TEXT-BOOK

OF

ORDNANCE AND GUNNERY

REVISED AND ARRANGED FOR THE USE OF MIDSHIPMEN AT THE U. S. NAVAL ACADEMY

BY

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PREFACE

The last edition of Ingersoll's Text-Book of Ordnance and Gunnery (which has been the standard in the Navy for many years) having been exhausted, and the author not being in a position to revise the work, this volume has been prepared to meet the demands of the Naval Academy as well as the service at large.

In preparing this work, Ingersoll's Text-Book and various official and standard publications have been consulted, and, with a view to bringing the book as nearly up to date as possible, only modern service materials and methods have been described in full.

Chapter I, on "Metals, Gun Forgings and Manufacture of Armor Plate," was prepared with the assistance of Lieutenant Henry F. Bryan, U. S. Navy, Inspector of Ordnance. The plates and some of the data for this chapter were obtained through the courtesy of Edward M. McIlvain, Esq., President of the Bethlehem Steel Company.

Chapters XXIV, on "Gunpowder," and XXXI, on "The Proving Ground," were prepared by Lieutenant Joseph Strauss, U. S. Navy.

Chapters XXIX and XXX, on "Armor Protection for Ships and Guns," and "Penetration of Projectiles," respectively, were prepared by Lieutenant Cleland Davis, U. S. Navy.

Chapter XXXIV, on "Practical Naval Gunnery," was prepared by Lieutenant-Commander William S. Sims, U. S. Navy, and Lieutenant Ridley McLean, U. S. Navy.

The official publications and pamphlets issued by the Bureau of Ordnance and edited by Lieutenant F. K. Hill, U. S. Navy, and Lieutenant William C. Watts, U. S. Navy, have been freely consulted with the permission of the Bureau, and the editors are indebted to Lieutenants V. O. Chase and F. K. Hill, of the Bureau of Ordnance for much valuable information and assistance.

The following named officers, on duty at the Washington Navy

Yard, have greatly assisted the editors by furnishing material and all necessary information relating to the most recent work at the Naval Gun Factory:

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Lieutenant Victor S. Houston, U. S. Navy.

The Naval Institute Proceedings, the Publications of the Office of Naval Intelligence, and the articles on Ordnance, by Professor P. R. Alger, U. S. Navy, have also been consulted.

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NAVAL ACADEMY,
Annapolis, Md., October, 1903.

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CHAPTER I.

METALS, GUN FORGINGS AND MANUFACTURE OF ARMOR PLATE.*

The Qualities of Gun Metals.

1. **Definitions**:—a. *Stress*.—The term stress is used to denote the system of forces which act to produce alterations of figure and volume of a solid and of its parts.

b. *Strain*.—In technical literature, the term strain is sometimes used to denote stress, and sometimes the change of shape caused by the stress. Here it will always be used in the latter sense; that is, to denote the change of shape caused by the stress.

c. *Fracture* of a solid occurs when, under the action of a stress, a strain is carried so far as to cause actual division of the solid into parts.

d. *Kinds of Strain*.—To each kind of stress there corresponds a kind of strain, as follows: For longitudinal stress we have a strain either of extension or compression; and, if the strain is carried far enough, a fracture will occur by tearing, in the former case, and by crushing or cleaving in the latter case. For transverse stress we have the strains of distortion, torsion, and bending, which, if carried far enough, produce fractures by shearing, wrenching, and breaking across respectively.

2. **Physical Properties of Metals.**—Metals have the following properties, to a greater or less degree, with which we are more particularly concerned in the case of metals used in gun construction. These principal properties are *malleability, ductility, hardness, toughness, tensile strength,* and *elasticity.*

*In revising this chapter the editors were greatly indebted to Lieutenant Henry F. Bryan, U. S. Navy, Inspector of Ordnance, for assistance and information. Acknowledgment is also due to President E. M. McIlvain and the officials of the Bethlehem Steel Company for details and sketches.

a. *Malleability.*—A metal is said to be malleable when it may be permanently extended in all directions without rupture, by pressure (as in rolling) or by impact (as in hammering).

b. *Ductility.*—A metal is ductile when it may be extended permanently by traction, as in wire drawing. Only malleable metals are ductile, but their ductility is not necessarily in the same ratio as their malleability.

c. *Hardness.*—A metal is said to be *soft* when it yields readily to compression without fracture, and does not return to its original form on the removal of the compressive stress; and on the other hand, a metal is said to be hard when it does not yield readily to compression; that is, when the ratio of the compressive stress to the permanent strain produced is very great. The terms *hardness* and *softness,* however, are only comparative when used in describing metals; thus we have hard and soft leads, while any sort of lead is soft as compared with wrought iron, which latter is called soft when compared with cast iron.

d. **Toughness* in a metal is a relative term to express the power of resisting fracture by bending or torsion; and is measured by the number of times to which a definite section of the metal can be bent through a certain angle on either side of the perpendicular without any fracture.

e. *Tensile Strength.*—The tensile strength, or ultimate strength, of a metal is the unit-stress required to produce fracture. Thus if a bar whose cross section is A breaks under a tensile stress P, the tensile strength of the material is $\frac{P}{A}$.

3. Elasticity, Elastic Strength, Modulus of Elasticity, Set.—The *elasticity* of a metal is the property it possesses of resisting permanent deformation when subjected to a stress.

"† All experiment and experience agree in establishing the five following laws for cases of simple tension and compression, which may be regarded as the fundamental principles of the science of the strength of materials:

"1. When a small stress is caused in a body, a small deforma-

* Steel and Iron, W. H. Greenwood.

† Text-book on the Mechanics of Materials, Merriman.

tion is produced; and on the removal of the stress, the body springs back to its original form. For small stresses, then, materials may be regarded as perfectly elastic.

"2. Under small stresses the deformations are approximately proportional to the forces, or stresses, which produce them, and also approximately proportional to the length of the bar or body (Hooke's law).

"3. When the stress is great enough, a deformation is produced which is partly permanent, that is, the body does not spring back entirely to its original form on removal of the stress. This permanent part is termed a *set*. In such cases, the deformations are not proportional to the stresses.

"4. When the stress is greater still, the deformation rapidly increases, and the body finally ruptures.

"5. A sudden stress, or shock, is more injurious than a steady stress, or than a stress gradually applied.

"The words small and great, used in stating these laws, have very different values and limits for different kinds of materials and stresses."

"*The Elastic Strength* is that unit-stress at which the permanent set is first visible, and within which the stress is directly proportional to the deformation. For stresses less than the elastic strength, bodies are perfectly elastic, resuming their original form on removal of the stress. The limit of *strain*, or deformation, within which the law holds good, is called the *elastic limit*. Beyond the elastic limit a permanent alteration of shape occurs, or, in other words, the elasticity of the metal has been impaired and a *permanent set* is produced. It is a fundamental rule for all engineering construction that materials can not safely be strained beyond their elastic limit.

"*The Coefficient of Elasticity* of a bar for tension, compression, or shearing, is the ratio of the unit-stress to the unit deformation (strain), provided the elastic limit of the material be not exceeded. Let 'S' be the unit-stress, 'e' the unit deformation, and 'E' the coefficient of elasticity. Then, by the definition $E = \frac{S}{e}$ and $S = Ee$. By law (2) 'E' is a constant for each material, until 'S' reaches the elastic limit. Beyond this limit 'e' increases more rapidly than 'S,' and the ratio is no longer constant. Since 'E' varies inversely with 'e,' the coefficient of elasticity may be regarded as a measure of the stiffness of the material. The stiffer the material the less is the change in length under a given stress, and the greater is 'E.' The values of 'E' for materials have been determined by experiments with testing machines. 'E' is necessarily expressed in the same unit as the unit-stress. 'E' is also called the *Modulus of Elasticity*."

4. **The Most Necessary Physical Qualities of Metals** used in steel gun-making are great tensile strength combined with high elastic limit, toughness, and the required hardness to endure the wear in the bore due to the erosive action of the powder gases, and the friction or balloting of the projectile.

Guns have been made of various metals, principally bronze, cast iron, wrought iron, steel, and nickel steel. At the present time (March, 1903), all the high power guns in use in the Navy are made of steel. Forgings for 12-inch, 10-inch and 7-inch guns are now being made of nickel steel; and it is probable that nickel steel will replace steel in gun-making. Nickel steel gun barrels have been used for the past seven or eight years for sporting fire arms, and for Army and Navy magazine rifles.

As we are especially interested in the metals now used in gun-making (steel, and nickel steel), only a brief mention will be made of the others:

5. **Bronze,** an alloy of copper and tin, is expensive, too soft for the bores of large rifled guns, is injured by the heat of high charges, and is liable to flaws due to the segregation of its constituents. It is very ductile, is tough, but is low in elastic limit and tensile strength. It is now used for minor parts subject to no great strain, as sight brackets, hand wheels, liners to avoid the wear of steel against steel, etc. Bureau of Ordnance requirements: Tensile strength 30,000, elastic strength 13,000, elongation 25 per cent, contraction 25 per cent.

6. **Cast Iron** is cheap, easily worked, but of low elastic limit and tensile strength. It can be fuzed and cast without difficulty, and is comparatively hard. It is not malleable, and cannot be welded, and is brittle. Castings are very uncertain in character, due to the method of manufacture. Many, apparently perfect on

surface inspection, develop serious flaws in machining, and have to be rejected. Cast iron is not now used for either guns or mounts.

7. **Wrought Iron** is almost infusible, but is readily welded. Its tensile strength and elastic limit are low; but on account of its ductility, requires a large amount of work to extend it from its elastic limit to fracture, which makes it a comparatively safe material to use for guns, as a gun will give evidence of giving away before actual fracture takes place. The bores of wrought iron guns have been permanently indented or bruised by moderate firing, the metal not being hard enough. This is a serious defect under the high pressures modern guns must stand. Wrought iron is no longer used in either guns or mounts.

8. **Cast Steel** has a higher tensile strength and elastic limit than, but not so great a ductility as, wrought iron. As stated in the case of cast iron, all castings are uncertain, hidden defects often being developed only in machining.

9. **Forged Steel** combines more good qualities for use in modern guns than bronze, cast iron, wrought iron, or cast steel. It is easily fused, is malleable, and is a more or less weldable, according as it is soft or hard. It is tough and elastic, with a much higher elastic limit and tensile strength than wrought iron or cast steel. Its elastic limit, or elongation within that limit, is much higher than for the other metals above noted; and this quality makes it especially suitable for gun-making, in view of the strains which are set up in guns by heavy charges. The method of manufacture, given later in detail, increases to a great degree its elastic limit and tensile strength. The manufacture of steel has been so perfected that a very uniform product is now obtainable.

10. **Temper.**—When steel is heated to a red heat and then suddenly cooled, for example by plunging it into cold water, we say that we *temper* it, and this operation, of frequent use in industry, considerably modifies the physical properties of steel. The hardness of the metal is sensibly increased, and becomes greater as the decrease of the temperature has been greater and more sudden, or, as is said, the temper has been *stronger*. The tensile strength also varies very much, but is greater or less according to whether the temper is weak or strong. With a weak temper, the tensile

strength reaches its maximum; by afterwards increasing the strength of the temper it diminishes more and more, and finally the metal becomes as fragile as glass. The metal acquires a new property by temper—*elasticity of flexion.* This consists of the quality possessed by a finely tempered steel blade, for example a sabre blade, of returning to its original form when, after having been bent under a certain force, it is left to itself.

The properties of wrought iron are not sensibly modified by temper, which is ordinarily expressed by saying that wrought iron does not temper.

The properties of certain cast irons are considerably modified when, after having been liquefied, they are cooled suddenly; therefore we may say, from this point of view, that cast iron takes temper like steel.

To state in a few words the physical characteristics which may serve to distinguish wrought iron, steel, and cast iron, we may say wrought iron is forgeable, weldable, practically infusible, and does not temper; steel is forgeable, weldable, fusible, and takes temper; cast iron is neither forgeable nor weldable, it is relatively very fusible, and is susceptible of being tempered.

11. Distinctive Characteristics of Steel.—That which particularly distinguishes wrought iron from steel is the property possessed by the latter of receiving temper; that is, of being considerably modified by the action of temper. With a metallurgist, all metal with an iron base which is forgeable and capable of being tempered is steel; if it cannot be tempered it is simply iron.

12. Definition of Steel.—Reasoning from the foregoing, steel is a *fusible, malleable alloy of iron produced in any way whatever, and containing a smaller proportion of carbon or other hardening element than is contained in cast iron, and is capable of receiving temper.*

13. Processes for Obtaining Cast Steel.—There are a variety of processes for removing a portion of the carbon from cast iron and producing steel, that is, by removing the carbon under such conditions as to obtain a melted product; among which may be mentioned that of melting in crucibles, giving *crucible steel;* the open hearth plan, giving Siemens or *Siemens-Martin steel;* the plan of blowing air through molten cast iron, producing *Bessemer* *steel.* In whatever way made, the material is essentially the same, depending upon its chemical composition and physical structure for its properties. The open hearth process is described later on.

14. High and Low Steel.—In consequence of the extension given to the word *steel,* we understand to-day under this name metals which present considerable differences both in regard to composition and physical properties. Hence, practicians have been obliged to distinguish the varieties of steel according to their proportion of carbon—sometimes by numbers, and sometimes by more or less characteristic names. When the metal contains a large proportion of carbon, it ordinarily is called *high* or *hard steel.* If the proportion of carbon is small, it is called *low* or *soft steel,* and a still smaller proportion will be *extra low steel.* In some maufactories, for example, the name of low steel is given to a metal containing 0.20 to 0.25 per cent of carbon, and a metal in which the proportion of carbon is inferior to 0.20 per cent is designated *extra low steel.*

15. Nickel Steel.—The use of nickel in steel for gun forgings, while only of recent development, has been found to impart very desirable qualities; and this alloy, containing definite proportions of nickel, can be successfully and uniformly produced by the open hearth process. The physical qualities of nickel steel vary greatly, according to the amount of nickel contained. A steel containing about 3¼ per cent of nickel, has, up to the present time, been generally used for gun forgings; and much information as to its qualities has been obtained. In general, the presence of this amount of nickel (3¼ per cent) increases the tensile strength and elastic limit without causing a corresponding reduction in elongation and contraction of area; and the elastic limit is also increased relatively to the tensile strength. This condition indicates toughness. Crystallization after forging is also avoided; and a fine granular or amorphous condition results. This steel is more sensitive to temper, and it is in tempered steel that the improved qualities are most apparent. As shown by the ballistic tests of armor plate, the presence of nickel materially increases the resistance in shock. In short, the nickel improves the physical qualities of mild steel in all respects. It is thought probable that tubes of nickel steel may offer an increased resistance to the erosion of the bore of the gun as compared with simple steel. The use of nickel also permits a reduction of carbon.

Gun Forgings.

16. The Open Hearth Process.—As all gun forgings are made of open hearth steel, only that process will be considered.

Iron is obtained from its ores by melting them in large blast furnaces with coke or coal, various fluxes being added, according to the nature of the ores, to carry off the earthy matters. The metal so obtained is run into sand or metal moulds in the shape of the well known bars called "pig iron." The metal in this state is termed "cast iron," and contains various foreign elements, carbon and silicon principally. Cast iron contains by weight from 2 per cent to 5 per cent of carbon, which exists in two states, either chemically combined with the iron or mechanically mixed with it. If we remove the carbon from the cast iron so that the amount is less than 2 per cent, we have either wrought iron or steel, according to the amount of carbon removed, the subsequent treatment of the metal, or both combined. Theoretically, wrought iron approaches to pure iron, and contains from .1 to .3 per cent of carbon. Extra soft or *low steels,* however, contain no greater proportion of carbon than this. Melted cast iron is reduced to wrought iron by puddling, or boiling, by the mere oxidation, or burning out, of the excess of carbon and silicon from the cast iron.

17. "* **The Regenerative Gas Furnace** was invented by William Siemens, afterwards Sir William. A Frenchman named Martin used this furnace, developing what was known for some years as Siemens-Martin steel, or open hearth steel; but now known only as open hearth steel.

"At first, open hearth steel was made upon a specially prepared sand bottom, by first melting a bath of cast iron and then adding wrought iron to the bath until, by the additions of wrought iron and the action of the flame, the carbon and silicon of the cast iron were reduced until the whole became a mass of molten steel. Sometimes iron ore is used instead of wrought iron as the reduc-

* Steel, William Metcalf.

ing agent; this is called the pig and ore process. Now in general practice, wrought iron, steel scrap, and iron ore are used, sometimes alone and sometimes together, as economy and special requirements make it convenient. This is known as the open hearth process.

"The fact that the phosphorus of the iron remained in the steel notwithstanding the active combustion and high temperature, led to the dictum that at high temperatures phosphorus could not be eliminated from iron. This conclusion was credited because, in some of the so-called direct processes of making iron when the temperature was never high enough to melt steel, all, or nearly all, of the phosphorus was removed from the iron. For many years steel makers the world over worked upon this basis, and devoted themselves to procuring for their work iron containing not more than ten points (.10 per cent) phosphorus. Two young English chemists, Sidney Gilchrist Thomas and Percy C. Gilchrist, concluded that the question was one of chemistry, and not one of temperature; and set to work to obtain a basic lining, and to produce a basic slag which should retain in it the phosphorus of the iron. They succeeded, and produced a steel practically free from phosphorus. For the practical working of their process, it was found better, or necessary to use iron low in silicon and high in phosphorus, using the phosphorus as a fuel to produce the high temperature necessary, instead of the silicon of the acid process. In the acid process, it is found necessary to have high silicon—2 per cent or more—to produce the temperature necessary to keep steel liquid; in the Thomas-Gilchrist process phosphorus takes the place of silicon for this purpose. This discovery, first applied in working out the basic Bessemer process, was tried in the open hearth; a basic bottom of dolomite, or of magnesite, was substituted for the acid sand bottom, and care was taken to secure a basic slag in the bath. Success was greater than in the Bessemer process; phosphorus was eliminated and a product better in every way obtained. This, the basic open hearth process, is now used extensively over the whole civilized world.

"Neither the basic nor the acid process removes sulphur, so that this element must still be kept low in the original charge, until some way be found for its sure and economical elimination.

If too much sulphur be present, the steel can not be worked conveniently under the hammer."

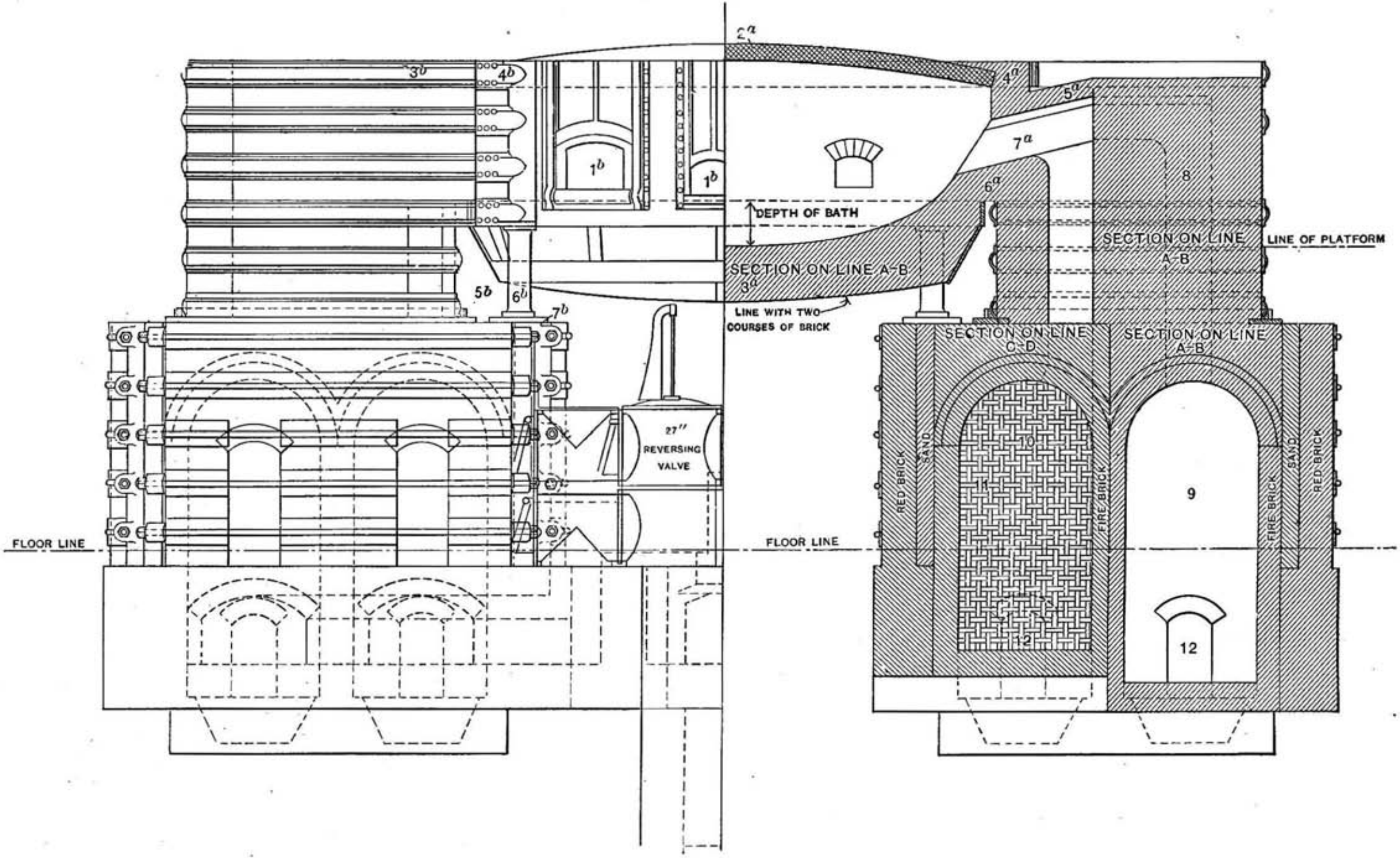
18. "**Carbon.**—In the acid open hearth process, it is usual to burn the carbon out almost entirely, and then add the desired amount with the spiegel-eisen or ferro-manganese. Higher carbon may be obtained by the addition of pure pig iron. In good practice, the melt is stopped at the carbon desired with great success, thus saving time and expense. In the basic open hearth the melter, by care and good judgment, stops his melt at the required carbon; and so avoids any additional operations, unless his charge is excessively high in phosphorus, and his steel is to be very low in the same; in that case, he may have to melt clear down and recarbonize. Steel of 1.30 per cent carbon with phosphorus less than .05 per cent may be made on the basic hearth from a charge containing .10 per cent to .12 per cent phosphorus without melting below 1.30 carbon."

19. "* **The Siemens Regenerative Gas Furnace** consists of three parts; viz., (1) the producers or apparatus for the generation of the crude gas; (2) the regenerators or chambers filled with a checker work of fire-bricks, which alternately absorb and store up the waste heat of the flame and gases as they escape from the furnace hearth, and then subsequently give up this heat to the gases from the producers, and to the air for supporting their combustion, as each of them passes through the separate regenerators before meeting for combustion upon the bed or hearth of the furnace; and (3) the furnace structure proper."

Plate I shows the details of a 40-ton open hearth furnace of the Bethlehem Steel Works.

On an elevated platform are located a number of these furnaces to which the charge of raw material must be raised. During the process of melting, a small dipperful of the molten metal is, from time to time, taken out of the furnace and rapidly tested, to find out how the refining is taking place; and when the charge is ready, the metal is poured from the furnace into ladles, which in turn empty into moulds located in the casting pit underneath. Plate II shows a ladle and an end view of the pit.

* Steel and Iron, Greenwood.


2a
3b
4b
4a
5a
7a
1b
1b
6a
8
DEPTH OF BATH
SECTION ON LINE A-B
LINE OF PLATFORM
SECTION ON LINE A-B
3a
5b
6b
7b
LINE WITH TWO COURSES OF BRICK
SECTION ON LINE C-D
SECTION ON LINE A-B
27″ REVERSING VALVE
RED BRICK
SAND
10
11
FIRE BRICK
9
FIRE BRICK
SAND
RED BRICK
FLOOR LINE
FLOOR LINE
12
12

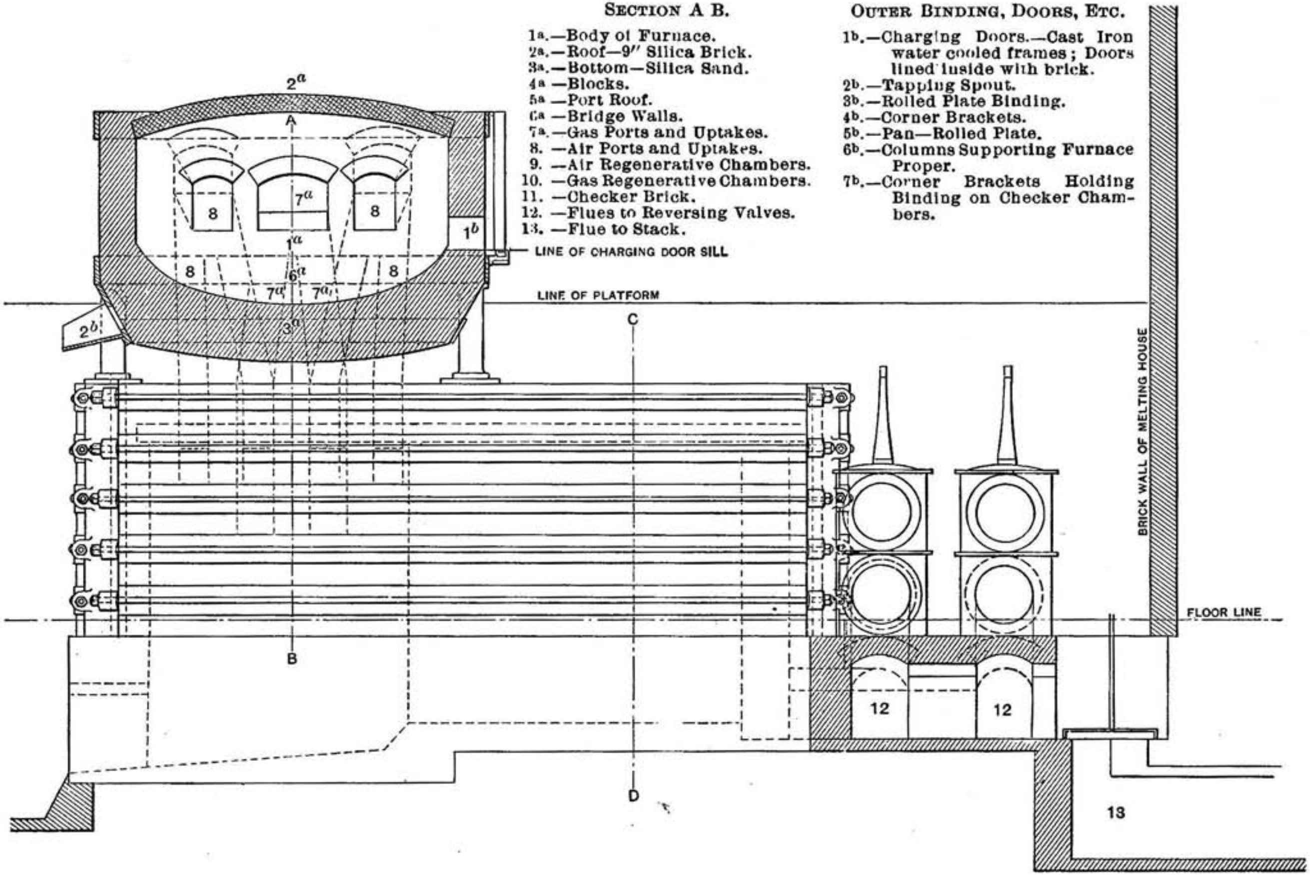
BETHLEHEM STEEL COMPANY'S 40-TON OPEN HEARTH FURNACE.

SECTION A B.

1^a.—Body of Furnace.
2^a.—Roof—9″ Silica Brick.
3^a.—Bottom—Silica Sand.
4^a.—Blocks.
5^a.—Port Roof.
6^a.—Bridge Walls.
7^a.—Gas Ports and Uptakes.
8. —Air Ports and Uptakes.
9. —Air Regenerative Chambers.
10. —Gas Regenerative Chambers.
11. —Checker Brick.
12. —Flues to Reversing Valves.
13. —Flue to Stack.

OUTER BINDING, DOORS, ETC.

1^b.—Charging Doors.—Cast Iron water cooled frames; Doors lined inside with brick.
2^b.—Tapping Spout.
3^b.—Rolled Plate Binding.
4^b.—Corner Brackets.
5^b.—Pan—Rolled Plate.
6^b.—Columns Supporting Furnace Proper.
7^b.—Corner Brackets Holding Binding on Checker Chambers.

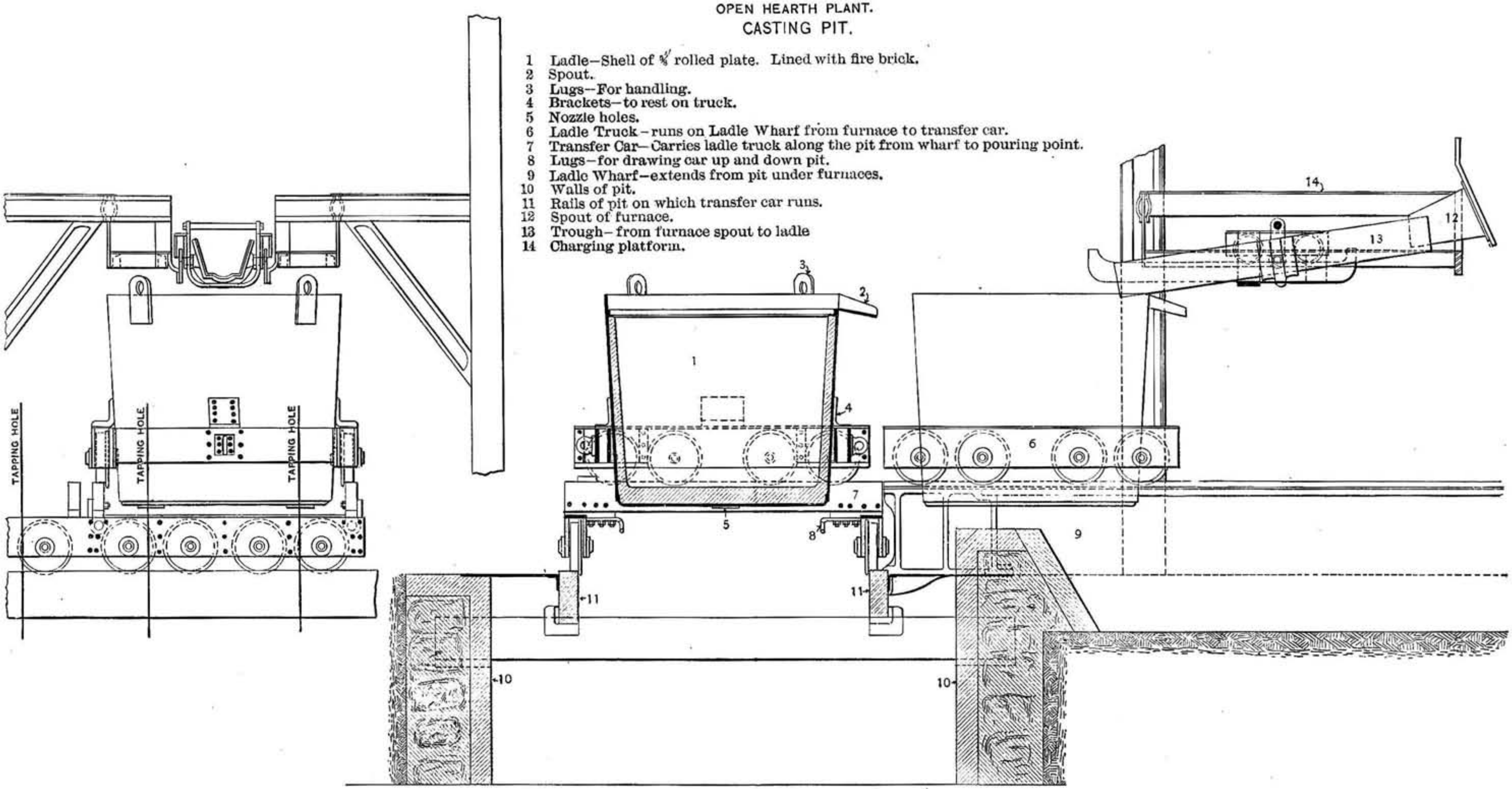


THE BETHLEHEM IRON CO.

OPEN HEARTH PLANT.

CASTING PIT.

1 Ladle—Shell of ⅜″ rolled plate. Lined with fire brick.
2 Spout.
3 Lugs—For handling.
4 Brackets—to rest on truck.
5 Nozzle holes.
6 Ladle Truck—runs on Ladle Wharf from furnace to transfer car.
7 Transfer Car—Carries ladle truck along the pit from wharf to pouring point.
8 Lugs—for drawing car up and down pit.
9 Ladle Wharf—extends from pit under furnaces.
10 Walls of pit.
11 Rails of pit on which transfer car runs.
12 Spout of furnace.
13 Trough—from furnace spout to ladle
14 Charging platform.



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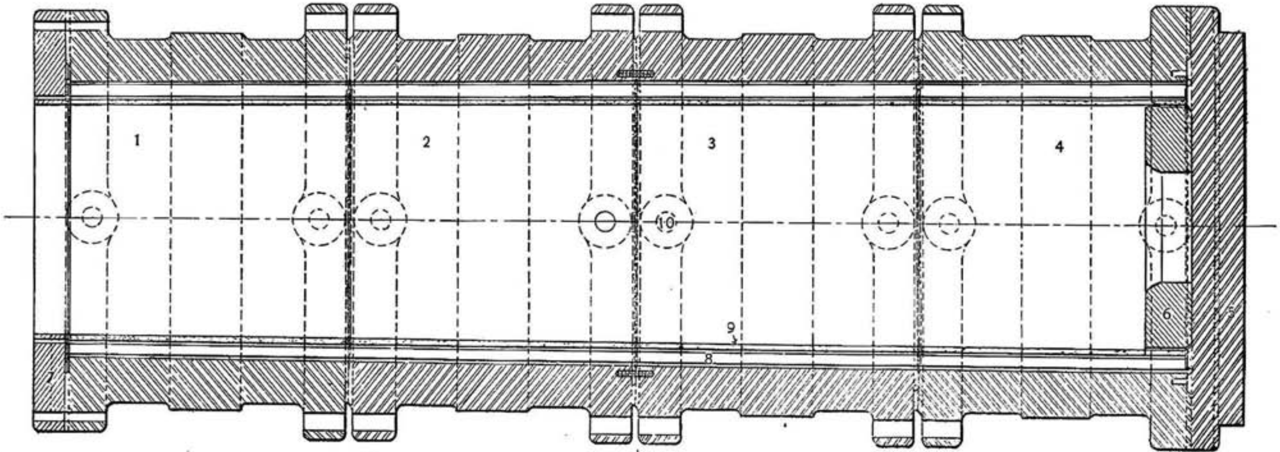
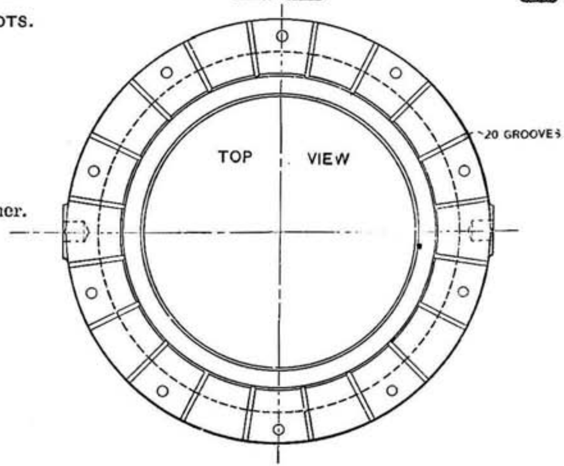


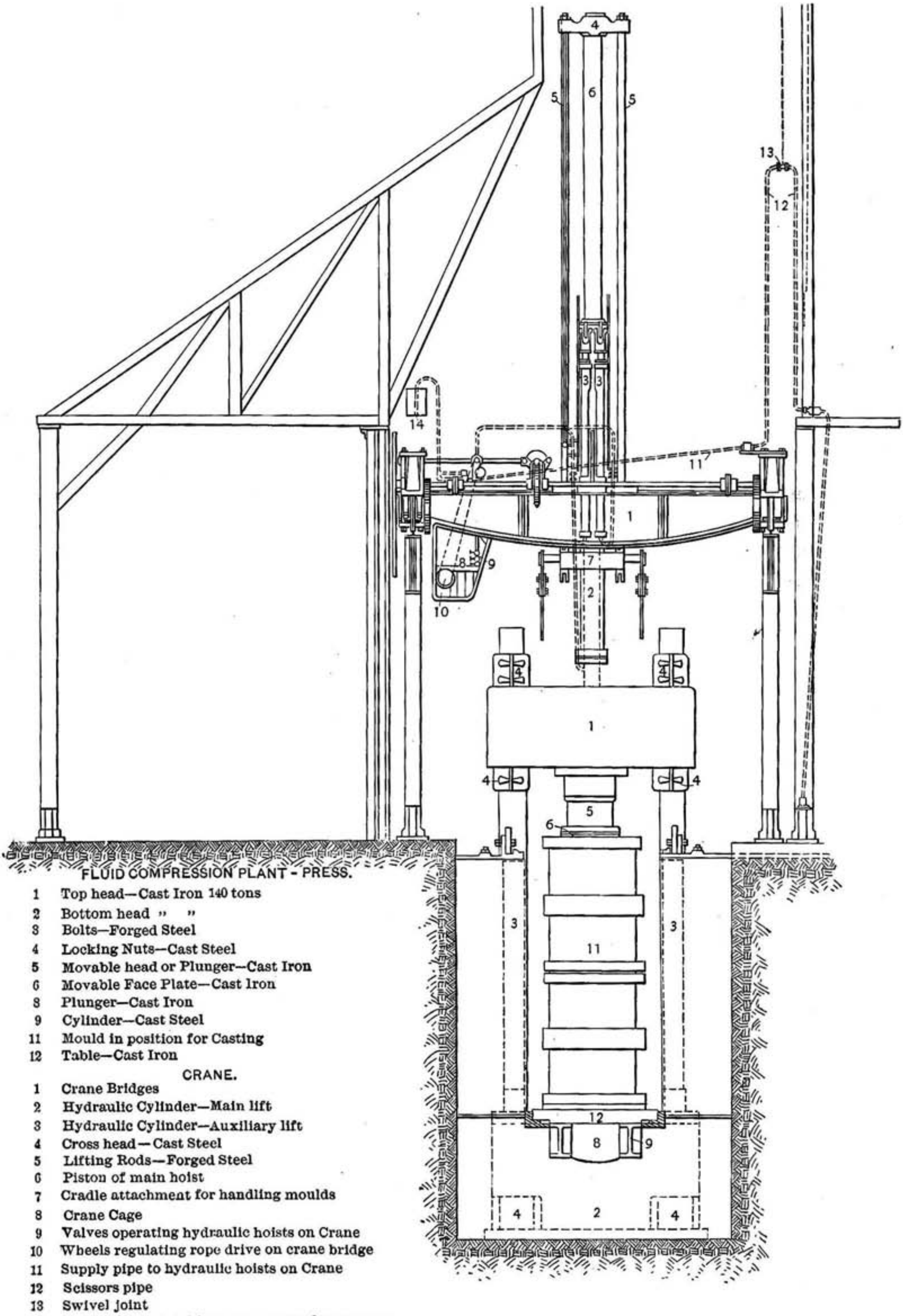
42"RD. MOULD FOR POURING FLUID COMPRESSED INGOTS.

1 2 3 & 4	Sections of mould.	Cast Steel.
5	Bottom	Cast Iron
6	Well Plate	" "
7	Top Ring	" "
8	Staves	" "
9	Lining	Sand
10	Holes for pins for Handling.	

Bottom is clamped on. Sections are bolted together.
Grooves in joints for gas vents.



THE BETHLEHEM IRON CO.
42-INCH INGOT MOULD.
FLUID COMPRESSION PLANT.



FLUID COMPRESSION PLANT - PRESS.

1 Top head—Cast Iron 140 tons
2 Bottom head " "
3 Bolts—Forged Steel
4 Locking Nuts—Cast Steel
5 Movable head or Plunger—Cast Iron
6 Movable Face Plate—Cast Iron
8 Plunger—Cast Iron
9 Cylinder—Cast Steel
11 Mould in position for Casting
12 Table—Cast Iron

CRANE.

1 Crane Bridges
2 Hydraulic Cylinder—Main lift
3 Hydraulic Cylinder—Auxiliary lift
4 Cross head—Cast Steel
5 Lifting Rods—Forged Steel
6 Piston of main hoist
7 Cradle attachment for handling moulds
8 Crane Cage
9 Valves operating hydraulic hoists on Crane
10 Wheels regulating rope drive on crane bridge
11 Supply pipe to hydraulic hoists on Crane
12 Scissors pipe
13 Swivel joint
14 Sheet Iron tank taking waste water from cranes.

THE BETHLEHEM IRON CO.

GENERAL ARRANGEMENT OF CASTING PRESS AND CRANES.

20. The Casting of the Ingot.—Steel ingots for guns are cast solid by the Whitworth process, and are known as fluid compressed steel. The object of compressing the liquid metal in the mould immediately after casting is to get rid of the blow holes, and to obtain a metal of high density. Blow holes are cavities caused by air imprisoned when pouring the metal into the mould; at certain stages in cooling, gas is generated, also causing blow holes.

21. The Flask.—The flask into which the molten metal is poured from the ladle is made of steel, and is built up of sections united by broad flanges bolted together in such numbers as to accommodate the length of the ingot to be cast. The interior of the flask is lined with long rods square in section, longitudinally arranged, which form when in place a complete cylindrical interior surface. Where the square edges of these rods meet they are cut away, both on the inside and on the outside, and, at intervals of two inches, small holes are drilled through between the rods, forming a channel way from the interior to the exterior for the passage of gas and flame. The interior is then lined with moulding composition. The flange at the bottom of the flask, as well as that at the top, is perforated with small holes which act as a continuation to the perforations between the segments of the lining for the escape of gas. The details of the mould for pouring fluid compressed ingots are shown in Plate III.

22. Fluid Compression.—The metal is poured directly into the mould from the top. The mould is then moved (by means of a railway at the bottom of the casting pit, which is a deep trench running parallel to the position of the furnaces) to a position under the movable head of the press which is allowed to descend until the piston is in contact with the metal in the mould, and in this position it is locked; a shower of metal is caused, which ceases almost immediately, by the complete closing of the mould. The first impress felt by the metal is due to the weight of the press alone. This pressure is gradually increased from below by hydraulic action, applied by four rams upon the table on which the flask rests, until the pressure exerted amounts to 6 tons per square inch. During the period of compression, the flow of gas and flame from the apertures in the flanges of the flask, at top and at bottom, is continuous and violent, exhibiting the practical effect of the compression. This pressure is applied by the direct action of steam and pumping engines, and is indicated by a dial. After the maximum pressure is reached, the pump is taken off, and a uniform pressure of about 1500 pounds per square inch is established by attaching an accumulator to the press, and allowed to remain until the metal is sufficiently cool to insure no farther contraction in the mould.

The contraction in length in the mould during the action of the pump, while the maximum pressure is being reached and sustained, amounts to one-eighth the length of the ingot. After this effect has been produced, there is no farther advantage derived from the pressure in the way of eliminating impurities, but the contraction in cooling still goes on, and the pressure by the accumulator is considered necessary in order to follow up the metal as it contracts, to prevent cracks being started at the end and on the exterior of the ingot by the adhesion of particles of the metal to the sides of the mould. The details of the fluid press, mould, and cranes are shown in Plate IV.

23. Defects of Ingots.—Besides blow holes, ingots often show "piping" and "segregation." The metal, when it is poured into a mould, cools and solidifies first at the surface of the mould; and, as the solid metal keeps cooling toward the center, it shrinks and draws away from it. This shrinkage draws principally from the center and top, these being the parts that solidify last. It is, therefore, to take care of this shrinkage that more metal is added to the length of the ingot than would otherwise be required. The hydraulic pressure applied at the top forces the fluid metal from this added part down through the center, and keeps the latter filled where otherwise there would be a cavity or "pipe." Segregation occurs principally in large ingots. This is a separation of the various ingredients of steel (sulphur, phosphorus, manganese, silicon, &c.), each of which has its own temperature of cooling. As the mass cools, the tendency of these ingredients is toward the central and upper portions where it cools, thus forming a central core of impurities. Even the fluid compression does not entirely prevent this. A solid ingot is, however, obtained, which is absolutely necessary, as steel will not readily weld; so that original defects in the ingot cannot be later remedied by hammering.

24. The Discard.—The extra length, having served its purpose of supplying metal to fill "blow holes" and "pipes," and of collecting segregation, is cut off and returned to scrap.

With fluid compressed ingots, the required discard is 10 per cent of the weight of the ingot from the upper end, and three linear inches from the lower end.

25. The Mandrel.—The ingot, after being cored, is forged on a mandrel. A mandrel is merely a cylindrical steel shaft (sometimes hollow, and sometimes solid), with a long tail piece, or handle (either forming part of the mandrel, or screwed into it at each end). The ingot is forged down over the body of the mandrel, thereby decreasing in exterior diameter, but increasing in length. By a skilled man, the ingot can be prevented from sticking to the mandrel; occasionally, however, it is necessary to withdraw the mandrel by means of a hydraulic tool.

Forgings are to be annealed, then oil tempered under such conditions as will assure their resistance, and again annealed. The last process must be an annealing one.

26. Forging.—The re-heating of the ingot before forging is a delicate operation, as great care must be taken to make the heat penetrate the metal slowly and uniformly. As already explained, the metal in the ingot, during the process of cooling, is being drawn out in all directions to fill the mould. When it is cold therefore, it is in a condition of strain throughout its interior. If it were put cold into a hot furnace to be re-heated, the surface metal would immediately expand, and draw further away from the center, causing an additional strain on the inside metal. In very large ingots, cracks are thus apt to form in the center, and the forgings are liable to break later in service, from the fact that they have not been properly re-heated.

Then comes the forging process proper. The pressure applied should be such as to penetrate the ingot to the center, causing a flow of metal throughout the mass. This flow of the metal requires a certain amount of time, during which the pressure must be maintained. Under the slow motion of the forging press, time is allowed for the molecules of the metal to move easily, and the pressure is felt throughout the forging. During the period of forging, a great deal of work is put into the metal.

In the manufacture of hollow forgings, the conditions of shaping are in all respects favorable to the production of sound work of the highest quality. The axial hole into which the mandrel fits removes the portions made defective by segregation and piping; and renders visible any interior defects which have not been removed by boring. The bored ingot forms a hollow cylinder with walls much thinner than the cross section of the solid ingot; this greatly facilitates heating and practically removes the danger of internal cracking during heating. The forging of the comparatively thin walls of the cylinder over a solid mandrel makes it possible to turn the forging out at a low and uniform heat, thus fixing a uniformly fine or amorphous grain. A solid forging, on the other hand, of the same outside diameter, would be much hotter toward the central axis than on the outside; and the gradual loss of this high internal heat will tend to coarse the grain by crystallization, and set up interior strains. In the hollow forgings, any internal defects are visible, while their presence in solid forgings are hidden and can only be disclosed by boring.

27. **Reduction of Cross Section by Forging.**—For tubes, plugs, and mushrooms, each ingot will be reduced in diameter, by forging, at least 50 per cent at the largest diameter of the piece, and at no point less than this. For jackets, each ingot will be reduced in diameter, by forging, at least 40 per cent at the largest diameter of the jacket, and at no point less than this.

In case tubes are forged on a mandrel from bored ingots, the walls of the ingots at all points must be reduced in thickness by forging, at least 50 per cent. In case jackets and hoops are forged in the same way, the walls of the ingots at all points must be reduced in thickness, by forging, at least 40 per cent.

In case hoops are forged from solid ingots by upsetting and punching and subsequent elongation or enlarging on a mandrel, the walls at all points must be reduced in thickness, by forging on the mandrel, at least 33 per cent.

28. **Annealing.**—The next process is that of annealing. The primary object of annealing is to relieve the internal strains set up by forging, and by the rapid and irregular cooling during and after forging. Further, annealing alters the molecular condition of the steel, and when applied under proper conditions, has a ten-

dency to break up crystallization and fix a finer or more nearly amorphous grain, whereby the toughness of the material is increased.

To anneal steel, the ingot is heated to a red heat, and then left to cool slowly. The particles thus readjust themselves to a normal condition. This may be done in a furnace by drawing the fires after heating, or by packing the ingot with cast iron borings or ashes so that it is protected from the air; the process sometimes takes several days for a large ingot. The general effect of annealing, as indicated by the tensile tests of specimens, is to lower the tensile strength and elastic limit and to increase the elongation and contraction of area.

29. **Tempering, or Hardening,** of steel forgings consists in cooling them rapidly, usually by immersion in oil, from a red heat varying in degree according to conditions, and hence it is generally spoken of as *oil tempering*. The object of this treatment is, first, to break up the irregular and more or less laminated and coarse crystalline structure produced by forging, and to fix a fine or amorphous condition of grain; and second, to modify the physical properties of the metal, with a view of obtaining the most desirable combination practicable.

The sudden cooling in oil, or otherwise, naturally produces strains which, unless properly guarded against and relieved, are hurtful, and, under certain conditions, may be so great as to cause actual rupture. To avoid this latter danger, precautions as to shape as well as to composition and heating are necessary, but of first importance is the removal, when possible, of the metal along axial lines before tempering, so as to effect internal as well as external cooling. This must often be done by machining, but it is evident that forging hollow furnishes a product especially adapted to tempering.

30. **The Process of Tempering.**—A tube of steel is lifted by a powerful crane and placed in a perpendicular position in an upright furnace which has been previously heated with wood or gas fuel to a red heat. It rests on an iron shoe placed on the grate bars to prevent the cold air from coming in contact with its extreme end. Great care is taken to heat the mass uniformly.

The amount of heat received by the steel is judged by eye—the color of the heat being the guide—and by long practice and attention. The more uniform the temperature, the straighter the tube will keep, and the more even its temper. After the steel has acquired the proper uniform temperature throughout, the traveling crane is brought over the furnace, its top removed, and the large iron tongs, pendent from the crane, fasten themselves to the steel tube; a small collar being upon its end to prevent the tongs slipping.

31. **The Oil Bath.**—The tube of steel is now drawn out of the furnace and sunk into a large iron tank of suitable depth containing several thousand gallons of oil. The heated steel, in passing into the oil will sometimes cause the surface oil to take fire, which is extinguished by closing the top of the tank.

A covering of coal is also formed round the steel by the burned oil, which greatly retards transmission of heat.

The tank has a water space surrounding it, and as the steel parts with its heat, raising the temperature of the oil, the temperature of the water is also raised. The water, as it is heated, is drawn off by an escape pipe, and a supply of cold water is continually running in, so that the heat is gradually taken from the mass. Exceeding toughness is the result of the operation; the tensile strength of the steel is made higher, and it is harder and more elastic.

32. **Re-annealing.**—*Annealing is again resorted to after tempering;* first, to relieve strains, and secondly, to soften the metal to a degree required to obtain the physical qualities aimed at. The effect of this double treatment—tempering and annealing—as indicated by tensile tests, is, in general, to increase the elastic limit relatively to the tensile strength, and, when the hardness is "drawn" by annealing, to increase materially the elongation and especially the contraction of area.

33. **Specimens** are now cut from the forging, before delivery to the gun-maker, to determine if it meets the requirements of the specifications.

34. **Recapitulation of Processes.**—The various processes through which the steel passes may be stated in their order as follows: casting, forging, annealing to get rid of stains induced by forging, tempering, and re-annealing. The last process, by whatever method followed, must be an annealing one.

35. The Effect on the Physical Properties of Steel of Oil Tempering and Annealing.—The effects of temper vary with the nature of the steel, and are much more pronounced as the steel is more carbonized and homogeneous.

The following table, from tests made by the Navy Department, will give an idea of the effect of oil temper on the physical properties of mild or medium hard steel, for example:

ELASTIC STRENGTH.		TENSILE STRENGTH.		ELONGATION.	
Before tempering. Tons.	After tempering. Tons.	Before tempering. Tons.	After tempering. Tons.	Before tempering. Inches.	After tempering. Inches.
13	29.2	26.8	45.2	.737	.433
13	27.8	27.8	46.0	.707	.345
12	26.0	27.6	39.6	.713	.420
12	25.8	28.0	41.0	.633	.480
13.77	34.15	28.11	49.8	.596	.260
12.18	34.8	26.9	49.4	.564	.202

Thus it will be seen that the elastic strength is more than doubled, the tensile strength raised more than 60 per cent, while the elongation is reduced over 40 per cent.

The re-annealing process reduces the tensile and elastic strength from 10 to 15 per cent, and restores the ductility, as measured by the elongation, from 25 to 40 per cent.

36. Determination of the Physical Properties of Metals.—This is accomplished by subjecting specimens of the metal to the action of different stresses in testing machines, and observing the effect on the specimens in alteration of volume and figure by means of accurate measuring instruments.

37. Testing Machines.—The testing machines are generally a combination of levers for recording the stress, and a system of gearing or hydraulic machinery by which the stress is produced.

Specimens are usually prepared to an adopted shape. In the case of gun metals they are cylindrical, and are turned to the same diameter for a certain length, usually not less than two inches and not more than ten inches for tensile tests; and in addition, ends are allowed for the purpose of attaching the specimen to the machine. For compressive tests the specimen is also cylindrical, the height being twice the diameter. The capacity of the machine limits the diameter of these specimens.

In making a tensile test the specimen is marked at two points as far apart as the finished length between grips will allow, and the length is carefully measured between these points. The diameter is also measured by micrometer calipers. It is then placed in the machine and subjected to successive tensile stresses, the elongation being noted for each stress, both when the load is on and after it has been removed. When a permanent set equal to the smallest division the measuring instrument is capable of recording is shown, the elastic limit has just been reached within the limits of accuracy of the instruments, and the corresponding stress is the elastic strength of the metal. It is usual to increase the load by small increments when near the elastic strength. If the elongation is not noted, the elastic strength may approximately be determined by watching the weighing lever as the increments of the load are put on, and if the lever remains steady, the limit has not been reached; but when a load is put on and the lever falls after it has recorded the stress, it shows that the metal has permanently stretched. The corresponding strength is then the elastic strength approximately. The elastic elongation should, however, be recorded whenever possible. After the determination of the elastic strength, the specimen is subjected to further stress until rupture takes place. The highest record made by the weighing bar is the *tensile strength*. After rupture, the pieces are joined, and the distance between points measured. The percentage of total elongation is thus determined. Similarly, the percentage of reduction of area is found by measuring the diameter at the point of fracture.

To obtain the elastic strength for compression, a compressive stress is put on the specimen, and the height of the cylinder carefully measured: the stress which produces the smallest permanent set observable is the elastic strength for compression within the limits of the accuracy of the instruments.

Finally, the results are reduced to a standard for area and length. Tensile and elastic strengths are expressed in pounds or tons per square inch; elongation, as elongation per inch, or per cent of elongation per total length.

38. Comparative Strength of Forgings.—It will be seen from an inspection of the tables in par. 57, showing the requirements of the Navy Department regarding the elastic and tensile strengths of tubes, jackets and hoops, that the hoops are stronger than the jackets, and the jackets stronger than the tubes. Manifestly it would be desirable that the opposite rule should obtain—that the tube should be the strongest part of the structure. The explanation is to be found in the fact that it is impossible to make a *large* mass of steel as nearly perfect as a *small* piece. The smaller the forging the more uniform its texture and the more readily and the more perfectly will it yield to the processes of annealing, tempering, etc.,—the processes that affect its tensile and elastic strength. The Navy Department is forced to recognize these facts in its specifications. This matter will be referred to later on in discussing the principles of gun construction.

39. Inspection of Forgings.—To ensure compliance with all specifications the Bureau shall have the right to keep agents or inspectors at the works where the guns and mounts are built, who shall have free access to all parts thereof, and who shall be permitted to witness all the processes of manufacture, and to examine all the contractor's records with reference to such matters.

40. Forgings are to be made of open-hearth steel, of domestic manufacture, from the best quality of raw material, uniform in quality throughout the mass of each forging and throughout the whole order for forgings of the same calibre, and free from slag, seams, cracks, cavities, flaws, blowholes, unsoundness, foreign substances, and all other defects affecting their resistance and value.

41. Forgings are to be annealed, oil tempered under such conditions as will assure their resistance, and again annealed. No piece will be accepted, nor will its test specimens be broken or considered, unless the last process has been an annealing one. The forging must be left with a uniform fine grain.

42. All pieces forged solid must be annealed and otherwise treated after being rough bored and turned to the above dimensions. Pieces forged on a mandrel may be annealed before being rough bored and turned. Hoops whose forged thickness is less than 4 inches may be treated and tested before being rough bored and turned.

43. The contractor must deliver each forging and casting in such condition as to allow of its being finished true and to the dimensions that were standard at the time said piece was rough bored and turned, ordinary care being exercised in machine work.

44. If the inspector finds that any part of a forging has received less hammering or other beneficial treatment than it should properly have received, as compared with the parts from which test bars are to be taken, the piece will be rejected.

45. After the final forging, all heating must be uniform or uniformly graded throughout the entire piece, and all heating for tempering and all immersing shall be executed with the forging in a vertical position. The whole of the piece must be subjected to the treatment at the same time.

46. The contractor shall state for each piece, in writing, the exact treatment it has received.

47. The inspector shall examine all fractures of the metal, in the course of manufacture, for the purpose of determining whether it is of uniform and homogeneous structure.

48. **Tests and Acceptance.**—Forgings presented for provisional tests and acceptance will be critically inspected for defects of soundness and workmanship (as aforementioned). The records and facts as to their composition and treatment, and all other matters affecting them, will be considered, and they will be subjected to physical tests. They must conform to the requirements in all particulars, and must meet all inquiry and tests successfully in order to be provisionally accepted.

49. Physical tests will be directed toward the exhibition of all the principal physical qualities of the metal. Those to which particular attention will be devoted are tensile strength, elasticity, and extensibility.

50. These tests are to be made on cylindrical specimens 2 inches long between measuring points, ½ inch in diameter, and of the general shape shown on the appended drawings. The specimens are to be taken from the forgings after final treatment *transversely to the axis of the bore of the finished gun,* and within the finished section prolonged. They are to be taken as near the finished piece as practicable, leaving sufficient metal for submitting additional test bars in case of re-treatment.

51. Test specimens shall not be cut off until from examination the forging is known to be sufficiently straight to machine finish to the required dimensions. If any doubt as to this exists the forging must be heated and straightened and then re-annealed before testing.

52. Test bars shall be cut and tests made under the supervision of an agent or inspector of the Department, who may make the tests personally if he should so desire. He will stamp and have the custody of each test bar.

53. If the contractor provides a testing machine of a pattern approved by the Department, the tests may be made at his works; otherwise the test bars will be suitably packed and delivered by the contractor, for transportation to such place as the Department may direct. The expense of *testing* in this latter case will be borne by the Department. The contractor has the right to be present at tests outside his works. Under any circumstances the Department may, if it so elects, have the tests made at any place.

54. The contractor shall first present three specimens from each end of a tube or jacket, from the end nearest the upper end of the ingot or casting of each hoop or plug, and from one face of a trunnion band; and from mushrooms, two transverse specimens from the head and one longitudinal specimen from the stem. The central axis of these longitudinal specimens from the mushroom stem need not be nearer the central axis of the forging than one-half of the radius of the latter.

55. In case the length of any hoop forging exceeds two and a half times its interior diameter, two specimens shall be presented from each end of such forging, instead of three specimens from the upper end.

56. The specimens taken from either end of forgings shall be considered independently of those taken from the other end of the same piece.

57. If all the specimens from any forging show physical qualities in each particular equal to or exceeding the figures in the following table, the forging shall be provisionally accepted, but if more than one specimen from either end of the forging fail to do so, the forging shall be rejected:

FOR GUNS OF 8-INCH CALIBRE AND BELOW.

	Tubes.	Jackets.	Hoops.	*Plugs.	*Mush-rooms.
Tensile strength	85,000	90,000	95,000	90,000	90,000
Elastic limit	45,000	50,000	55,000	60,000	60,000
Elongation after fracture	†18	†18	†18	†18	†18
Contraction of area	†30	†30	†30	†30	†30

*Nickel steel. †Per cent.

FOR GUNS ABOVE 8-INCH CALIBRE

	Tubes.	Jackets.	Hoops.	*Plugs.	*Mush-rooms.
Tensile strength	85,000	88,000	95,000	90,000	90,000
Elastic limit	45,000	50,000	55,000	55.000	55,000
Elongation after fracture	†18	†18	†18	†17	†17
Contraction of area	†30	†30	†30	†30	†30

*Nickel steel. †Per cent.

When forgings are required to be of nickel steel the physical requirements for guns of all calibres shall be, with about 3½ per cent of nickel in all forgings, as follows:

	Tubes.	Jackets.	Hoops.	Plugs.	Mush-rooms.
Tensile strength	90,000	90,000	95,000	As prescribed for the different calibres in the above tables.	
Elastic limit	55,000	60,000	65,000		
Elongation after fracture	*18	*18	*18		
Contraction of area	*30	*30	*30		

*Per cent.

Manufacture of Armor Plates.

58. **Modern Armor** is made of steel, the face of the plates being hardened by the process of supercarbonization.

The ideal plate would be composed of a metal homogeneously hardened throughout so as to make it as hard, if not harder, than an armor piercing projectile, and at the same time so tough as not to be shattered upon impact of the projectile. But this is metallurgically impossible of attainment. The most that can be done at present is to harden the face of the plate for a certain depth, leaving the back of the plate of tough steel to support the hard face. The principle is therefore very similar to that of compound armor which was composed of a hard steel face cast and supported upon a wrought iron back.

A short history of the development of armor, and a description of the methods of applying armor to a ship, together with a discussion of ballistics, will be found in chapter XXIX.

59. **Face-hardened Armor.**—Two kinds of face-hardened armor are used in the United States Navy—the "Harvey" and the "Krupp."

The Harvey process is used for plates having a thickness of five inches and less; the Krupp, for those having a thickness greater than five inches.

Thin plates and hollow forgings, such as turret tops, doors, communication and ammunition hoist tubes, are made of homogeneous nickel steel oil or water tempered and annealed, but not face-hardened.

The bolts are of the best quality of nickel steel, oil or water tempered and then annealed, and contain about 3¼ per cent of nickel.

60. **Harvey Armor** contains carbon, manganese, silicon, phosphorus, sulphur, generally a small amount of copper and nickel. The per cent of phosphorus, sulphur and copper is kept as low as possible, while the carbon and the nickel, silicon and manganese are present in predetermined quantities.

61. **Krupp Armor** contains carbon, manganese, silicon, phosphorus, sulphur, nickel and chrome, the nickel, carbon, and chrome appearing in predetermined proportions, while the silicon, phosphorus and sulphur are kept at a minimum.

The addition of nickel (about 3¼ per cent), aided somewhat by the small per cent of manganese in the case of Krupp armor, gives great strength and toughness. The further addition of the chrome makes the metal more sensitive to temper, thereby permitting a greater depth of chill below the surface. It increases the affinity of the metal for carbon, which results in supercarbonization to a greater depth, and with careful treatment, gives the plate a tough fibrous back which resists cracking. It is this quality which marks the superiority of Krupp armor.

62. **Manufacture of Armor Plate.**—The manufacture of modern face-hardened armor comprises a series of operations which require the greatest care and attention to details to produce the best results, and these operations are so elaborate that a period

of nine months is allowed in the manufacture of service armor from the time of the receipt of the original drawings until the completion and delivery of the plates. The ingot is cast from steel made by the open-hearth process. The composition is predetermined.

63. **Casting the Ingot.**—The ingot mould is made up of cast iron sections, the parts of which are bolted together, the horizontal sections being held together by clamps. Each section contains on the interior numerous vertical webs, between which the back sand is pressed. A wooden pattern, in sections, is used, around which the facing sand (that next the ingot) is tightly pressed by rammers. The pattern is finally withdrawn, and long nails driven into the sand at close intervals to hold together the facing and the back sand, thus making the mould stronger, permitting the ingot to strip better. Outside of, and at each end of the mould, is a vertical tube or gate, each connecting with the interior of the mould at the bottom, near the middle of its length.

64. The molten metal is run from the open hearth furnace into a large ladle, which in turn is moved over a gate of the mould and then tapped. It is to get rid of the part containing segregation that the discard is made. When the mould has been filled, it is allowed to cool. The shape of the ingot is shown in the accompanying sketch. The projection on one end is for the purpose of handling the ingot.

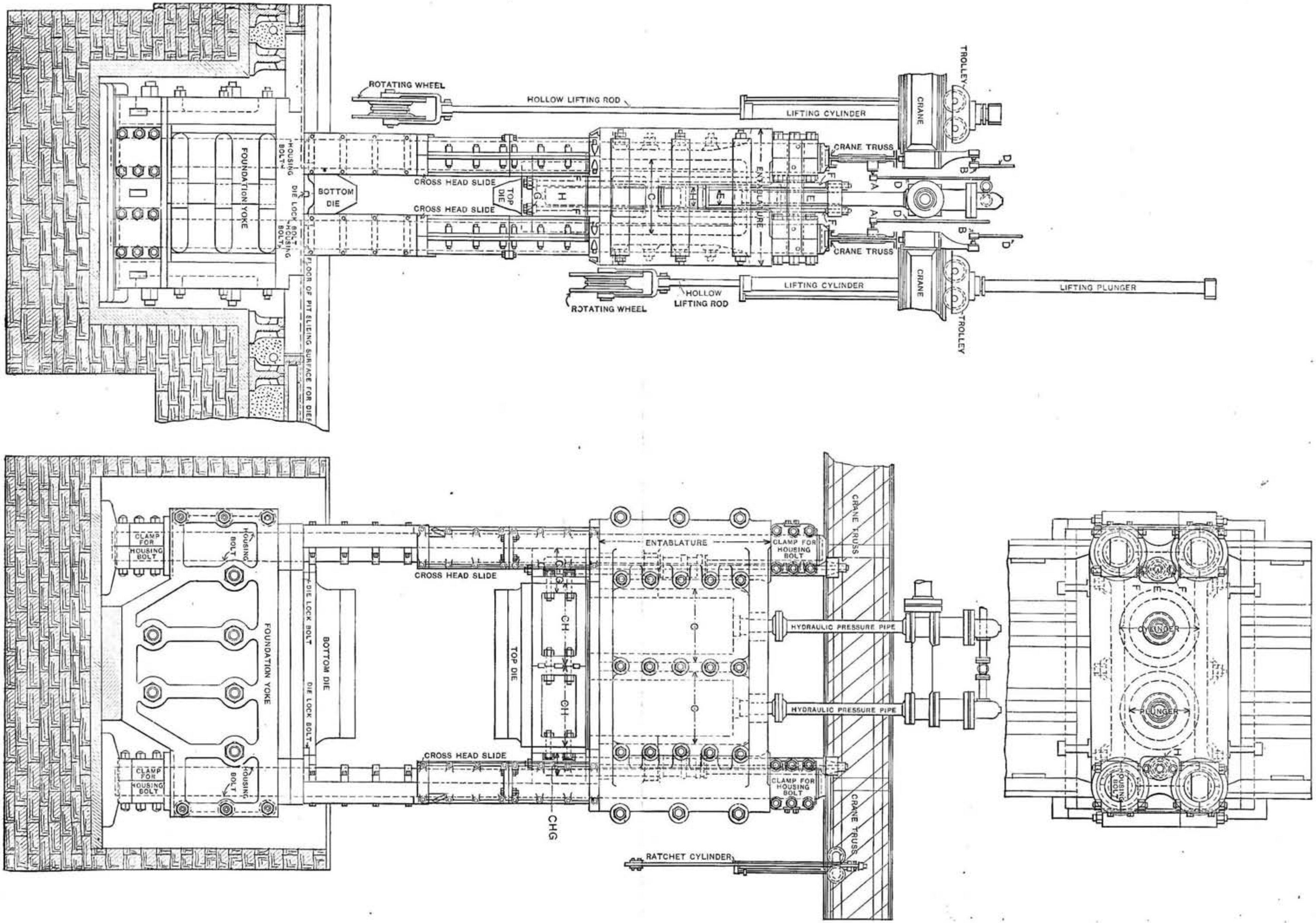
65. **Forging.**—When the ingot is cool enough, the mould is stripped away, and the ingot lifted out and cleaned. It is then sent to the forge where it is reheated in a furnace, and then forged by the forging press to a thickness somewhat greater than the finished plate.

66. **Forging Press.**—A general view of the Bethlehem Steel Company's Double Forging Press is shown in Plate V.

The construction of the press embodies a number of principal parts which are named or lettered on the plate mentioned.

The *foundation yoke* is made of heavy sections bolted together by powerful bolts.

Four vertical *housing bolts* pass through the "foundation yoke" and through the *entablature,* which is made in two parts clamped together by heavy bolts.



THE BETHLEHEM IRON CO.
50½-INCH DOUBLE FORGING PRESS.

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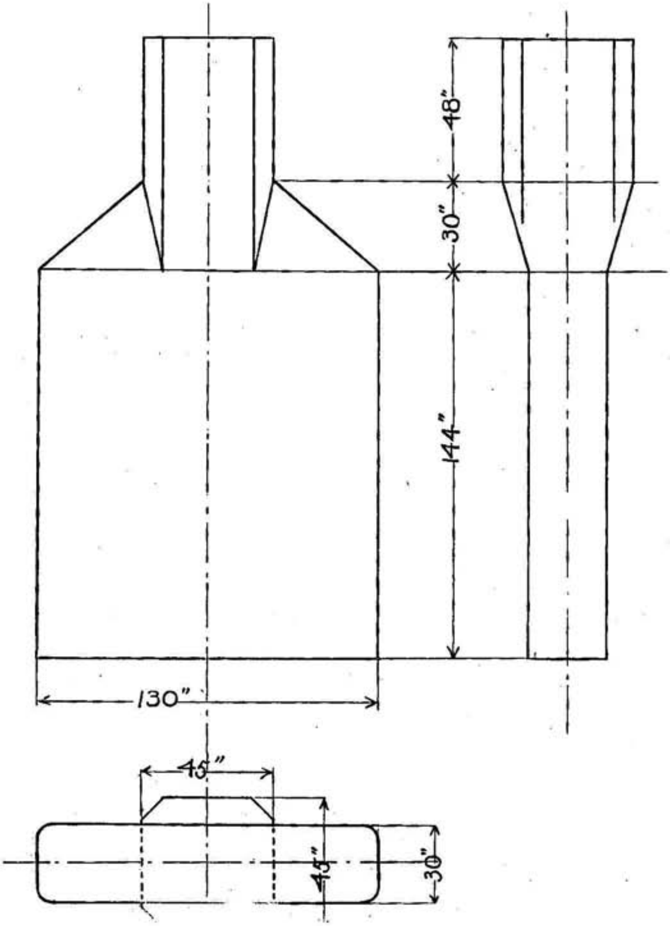
A number of parallel grooves, somewhat similar to threads, are cut at each end of each housing bolt and *split clamps* are bolted over these threaded parts, thus transmitting all strain due to forg-



Armor Ingot. Par. 64.

ing, through the housing bolts, and making of the entablature, the foundation yoke and the four housing bolts, a self-contained apparatus requiring no bracing from without.

The entablature is bored out to receive two steel cylinders (marked "C" "C") of 50½ inches internal diameter.

Within these two cylinders, two *plungers* operate with vertical motion.

Cast on the bottom end of each of these plungers and in one piece, with each plunger, are the two halves of the *cross-head* (marked "C. H.").

Bolted to each end of the cross-head are the *cross-head guides* (marked "CHG") which serve to transmit lateral strain to the *cross-head slides,* which are bolted to each of the four vertical housing bolts.

A removable *bottom die* is arranged to slide on the steel floor of the pit. This die is made either straight or tapered along its top edge according to the shape of the armor plate desired.

This die is pushed along the floor of the pit in either direction by an aparatus operated by two powerful hydraulic cylinders, which are not shown on the drawing.

The removable *top die* may be bolted to the under surface of the cross-head, and this die also, may be made of the proper shape to forge any shape desired in the armor plate. Hydraulic pressure is introduced to the interior of the cylinders by *hydraulic pressure pipes* passing through the top of the entablature and fitted into the tops of the cylinders in such a manner that the greater the pressure, the tighter the joint becomes. The engine for producing this pressure is not shown in the drawing, but is capable of producing a pressure of seven thousand pounds per square inch.

The total maximum pressure which the press is able to exert, is in the neighborhood of fourteen thousand (14,000) tons.

The seven thousand (7000) pounds hydraulic pressure is used only for driving the plungers downward, as the forging is done on the down stroke. The plungers are lifted on the stroke after each blow, by two *lifting cylinders,* one on each side of the press (marked "H").

A plunger (marked "E") operates in each cylinder ("H") which is connected to the cross-head through two lifting rods (marked "F" "F"), which pass through the cross-head guide on each side and are secured by nuts shown at "G."

In order to remove dies from the pit, to place new dies in the pit, and to handle armor-plate ingots which are being forged, two heavy traveling cranes are used with a capacity of about 250 tons each. These cranes are also used to charge ingots into the heating furnaces and to draw them from the furnaces when they are ready to be forged.

The ingots are carried in a very heavy flat link chain, similar to a bicycle chain on a very large scale.

This chain passes over a *rotating wheel,* to which rotary motion can be imparted by means of a combination of worm and spur gearing not shown on the drawing.

The worm is situated at the bottom end of a vertical shaft which passes through the *hollow lifting rod.* On the top end of the vertical shaft are arranged bevel gears which are connected through a series of shafting to a pneumatic engine situated at one end of the crane.

The hollow lifting rod is fastened at its top end to a small crosshead extending across the tops of two *lifting plungers.*

These lifting plungers operate up and down in a pair of lifting cylinders which are carried along the bridge of the crane by a heavy *trolley.*

The motion of the trolley along the bridge of the crane is obtained by means of a pair of pneumatic engines situated at one end of the crane.

The bridge of the crane is also moved along the rails on the top of the crane trusses by a pair of pneumatic engines.

All the pneumatic engines on the crane are controlled by an operator in a cage at one end of the crane.

All lifting on the crane is done by hydraulic power under a pressure of twenty-six hundred (2600 lbs.) pounds to the square inch.

The hydraulic power, as well as the pneumatic power, is transmitted from stationary connections (marked "A" "A") through hinged *scissors pipes* (marked "DD") to the moving connections (marked "B" "B") on the plate. Separate pipes are used for the water and air, although only one set of pipe connection is shown.

The lifting rods on the crane are controlled by a lever situated on the floor of the building.

67. Process of Forging.—The armor ingot being heated to a red heat is removed from the furnace by the crane, the chain being secured at the projection on the ingot, and the weight of the ingot being counterbalanced by a long, heavy beam on the opposite side of the lifting chain.

The ingot is swung easily into position and its end is pointed fair and landed on the lower die of the forging press (see Plate V). The upper die is then forced down upon the ingot, the throw being so regulated as to diminish the thickness of the ingot about 3 inches at each stroke. The metal flows evenly in all directions under the irresistible and steady pressure of the press, and after each stroke the ingot is moved along on the lower die until its thickness has been reduced by the same amount throughout its length. Its thickness is thus gradually diminished, while its length and breadth are increased until the desired dimensions are reached. This ends the operation of forging, and the plate is now ready for the process of carbonization, or face-hardening.

68. Carbonizing—Harvey Process.—After forging, the plate is face-hardened. The Harvey process of cementation, or face-hardening, is accomplished in a dry carbon furnace, the result being an integral plate supercarbonized to a considerable depth, giving an extremely hard, elastic face, bound together and supported by a tough back, having a minimum tendency to crack.

69. The Dry Carbon Furnace is built with a row of longitudinal flues under its floor. The flame from the coal comes from two fires placed at the smoke-stack end of the furnace, passes over the charge, then down vertical flues in the opposite end and then returning to stack through the longitudinal flues underneath the floor.

In this furnace two plates are generally carbonized together, the bottom plate resting on a bed of sand. The dry carbonizing material is placed on top of this plate and the other plate placed face down on the carbonizing material. The whole charge is then covered with sand to prevent contact with the flame or with air.

Two gas pipes are run through the carbonizing material into which iron rods are introduced and periodically drawn to examine the temperature of the furnace; the temperature being judged by the color to which these rods are heated.