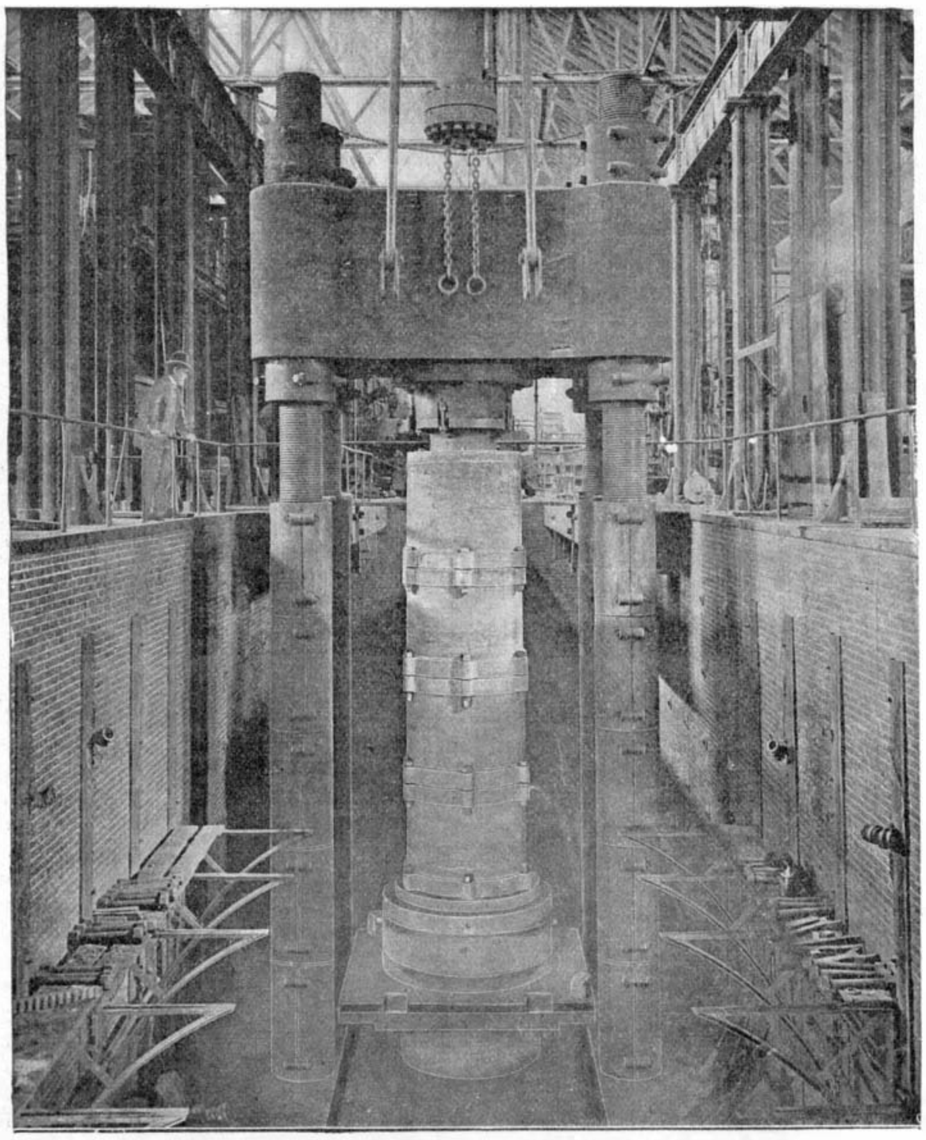
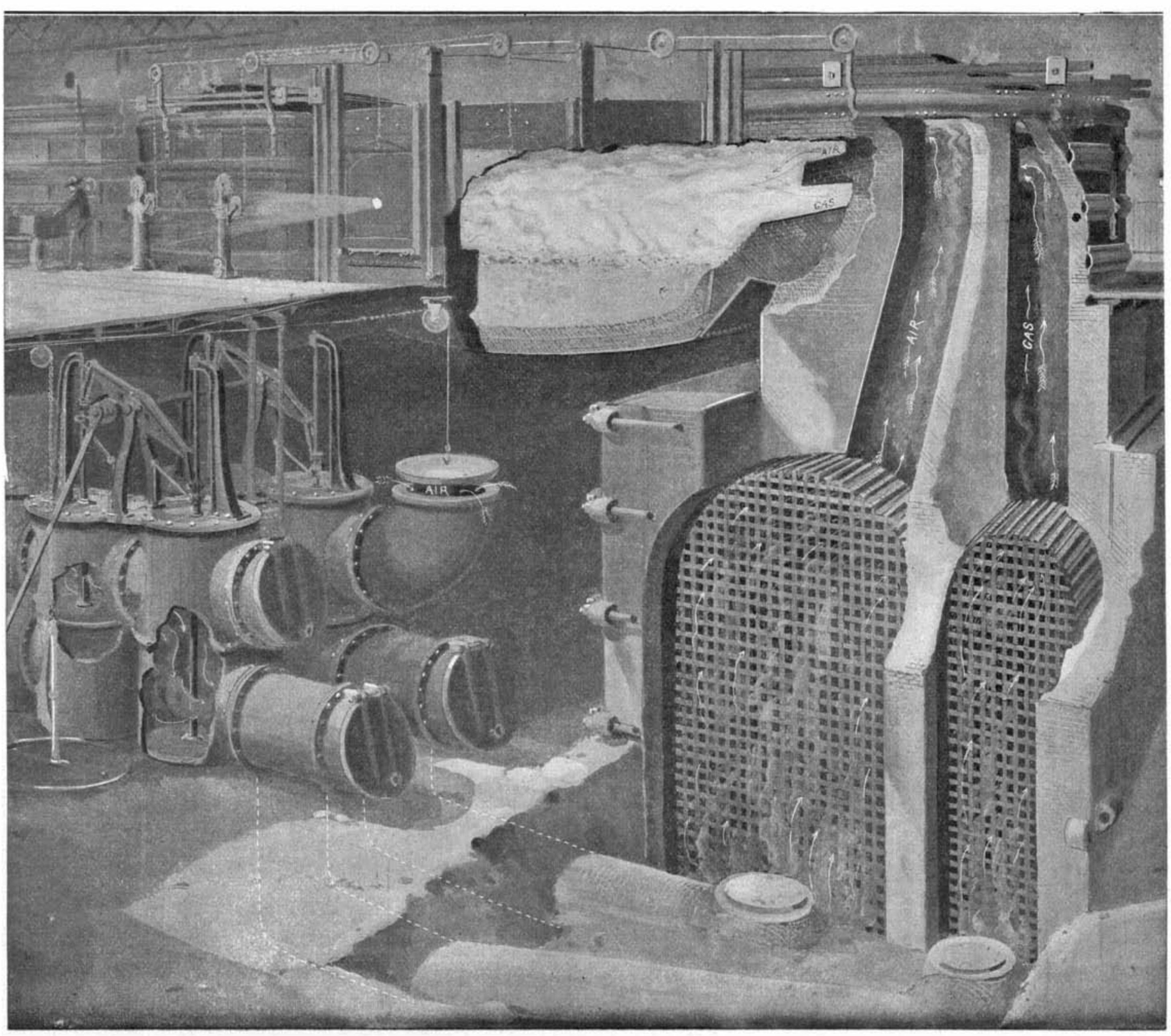
feet in length. Then it is sheared into two or three lengths, according to the length of the rail which is to be rolled. The blooms, as they are called, are now heated in the bloom furnaces and carried direct to the great rail mill, consisting successively of roughing rolls, intermediate rolls, and finishing rolls, which extend one after the other down the full length of a building that is 900 feet in length. In the roughing rolls the bloom receives five passes, during which it is brought down roughly to the desired section of rail. It then, without any reheating, passes on to the intermediate or "short" rolls, where it receives another five passes and is brought still more closely to its finished shape. At this point is introduced at these works a most important innovation in rail rolling, known as the Kennedy-Morrison rail-finishing process, to describe which it is necessary to go back in history a little, and explain that a few years ago it was customary to let the rail pass through the three sets of rolls and be finished on a single heat without any intermission in the process. This gave good results when rails were lighter, but as the section of the rails increased in later years, the greater mass of steel in the rail caused it to retain its heat longer, and it passed through the finishing rolls at too high a temperature for good results. Consequently, the modern 80 to 100-pound rail had not been giving such good results as the earlier 50 to 70-pound rail. To overcome this difficulty, the rails, after passing through the short rolls, are left to cool on a table for from 45 to 90 seconds, at the end of which time they are passed through the finishing rolls. Rolling at a lower temperature has produced a much better quality of metal, particularly in the head of the rail. After leaving the finishing rolls, the rails are sawn into lengths of 30 or 60 feet as the case may be. They are then passed through the cambering rolls, where they receive sufficient camber to insure that when the rail is cooled, it will be practically true and straight. After they have cooled off upon the hot beds, the rails pass to the straighteners, then to the chippers and filers, and finally to the stock yards, where they are loaded on to the cars at the rate of between 7,000 and 8,000 rails, or say 3,000 tons of finished steel, per day.

In closing our account of this wonderful industry, emphasis should be laid upon the fact that the work of smelting the iron in the blast furnace is continuous day and night, year in, year out, absolutely without intermission. The converters, however, and the rolling mills are shut down from Saturday at 1:30 o'clock in the afternoon to 5 o'clock on Sunday evening. During this interval the product of the blast furnaces, instead of being poured into the mixers, is run into the pig-casting machine. This consists of a series of parallel endless chains of molds which pass in front of the pouring mouth of the ladle. Each mold receives its quantity of metal at the lower end of the chain, and delivers the cast pig iron at the upper end of the system, where it is dumped into railroad cars for shipment.



OPEN-HEARTH CASTING PIT, SHOWING THE FLUID-COMPRESSION PLANT.



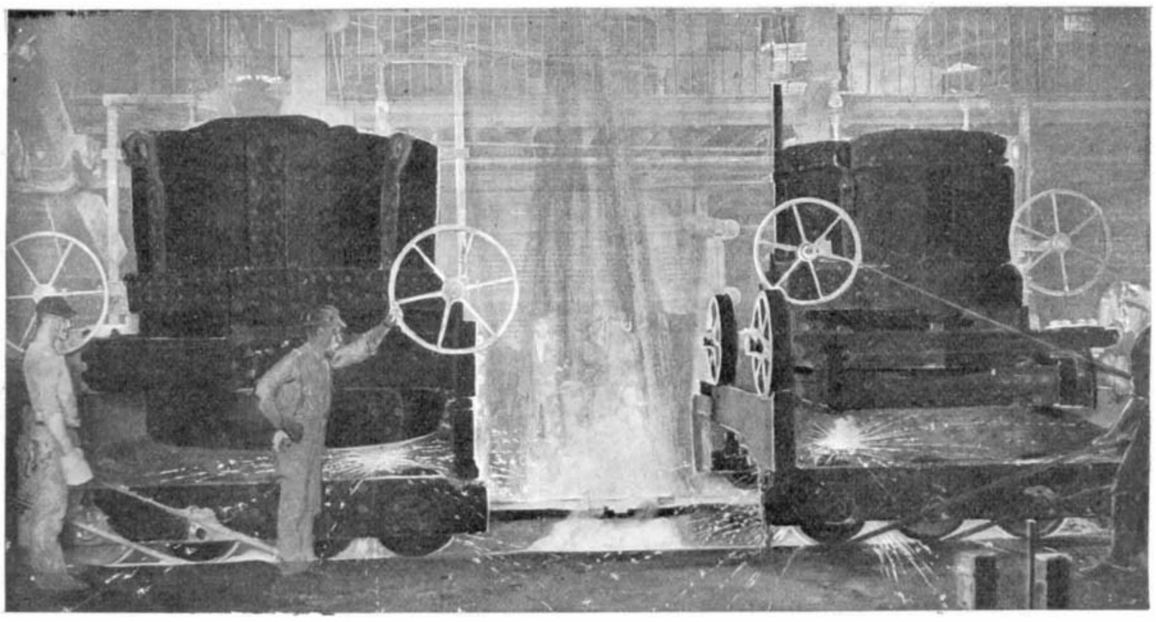
SECTIONAL VIEW THROUGH OPEN-HEARTH FURNACE, SHOWING REGULATING VALVES, CHECKER-WORK AND FLUES.

MANUFACTURE OF GUN STEEL AND ARMOR PLATE.

Too much cannot be said in praise of the policy of the government in its encouragement of the construction of navy and army material by private firms that are capable of undertaking this class of work. The more perfect and extensive the plants, the more experienced the working staff of the establishments that manufacture gun steel and armor plate, the more speedy will be the completion of contracts and the greater the reserve forces of the nation, should it ever be called upon to face the crisis of a sudden war. There is no branch of the manufacture of war material that calls for more thorough scientific knowledge, a wider range of experience, and more highly developed mechanical appliances, than that of the production of Krupp steel for the armor and fluid-compressed steel for the guns of our modern warships. By the courtesy of the Bethlehem Steel Company, we are enabled to present a series of views of what is recognized as the most important gun and armor plant in this country.

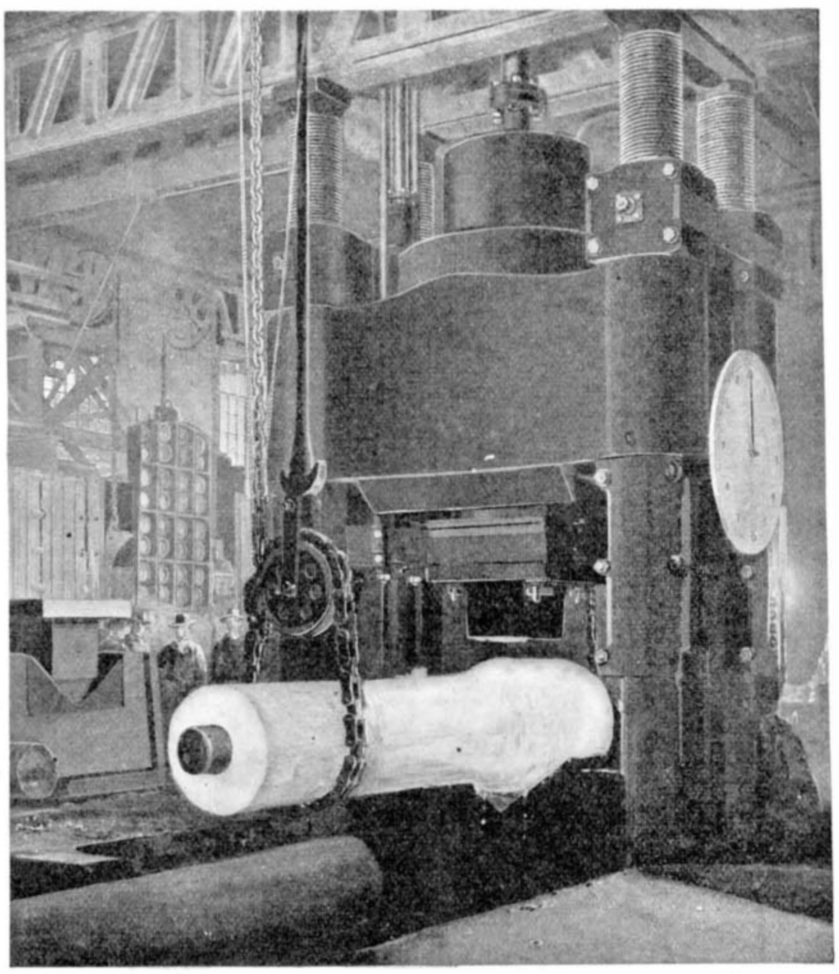
In the whole range of the iron and steel industry there is no single branch, not even that of railmaking, that calls for plant and machinery of such colossal size as this; and though the total output measured in mere dead weight does not compare with that of the industry which has been described in the preceding article, it must be remembered that whereas steel rails may cost anywhere from $20 to $40 a ton, a finished gun is worth $1,000 per ton, and finished armor plate from $400 to $500 per ton. Nowhere among the plants that manufacture iron and steel in bulk can we find an instance where the elements of time and labor enter so largely into the cost of the finished product.

THE OPEN-HEARTH PROCESS.—Broadly speaking, it may be said that the bulk of the steel that is annually produced throughout the world to-day, with the exception of a relatively insignificant amount, is made either by the Bessemer or the open-hearth process. The former process was described in the preceding article, and every ton of finished rail that goes out of the Edgar Thomson Works is made by the Bessemer process. At the Bethlehem establishment, however, no Bessemer steel whatever is manufactured, the whole of it being made by the open-hearth process. The conversion of the cast iron into steel by the Bessemer process is accomplished, as we have seen, in from 10 to 15 minutes, and it is the simplicity and rapidity of the process that has so greatly cheapened the cost of steel throughout the world. But while Bessemer steel is well suited for steel rails and for a large variety of structural material, it is not possible to secure by this rapid process the high qualities which are demanded in all specifications for gun steel and armor plate; and it is only by the slower and more carefully watched and manipulated open-hearth process that these qualities can be imparted. The superior results obtained with the open-hearth process are due to the fact that the process of decarbonizing the cast iron being greatly protracted, it is possible to make a larger number of successive tests, and turn off the heat at the moment when the steel in the furnace has reached the exact composition required. In the Bessemer process the impurities and the whole of the carbon are burnt out of the hot metal in a few minutes, and the proper percentage of carbon is sought to be secured by adding some spiegeleisen as the blown metal is being poured into the ladle. The open-hearth process, however, occupies from eight to twelve hours for each heat, and the operator can tell at any time just what is the chemical condition of the heat, and can control with the greatest nicety the temperature.



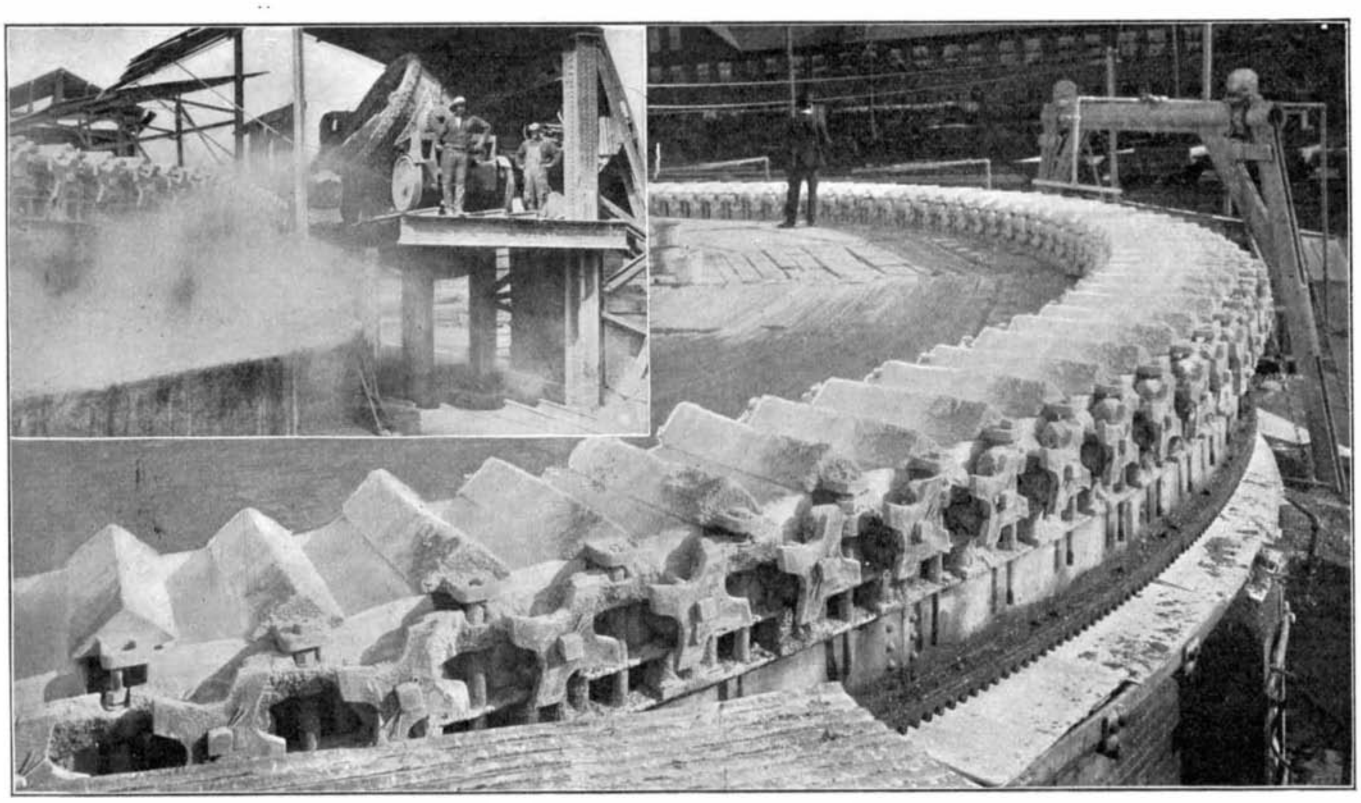
CASTING AN ARMOR-PLATE INGOT.

The high qualities of gun steel and armor plate are secured by varying the composition of the furnace mixture; by the method of treatment in the furnace; and by subsequent treatment of the metal by fluid compression, forging, tempering, and annealing. Gun steel must be hard, to resist the friction of the projectiles and erosion of the powder gases; elastic, so that it may give under powder pressure and yet return without permanent set to its original dimensions; and it must have a high ultimate breaking strength. The desirable qualities for armor plate are extreme hardness at the face combined with great toughness throughout the whole body of the plate. In Harveyized armor this toughness is secured by the introduction of a certain amount of nickel, and in Krupp armor of chromium and other elements during the furnace treatment. The desired physical qualities are further developed by that elaborate system of forging, tempering, and annealing, which renders the manufacture of armor plate so tedious and costly.



HOLLOW-FORGING A GUN TUBE IN THE 5,000-TON PRESS.

The open-hearth furnace is a large dish-shaped structure lined with refractory brick and sand, into which the mixture is loaded by powerful Wellman-Seaver electric charging machines, that run on tracks laid upon the charging platform in front of the furnaces. The furnace is heated by producer gas, which is fed through the large regulating valves shown in our engraving below the charging platform. From the valves the gas passes through a mass of firebrick checker-work (whose function is the same as that of the hot-blast stove used in blast-furnace practice), and from the checker-work it enters the furnace through the lower flue shown in the engraving. Air is admitted to the furnace by way of the valves, and passing through another mass of checker-work built alongside the first mass, finally enters the furnace by two flues, one on each side of the gas flue. Combustion takes place at once, at a temperature ranging from 2,700 to 3,000 degrees. The products of combustion pass over the charge, out at the opposite side of the furnace, and down through a duplicate set of flues and checker-work, exactly similar to those through which the gas and air entered, thereby raising the checkerwork to a very high temperature. About every twenty minutes the valves are thrown over, and the flow of the gases is reversed. By this regenerative process the gas and air enter the furnace at a temperature of from 1,500 to 1,800 degrees. As soon as the various impurities have been burned out of the charge, and the percentage of carbon, etc., brought down to the desired ratio, the furnace is tapped at the rear, and the steel is run off into the molds. One of our engravings shows a large ingot weighing 62 tons that has been cast to form a side armor plate for the new battleship "Virginia." The large mass at the top of the plate contains an excess of metal known as the "sinking head." This is formed in the mold with the purpose of increasing somewhat the density of the metal and closing any cavities which might form during cooling in the casting.

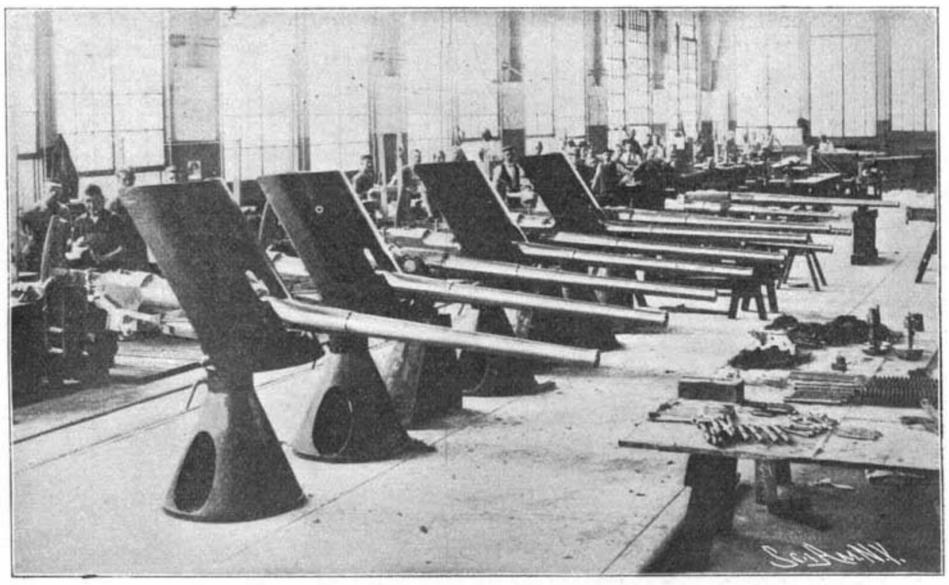


CIRCULAR PIG-CASTING MACHINE.

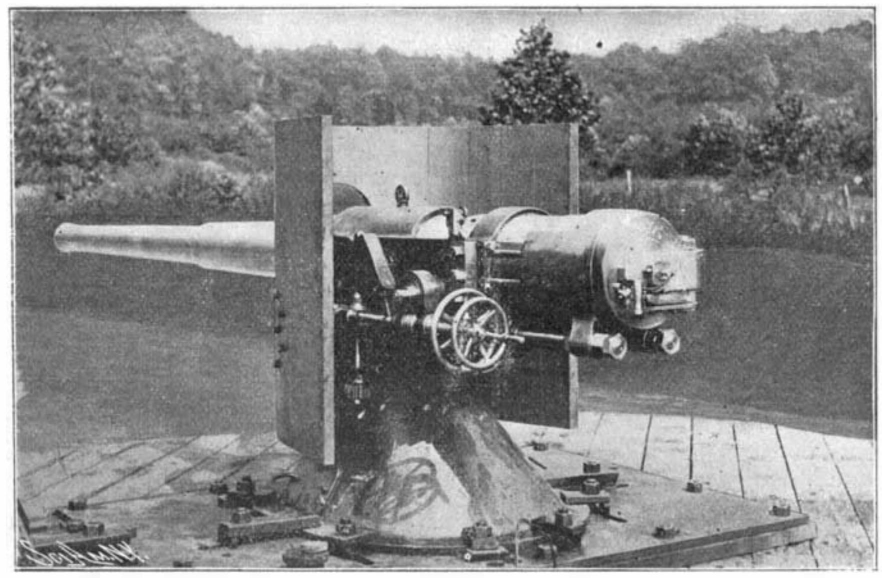
Fluid Compressor.—The metal which is to be worked up as gun steel is subjected to fluid compression, which is designed to remove certain defects that are common to all steel ingots not so treated. These defects are the formation of blowholes, "piping," which is the formation of a hollow cavity through the center of the ingot in cooling, and segregation, which is the mechanical and chemical separation of the component parts of the solidifying steel, due to the fact that each of them has its own temperature of cooling. Now, by subjecting the molten metal during the cooling to an extremely high pressure, the above-mentioned defects are prevented, or at least very largely mitigated. The 7,000-ton press, as herewith illustrated, is of monumental proportions. It consists of an upper head weighing 120 tons, which carries the plunger, a 135-ton base, containing the hydraulic cylinder, and four vertical connecting columns, each 50 feet long and 19 inches in diameter. After the molten metal has been poured into the mold, which is built up in sections, the mold is raised under a pressure of 7,000 tons, and a plunger attached to the head bears down upon the fluid metal, preventing its escape and compressing it. When the ingot has cooled, the ends are cut off in a lathe, and an axial hole is bored through its center. It is then placed in the furnace, and being hollow, heating takes place very evenly throughout the whole mass, and the danger of cracking is removed. The ingot is removed from the furnace at a temperature of about 1,900 degrees, a steel mandrel is passed through its center, and it is placed under the hydraulic forging press. The mandrel serves as an internal anvil, and the work of the press is concentrated upon less than half of the thickness of metal that it would act upon if the piece were solid throughout. Thus the metal receives that thorough "working" which is the very soul of first-class forging. All armor plate and gun forging is done at the Bethlehem Works under hydraulic presses, of which there are three—one of 2,500 tons, another of 5,000 tons, and a huge affair of 14,000 tons, the first two being used for gun forgings, while the biggest press, a truly gigantic structure, is mostly engaged in the manufacture of great masses of armor plate.

The Hydraulic Forging Press.—The general construction of the hydraulic press is similar to that above described of the fluid compressor. The hydraulic cylinders are carried in the upper head, and the travel of the piston is controlled by a hydraulic lever in the hands of an attendant. A disk and pointer attached to the side of the press indicate the number of inches of stroke of the piston, and as the same length of stroke is maintained throughout a complete revolution of the forging in the press, the piece is roughed out with an accuracy as to diameter and line that greatly reduces subsequent work in the machine shop.

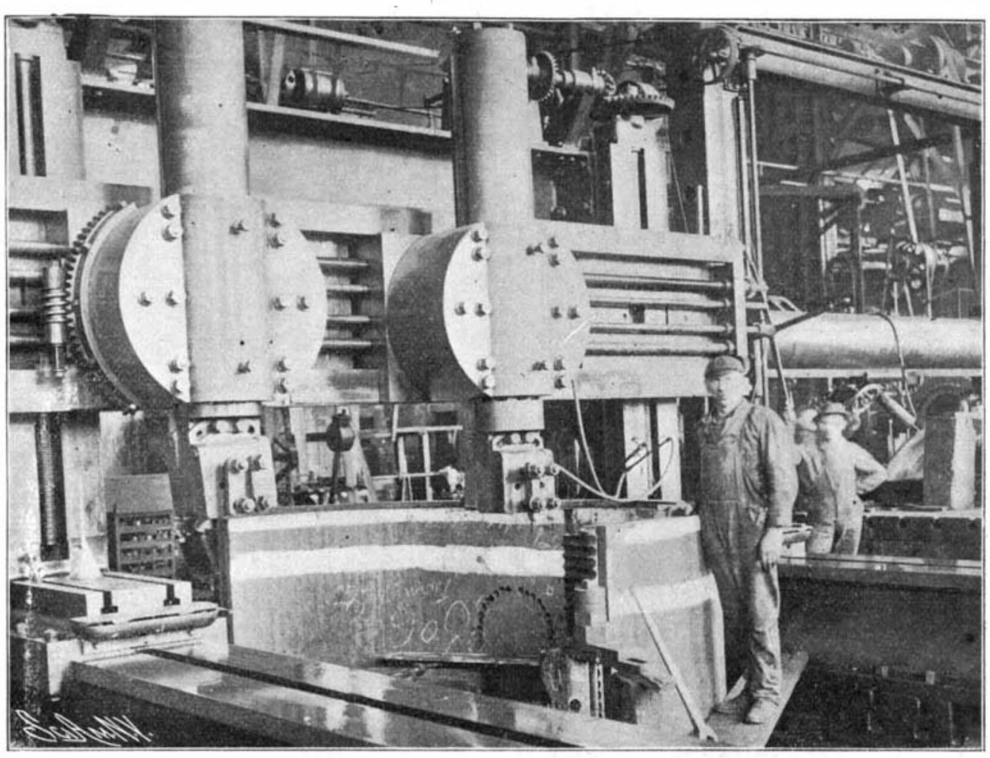
Annealing.—The successive heating and forging that are necessary in the production of such large pieces set up in the work a complication of forging strains which are relieved by treatment in the annealing furnace. In this process the forging is slowly and carefully heated to a temperature slightly above the point at which crystallization is destroyed and the molecules thrown into an amorphous condition, and it is then allowed to cool very slowly. During the cooling the molecules rearrange themselves, leaving the metal in a state of complete rest. After annealing, the forgings are oil-tempered to impart the necessary toughness. This is done by lowering the piece into a large cylindrical furnace, whence it is lifted at a predetermined temperature and lowered suddenly into a bath of cold oil. As the temperature of the piece is slightly above the recalescent point, there is no time during the cooling process for the formation of crystals, and the result of the readjustment of the molecules which takes place is to give that high elastic limit and ultimate tensile strength that characterize gun steel. The forgings are again annealed to relieve the metal of any hardening due to the cooling process, and they are then taken to the machine shop, where they are bored, turned, and assembled or built up into the finished gun. A chapter could be written on this interesting department; but we must be content to refer to the accompanying views of some of the latest finished guns, and direct the reader's attention to the chapter by John F. Meigs, the ordnance expert of the Bethlehem Steel Works, at the commencement of this issue.



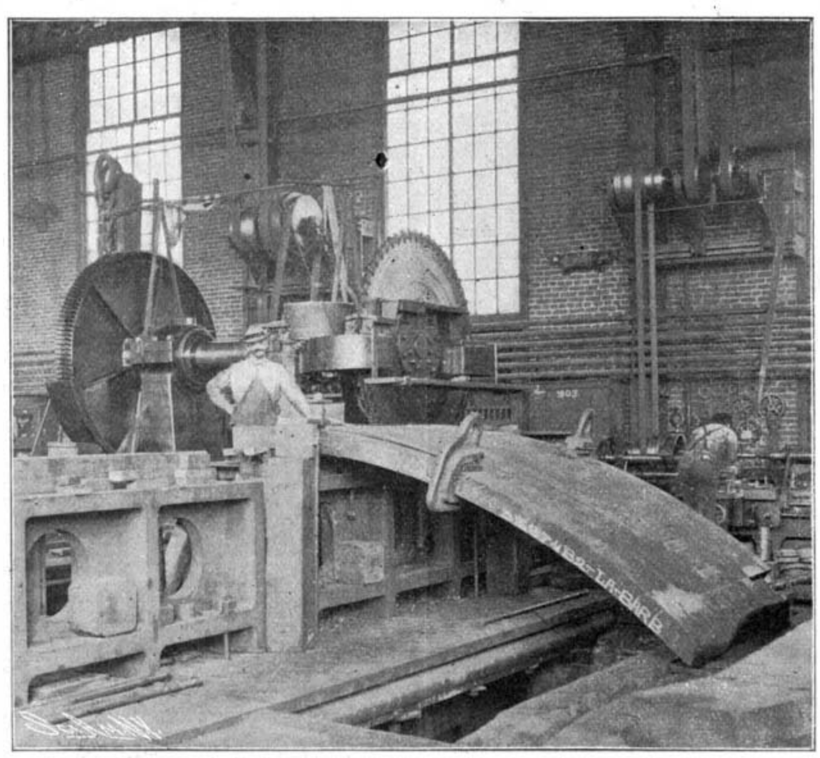
GROUP OF 6, 3 AND 1 POUNDER GUNS IN GUN SHOP.



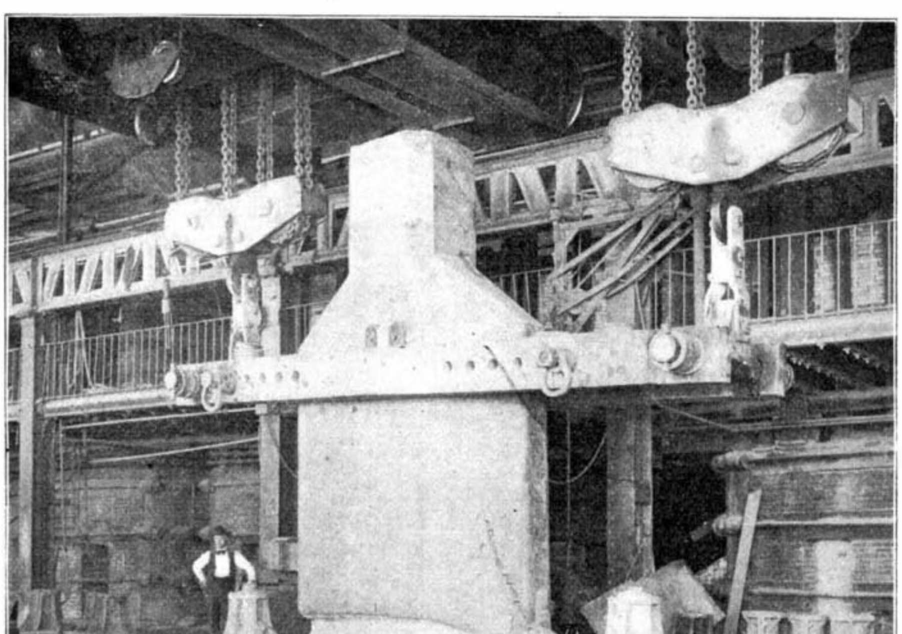
FOUR-INCH, 50-CALIBER GUN AT PROVING GROUND.



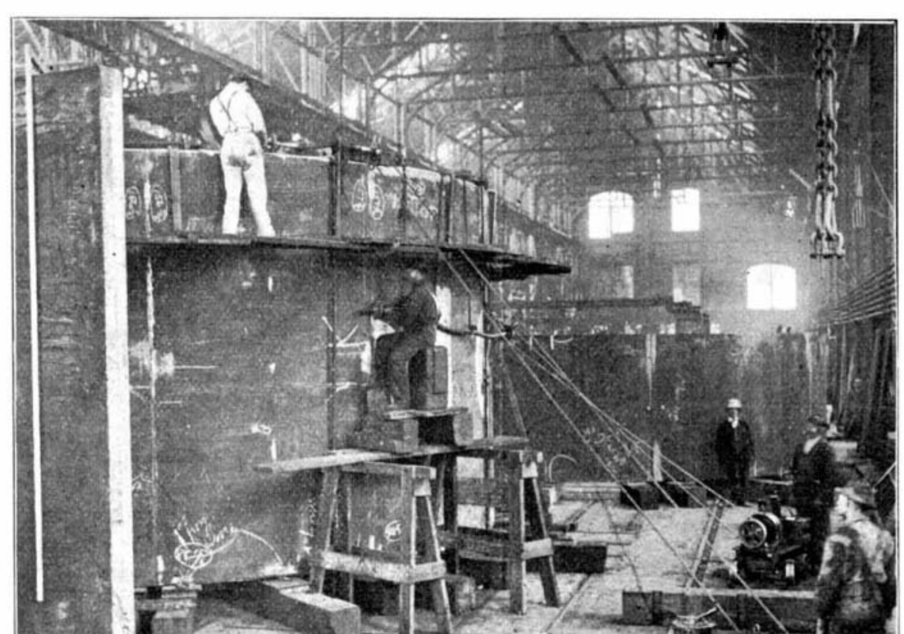
PLANING RABBET IN "LOUISIANA'S" CONNING TOWER.



SAWING ROUGH ENDS FROM A "LOUISIANA" BARBETTE PLATE.



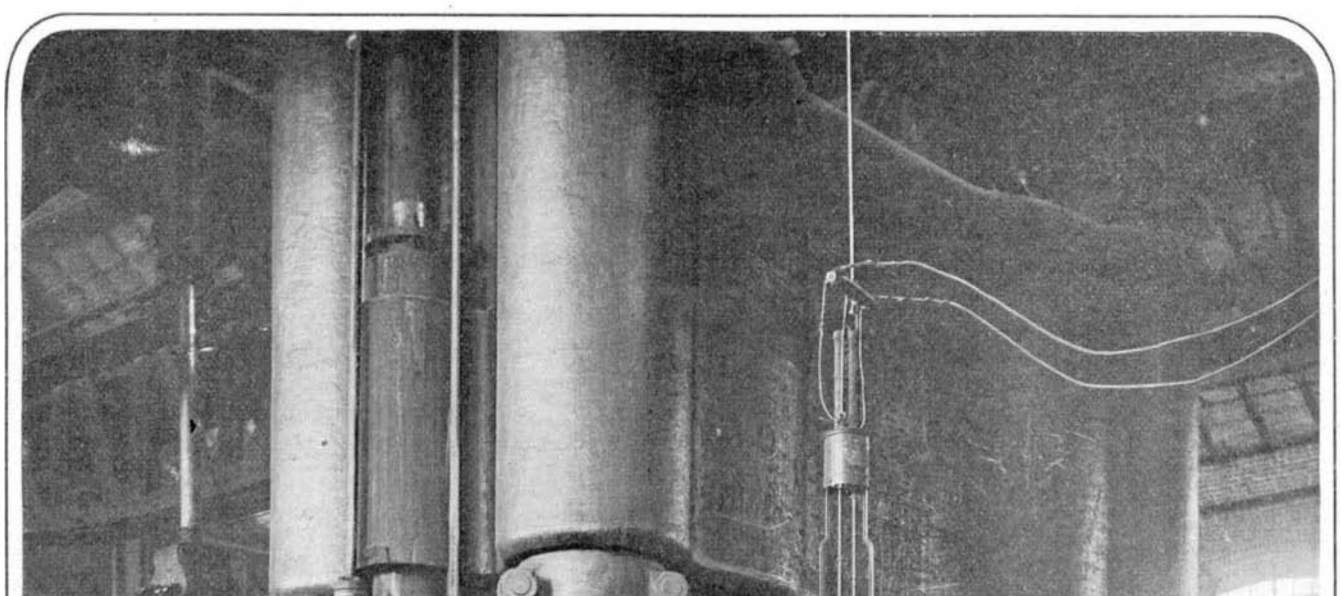
LIFTING FROM THE CASTING PIT A 62-TON INGOT FOR SIDE ARMOR OF BATTLESHIP "VIRGINIA;" PART OF MOLD STILL ATTACHED AT BASE.



ERECTING BARBETTES OF THE BATTLESHIP "LOUISIANA;" GRINDING DOWN ROUGH EDGES AT THE JOINTS.

MANUFACTURE OF ARMOR PLATE.—As already explained, the armor-plate ingots are cast with a large excess of metal, which serves both as a "sinking head" and also as a rude sort of handle, by which the enormous mass may be manipulated on the mandrel of the hydraulic press and transferred to and from the furnace. The excess of metal in an armor-plate ingot is greater than that of any other mass of metal casting, the finished plate representing on an average about 40 per cent only of the original casting. Some of these castings weigh as high as 275,000 pounds. When the ingot has been hauled to the forge, its "sinking head" is placed in one end of a massive cast-steel sleeve, from the other end of which projects a long steel bar about two feet in diameter, which is provided with sliding balance weights. The sleeve is supported in an endless chain sling from an overhead crane, by which it is transferred from the heating furnace to the hydraulic press. Here the total "squeeze" given to the plate when it is upon the anvil is the same as though a big battleship like the "Maine" were permitted to bear with its full weight upon it. The massive forging is lifted, turned over, flattened (kneaded as it were) and brought down to size with an ease which must be seen to be appreciated. At the first forging the ingot is roughed down to the approximate shape of the finished armor plate, but is considerably thicker. It is now ready for that most important process of hardening the face, technically known as cementation. This varies greatly in its details for Harvey and for Krupp armor, although its general principles are the same. In both processes the plate is placed in a furnace, and exposed for from three to four weeks to the action of highly carbonaceous material. In the case of the Harvey plate the carbonizing is effected by a layer of bone dust, charcoal, and other suitable materials. In the Krupp process the carbonizing agent is used in the form of a gas. After the plate has taken up an excess of carbon for the depth of an inch and a quarter to an inch and a half, it is returned to the forge, heated, and forged down to the finished thickness. Then it is transferred to the machine shop, where test specimens are removed and subjected to tensile tests in the presence of naval inspectors. Here the plate is sawn down to the correct size, and such machining as is necessary is done upon it. We present some illustrations of the remarkable collection of machinery in the armor-plate machine shop. It was all built specially for this work, and is framed on a colossal scale. In one place will be seen a circular saw that is capable of taking a cut through a steel plate 24 inches in thickness and 33 feet long. Elsewhere will be seen a huge rotary planer engaged in taking a 6-inch cut from the edge of a 10-inch plate faster than a saw will cut on a 6-inch strip from the same plate. Practically the whole of the machine work has to be done before the final hardening of the armor-plate by the water spray, for the steel tool does not exist that can touch the hardened face of a Harvey or Krupp plate. The plate then takes a journey to the forge again, where it is carefully straightened or bent, as the case may be, and brought to the desired form. Time and again the huge mass, weighing as much as a locomotive, will be lifted on to cars and transported from one building to another, undergoing operation after operation, until at last it is ready for the process of hardening, which consists of heating the plate to a temperature slightly above the recalescent point, and then case-spraying it with innumerable streams of water delivered under high pressure. Then follows the oil-tempering, to remove strains, and another heating for the final "rectification" to the proper shape. After the hardening, the plate is again taken to the machine shop, where additional tests are taken for the satisfaction of the navy inspectors, and it receives its finished machining by means of grinding machines. In the rough-machining already alluded to, the plate was brought practically to its finished shape and size, and now that its face has been hardened, it is only possible to act upon the inch and a half of extremely hard surface by means of the emery grinders. All the warped surfaces, such as those at the portholes, at the sighting hoods, etc., have to be chipped and finished by hand with files, the outer hardened portion being ground down. Then follows the drilling of the holes for the bolts by which the armor is fastened to the backing and framework of the ship, and the tapping of the bolt holes, after which the armor plates are assembled to make sure that the joints are true and close. One of our illustrations shows the barbettes for the battleship "Louisiana" in the erecting shop, and the workmen busy with the grinding wheels, finishing off the top edges and smoothing down irregularities in the vertical joints. Each grinder is operated by a rope drive from a portable motor standing on the floor of the shop. After the armor has been assembled and the bolts tried in the bolt holes, it is inspected carefully by government representatives. Then it is taken down, the bolt holes are filled with tallow and white lead, and the plates stamped with the name of the vessel and the part of the ship to which plate is assigned. The final operation is the weighing, which, in the case of such costly material, is carried out with the greatest care.

WHY ARMOR PLATE IS COSTLY.—The general public has always been mystified at the extremely high price paid for armor plate. We have endeavored to indicate in the course of this article some of the causes of this high cost, the most important of which is the great length of time required for the successful manufacture of a plate; for, on an average, every plate is being constantly worked upon, either in furnace, forge, machine shop, or annealing and tempering department, for a continuous period of nine months. Other causes of high cost are: the large number of separate operations, the frequency with which the great masses must be transported, and the distances over which they must be carried in their journey from one department to another. To illustrate the vast scale on which the works are laid out and the distances to be covered from shop to shop, we may mention that the whole establishment extends in one direction continuously for a length of a mile and a quarter, and that the forty or fifty handlings and transshipments, which occur in making a single Krupp plate, take place in and between such buildings as the open-hearth structure, which is 111 feet wide by 1,950 feet in length; the machine shop, 116½ feet in width by 1,375 feet in length; the armor forge, 850 feet in length; and a face hardening department and an armor-plate machine shop, both of which are but little less in size. Further elements of expense are the large percentage of losses which is liable to occur, the high first cost of the extensive plants that must be laid down, and the fact that new and improved methods of manufacture may at any time render the plant more or less obsolete. The greater cost of the Krupp armor is largely compensated for by its much greater resisting qualities, which make it possible to give equal defensive qualities for 20 to 25 per cent less weight of armor.



STRAIGHTENING A 14-INCH ARMOR PLATE UNDER A HYDRAULIC PRESS.

STATISTICS OF OUR IRON AND STEEL PRODUCTION.

The statement that last year forty per cent of the pig iron in the world was produced in the United States gives one no very definite realization of the quantity of that product, though he be reminded on every hand by iron and steel ships, bridges, railroads, buildings, machinery, tools, nails, tacks, etc., *ad nauseam*, that this is the iron age. Even the statement that the United States last year mined over thirty million long tons of iron ore, gives one no adequate impression of the vastness of this amount. On the other hand, if one should see the entire iron ore production of the year piled up in a single heap, he would readily comprehend this quantity by a comparison of the pile with familiar objects in the landscape. This shows us that it is large numbers instead of large quantities which confuse the mind; for example, the statement that a wagon holds over 30,000,000 grains of coal would give a person a very hazy idea of the actual quantity specified, but he would immediately comprehend the quantity if told that it represented two tons; for a larger unit of weight would be used, thereby reducing the count to a figure well within the mental grasp. Thus in trying to represent to our readers just how large are the quantities of materials used in the iron and steel industry, we have endeavored to choose larger units of measurement; and finding that our standard measures