to be brittle, to be weak in the body, and to be less easily forged and annealed, the manganese is now kept low and chromium is used in its place. The tungsten-chromium steels when hardened retain their hardness when heated to a dull red by the friction and pressure of chips in cutting. This has led to the term "red-hardness" as applied to this class of steel, and it is this property which has increased the cutting speeds of tools.

Tungsten when added to steel does not make it any more self-hardening than the carbon tool steels if the manganese and chromium are low, but every increase up to 19% increases the red-hardness if chromium is increased proportionately. Beyond 19% of tungsten, the red-hardness is decreased no matter what the percentage of chromium may be. The increase in red-hardness is about 50%, with an increase in tungsten from 6 to 19%, and that with manganese as low as 0.15%. With the chromium in the proper percentage tungsten will make steel self-hardening in all percentages over 0.85, but if the chromium is too high proportionately the steel is liable to become injured by overheating when the lower percentages of tungsten are used, but when the higher percentages of tungsten and chromium are used, the metal can be heated to just below the melting point and then quenched without injury. In fact, with the tungsten at 18% and the chromium 6% the best results for cutting tools are obtained when hardening at this high temperature.

The carbon content of these steels is kept low as compared with ordinary tool steels, or the air-hardening steels of a few years ago. The carbon content in the high-speed steels of to-day usually varies between 0.65 and 0.80%, whereas it was used in varying percentages up to 2.4 in the older air-hardening steels. This latter percentage was used in Mushet steel.

The quality of red-hardness given steel by the tungsten-chromium ingredients increased the cutting speed of tools about 45% over that of the older air-hardening steels, when cutting hard forgings or castings. Similarly an increase of about 90% was made when cutting softer metals. This has led to their almost universal use to the exclusion of Mushet steel, which but a few years ago filled 50% of the sales of tool steel.

Tungsten either in combination with manganese or chromium has greatly lessened the skill and knowledge required in heat-treating tool steel. To get the proper degree of red-hardness in the best grades of high-speed steel, they should be heated nearly to its melting point, which is about 2500° F. If this temperature were reached it would soften the steel so that the point of the tool would run. This would not harm the cutting qualities as it would not lessen the red-hardness given the metal by the tungsten and chromium. If a greater temperature were reached it would melt the steel, so it can easily be seen when the melting temperature is reached. On the other hand, if a temperature of 2300° F. is reached, the same red-hardness will be given the steel, so that there is a range of about 200° that will give the same results in heat-treating.

The carbon tool steels, however, have to be heated to a few degrees above the recalescent point and then quenched to obtain the greatest degree of hardness. After this they must be drawn to remove the brittleness caused by the high temperature. This requires a great deal of skill to judge the correct temperatures, as a variation of 25 degrees will make quite a difference in the temper and consequently in the cutting and wearing qualities.

MOLYBDENUM

Molybdenum, like tungsten, forms a large variety of compounds, among which are four oxygen compounds that include a mon-, bi-, and tri-oxide. It occurs, principally, in nature as molybdenite, which is the sulphide, MoS_2, and as wulfenite, the lead molybdate ($PbMoO_4$;) also less frequently as the trioxide (MoO_3).

Molybdenum is often used in high-speed steels in place of tungsten, as its action is very similar. Where 2% of tungsten is used, 1% of molybdenum will give the same results, that is, one molecule of molybdenum appears to have the same effect as one molecule of tungsten, its atomic weight being double that of tungsten. The cost of molybdenum is so much higher than that of tungsten that its use is prohibitive, unless much better results can be obtained, but a few high-speed steel makers consider this to be the case and are using it to replace the tungsten or else in combination with this element.

Many experiments have been made with molybdenum in place of tungsten, and molybdenum combined with tungsten, but these showed considerable irregularity as compared with the tungsten-chromium steels. The cause of these irregularities was not determined definitely, but the molybdenum tools seemed to run at their highest cutting speeds when heat-treated at a lower temperature than the tungsten steels. This would indicate that the heat-treating would require more skill in judging the temperature, as it is very difficult to judge a definite temperature by the color of the steel after it has passed a yellow.

Molybdenum also has a tendency to make the steel more brittle, and, therefore, weaker in the body, as well as giving it a tendency to fire-crack, which is a serious defect in tool steel.

URANIUM, which also belongs to this same chemical group, has stronger basic properties than either tungsten or molybdenum, and differs from chromium in that its trioxide forms salts with acids. Uranium occurs chiefly in nature, in the mineral pitchblende, or uraninite, which consists of the oxide (U_3O_8), and this is heated in the electric furnace with charcoal to isolate the metal. It has the color of nickel.

Owing to the fact that uranium resembles nickel and has many of the characteristics of the other members of the chemical group to which it belongs, many experiments have been carried out to see if it could not be made a beneficial ingredient of steel. None of these experiments, however, have shown that it was as good as the other materials used daily in the composition of steel, and its chemical actions, as described above, would not make it appear that anything could be expected of this element that could not be obtained with cheaper materials, while some detrimental effects might be obtained.

VANADIUM

Vanadium occurs in nature in the form of vanadates or salts of vanadic acid (H_3VO_4), which is analogous to phosphoric acid. When used in steel making its direct action is of minor importance, but it acts as a powerful physic, cleansing the steel from dissolved oxides. It gives the best results in the quaternary steels, such as vanadium-chromium-manganese-carbon, vanadium-nickel-manganese-carbon, and vanadium-tungsten-chromium-carbon. It has an affinity for oxygen and oxides out of the steel whenever it comes in contact with this element. Therefore it has the property of elusiveness to a marked degree, and has to be handled carefully by the steelmakers in order to keep it in the finished metal.

Vanadium aids the natural formation of the sorbitic structure, which makes the steel better able to withstand wear and gives it a greater resistance to fatigue. It retards the segregation of the carbides, which renders steel susceptible of great improvements by heat-treating. Vanadium produces a mechanical soundness and therefore toughens the steel by acting as a physic on the other ingredients and scavenging out the oxides and occluded gases; by so doing it increases the molecular cohesion. The percentage of oxygen in the steel, however, should be reduced to a minimum by other materials, before adding the vanadium, to take care of what cannot otherwise be removed, as it is too expensive a material to use as a deoxidizer.

While vanadium greatly increases the resistance to fatigue of open hearth steels and to a lesser degree of crucible steels, this may be accomplished by other methods. The higher the steel's percentage of oxygen, nitrogen, and occluded gases, the quicker will the grains or crystals start to slip past one another and eventually cause rupture when the metal is submitted to repeated strains, alternating stresses, and simple repeated or alternating impacts. These elements are being reduced to a minimum in steels made in electric furnaces and hence vanadium is practically useless there. By using careful methods they can so be reduced in the crucible process, but vanadium probably furnishes the cheapest way for open hearth steels. Vanadium removes nitrogen to some extent and also toughens the constituent called pearlite. When used in combination with chromium it reduces the mineral hardness given to steel by this element, so that it can be machined and forged as easily as an ordinary carbon steel.

Vanadium has made great strides in the past few years as an alloying element, and is used in steel castings, cast iron, and the bronzes and brasses, as well as in steel mill products. In one respect it is similar to carbon in that very small percentages give the desired results. It is used in percentages varying from 0.16 to 0.18 for the moving parts of machinery and springs, while for case-hardening steel, 0.12% is sufficient. In high-speed steels it has given good results in from 0.28 to 2%. If used in too large a quantity, that is, much over 0.30%, it dynamically poisons the metal, and the dynamic qualities for which vanadium steels are noted are rendered no better than, if as good as, the ordinary carbon steels. In high-speed steel, however, the cutting qualities are considered of greater importance than the dynamic strengths, and the best high-speed steels that have been placed on the market contained 1% of vanadium. These steels increased the cutting quality of tool something over 10% when working on hard steel or castings.

While the cost of vanadium-chrome steel is from 6 to 10 cents per pound, one firm, which builds gasolene engines, claims that it is no more expensive in actual practice than carbon steel, and is much cheaper than nickel steel, owing to the ease with which it is machined and forged, the lighter weight of the parts, owing to its great strength, and the greater accuracy obtainable, owing to the uniformity of the metal.

Vanadium steel is used largely for crank-shafts, connecting rods, piston rods, axles, crank-pins, gears, gun barrels, springs, locomotive side frames, or other parts of moving machinery that are submitted to vibrational, impact or torsional strains and stresses.

TITANIUM

Titanium belongs to the same chemical group as silicon, and three other elements which are quite rare. In some respects it resembles carbon. It forms a compound with oxygen, namely, TiO_2, and this titanium dioxide occurs in nature in three distinct forms. The principal one of these is the titaniferous ores that contain ferrous titanate ($FeTiO_3$).

It is very difficult to reduce in the blast furnace and thus make beneficial to the metal, but when separated in the electric furnace and made into a ferro-titanium, that contains from 12 to 15% titanium, about 6% of carbon, and 5% of all other impurities, with the balance iron, it greatly improves steel and iron, if added in the proper proportions.

Titanium burns more energetically in oxygen than any known substance. When heated in oxygen it creates an instantaneous dazzling flame like lightning. Its combination with nitrogen gas is attended with the evolution of heat; it being the only undisputed example of the combustion of an element in nitrogen. While nickel, chromium, molybdenum, and tungsten add certain good qualities to steel, none of these combine with nitrogen and thus remove it from the metal as titanium does.

Titanium has a great affinity for nitrogen and carries this off into the slag; nitrogen being, at least, as detrimental to the physical properties of steel as phosphorus, and present in larger percentages than has hitherto been supposed. It also has a strong affinity for and removes oxygen. By removing the oxygen and nitrogen it prevents the injurious effects of these elements on the steel. Titanium forms with oxygen an oxide and with nitrogen a stable nitride that shows as tiny red crystals under the microscope. Both of these substances are then carried off into the slag. The quantity of slag that is removed or lifted from the molten metal is also increased. Unless an unnecessary quantity of the alloy is used, the titanium itself passes off with the slag, and will not show on the analysis of the metal. The titanium itself is of no special benefit as a component of the finished steel, and only enough should be used to remove the impurities. Any excess above this will remain in the steel, and if proof is wanted that one is buying a titanium-treated metal, enough of the alloy could be used to show by analysis, as a small percentage left in the steel is not harmful.

One instance of the removal of nitrogen was shown in some ordinary Bessemer steel rails that were found to contain from .013 to .015% of nitrogen. When 0.50% of ferro-titanium containing 15% of titanium was added, the nitrogen was reduced to from 0.004 to 0.005%. As it also has a strong affinity for oxygen it provides a simple means of thoroughly deoxidizing steel.

Titanium, by removing the oxygen and nitrogen, prevents the formation of blow-holes in steel. It also reduces the size of the pipe, as it makes the bath more liquid by freeing it from the free oxide and slag. This makes the metal subside in the mold while cooling, and the pipe will be smaller and flatter. It also makes it roll well. In this connection the record of a day's work in rolling, as taken from a pyrometer, showed an increase of not less than 30° F. in the heat of the metal at a given point. That is, 30° above that of untreated metal at the same point, while passing through the roll. The metal almost invariably does not boil but lays dead in the ingot molds.

Due to the removal of nitrogen and oxygen from the steel, the physical properties are improved and its density increased. The tensile strength, elastic limit, reduction of area, transverse strength, hardness, elasticity, wearing qualities, resistance to shocks, and torsion, are greatly improved. Thus titanium gives practically the same results as vanadium, and the ferro-titanium can be produced for a fraction of the cost. One example of its ability to withstand torsional strains was shown with a bar 4 feet long and $1\frac{1}{8}$ inches square. This was twisted through seven complete revolutions without the sign of a fracture. The Brinell hardness test shows titanium steel to be softer than ordinary steel rails of the same analysis and section, and this is probably due to the finely divided ferrite network.

A ferro-titanium alloy that contains from 10 to 15% of titanium gives the best results, as this goes into almost instant solution. When a higher percentage is used the titanium is always liable to segregate, as it has a much higher melting point than that of steel. Thus when a 25% alloy was tried nothing was gained by its use. When, however, an alloy is used that will allow the titanium to enter into solution in the molten metal it retards the segregation of the other ingredients and produces a very homogenous steel.

One per cent of the 10 to 15% ferro-titanium alloy is all that is necessary to add to the steel, as this amount will seize all of the oxygen and probably all of the nitrogen that has been left in the bath. In many cases this can be reduced to one-half of 1%, and after some experience in its use the one-half of 1% might be sufficient for all steels. This small amount removes the bulk of the blow-holes and segregation found in Bessemer steel, and in the case of steel rails it only increases their cost about $2 per ton. With the titanium steel rails numerous use tests have been made, and all of these prove that they wear about three times as long as the ordinary steel rails, while in some cases they have outworn six of the Bessemer rails.

In the Bessemer and open-hearth process of steel making it is always best to add the ferro-titanium in the ladle. It should be shoveled in loosely, and never preheated but used cold. The first shovelful should be put in after the bottom of the ladle is well covered with molten metal and after the ferro-manganese has been added. One shovelful at a time should then be thrown in while the ladle is filling, so as to give it the benefit of the swirling and churning motion of the molten mass. The last shovelful should be added before the ladle is three-quarters full. One reason for this is that the alloy is lighter than iron and would not sink and disseminate through the bath if it were added near the top. Another reason is that if it were near the slag it would unite with the oxygen in the slag and consequently would not benefit the metal.

The alloy should never be used in connection with aluminum, as aluminum adds brittleness and titanium removes brittleness; hence the two alloys are antagonistic, and the titanium will do its work much better alone.

In crucible steel making it is sometimes preferable to add the titanium alloy with the charge of metal that is to be melted down, and in this case it should be added well down toward the bottom of the crucible. It has, however, been successfully added after the metal is melted, and when the manganese is added. At this time the titanium alloy should be added after the manganese. In fact, at all times it should be the last material added to the bath.

After adding the alloy the ladle of metal should be held for from 5 to 15 minutes before pouring in order to allow the titanium to do its work and scavenge out the oxygen and nitrogen. There is little danger of the metal in the ladle becoming chilled by holding it, as the reaction caused by titanium tends to cause its temperature to rise rather than lower, and the metal is in better condition for pouring after standing than before. In one case a ladle of steel was held for 20 minutes after tapping and adding the titanium, and is said to have then been in better condition for pouring into ingots than is steel without titanium soon after it is tapped.

Titanium also prevents steel from heating up as quickly as steels in which it is not used. An instance of this was some titanium-treated ingot molds that did not show red in the dark when filled with molten steel, whereas, the ordinary ingot molds, standing beside them, were distinctly red hot. The metal is also comparatively slow in heating from friction, and this is one of the causes why metals treated with it are much more durable than others. Steels treated with titanium heat up more slowly than others when machining them. The cutting speed can therefore be increased, and the machine work done more quickly. This also makes it very advantageous to use in tool steels; whether of the carbon or high-speed kind.

Owing to the fact that titanium increases the heat of the molten metal to a very marked degree, it is seldom necessary to use much ferro-silicon, as silicon is largely used for this purpose. Silicon, however, is not so efficacious and is known, at times, to precipitate phosphorus with disastrous results. Thus, when titanium is used the proportion of ferro-silicon should be decreased and, if possible, eliminated entirely. If not eliminated entirely, it could be reduced from time to time until no further improvement is noticed. If defects are found in the surface of the finished steel, a slight increase in the ferro-manganese and a decided decrease in the ferro-silicon used will overcome that.

Steel castings that have been treated with titanium are more blue in color, free from blow-holes and brittleness, and heat less under cutting tools than ordinary steel castings; thus they can be machined more easily and rapidly. The transverse strength has been increased from 17 to 23% by its use.

Titanium increases the breaking strains, wearing qualities, and hardness in the chill of cast iron, and hence is very beneficial for such castings as car-wheels, but it decreases the chilling effect.

Titanium also promises some good results when used in copper, brass, or bronze, in which case a cupro-titanium instead of a ferro-titanium is used. This has been used in about the same proportions as the ferro, but the best results have been obtained in copper with from 1½ to 2% of the cupro-titanium.

ALUMINUM

Aluminum is the third element in the earth's crust in importance, and comprises 7.81% of it. It occurs widely distributed and in many forms of combination; one of the most common of which is clay, where it exists in various conditions of purity. It is only within recent years, however, that it could be separated from its impurities cheaply enough to make it a commercial metal.

Since aluminum has come into prominence in metallurgy it has found many uses, and one of these is in the making of steel. This element, however, is only used as a purifier, as it adds nothing to the strength of steel except in so far as it removes some of the impurities.

Aluminum suppresses the evolution of gas either by increasing the metal's solvent power for that gas or by removing the oxygen, and thus preventing the later formation of carbonic oxide, or by both means jointly. This makes the metal more dense by removing the microscopic bubbles formed, and greatly decreases the tendency to segregation, as the aluminum has a quieting effect on the molten metal.

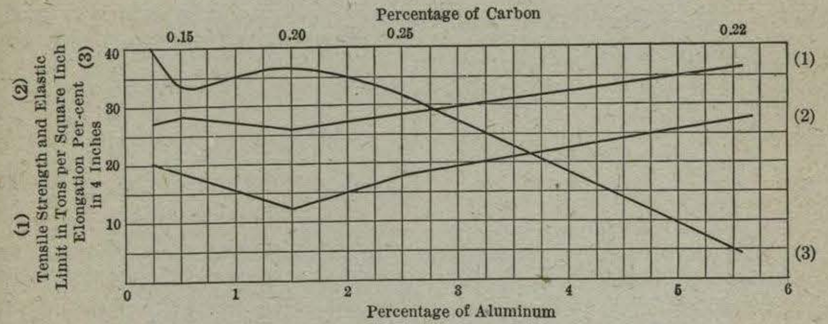


FIG. 51. — Effect of aluminum on steel.

Only enough aluminum is used to cause this effect, and thereafter work out of the metal. If the solid alumina produced remains suspended in the metal it causes a lack of continuity of the metallic structure, and thus a loss of strength.

Fig. 51 shows the effect of aluminum on the tensile strength, elastic limit, and elongation of steel with various percentages of carbon.

OTHER ALLOYING ELEMENTS

Some tin steels have been made. These cannot be rolled. If there be more than 1% of tin present they are extremely hard and brittle. Annealing has the same effect upon these as upon the ordinary steels and there is in no case precipitation of the carbon in the state of graphite.

Yttrium has been mentioned as an alloying element for steel, but it is only found in combination with a few rare minerals, and consequently is only seen in the laboratory. It belongs to the same chemical group as aluminum, and if it were found to be beneficial to steel it could not be obtained in sufficient quantities for commercial use.

Cerium and lanthanum have been combined with iron in the electric furnace to make an alloy that will give off luminous sparks. The maximum sparking effect seems to be obtained with about 50% of iron, and this will light illuminating gas. The sparks are obtained by striking the alloy with steel similar to the way flint was used before the days of matches. Some such combination might be used for generating the spark in internal-combustion engines. One such alloy was sold to the match trust and killed, as they feared competition from its use.

CHAPTER VII

WORKING STEEL INTO SHAPE

Rolling

AFTER the iron ore has been reduced to pig metal, and this refined and combined with the other ingredients that go into the making of the different grades of steel, and then cast into ingots, the ingots are sent through slabbing rolls, as shown in Figs. 52 and 53. The slabs thus formed are then rolled into the numerous shapes that are used for manufacturing purposes.

The slabbing mill, with a single pair of rolls and stationary table, which is used by many steel makers, is shown in Fig. 52. In Fig. 16 is shown the mechanically operated grip that has just brought an ingot from the soaking pit, and dropped it onto the carrier that conveys it to the rolls, and Fig. 17 shows the same ingot just as it has made its first pass through the slabbing mill. After this the mill is reversed and the ingot passes back through another section of the rolls to further reduce it. After some four or five passes back and forth through the rolls, during which time it is turned over so as to roll all four sides, it is sent to other rolls that reduce it to commercial shapes.

In Fig. 53 is shown the three high mill with tilting table. This has a double set of rolls, and for the first pass of the ingot the end of the table next to the rolls is lowered to receive it as it comes through. The rollers of the table are then reversed, and while reversing the end of the table is elevated, as shown in the illustration, and the ingot sent back through the upper rolls. The rolls, as well as the tilting table, are controlled from the platform of the pulpit, shown to the right of the picture. In this design a much narrower mill can be used for the same number of passes than in the design of mill shown in Fig. 52.

After slabbing the metal, various kinds of rolling mills are used to get the steel into the shapes desired. Many times the different mills are combined so as to make the rolling operations continuous from the steel furnace to the finished product. In some cases the desired shape is finished before the metal has had time to cool off after leaving the fur-