CHAPTER A5
MANUFACTURING OF METALLIC PIPE

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DEVELOPMENT OF COMMERCIAL PIPE-MAKING

There have been increasing societal demands for modern structures and facilities and concomitant increased emphasis on safety and reliability of equipment under all operating conditions. Piping manufacturing processes have been developed to provide the quality and reliability commensurate with these demands, together with economically feasible production methods. To meet the more stringent reliability goals, the quality control of the piping manufacturing process from the production of the raw material to the finished product is of significant importance. Driving the need for process quality improvement are the social and economic consequences of equipment failure in critical applications such as power generation, chemical and petroleum production, and transportation.

This chapter considers the methods by which different types of metallic pipe are produced. It also considers the various steel-making processes which are important to the ultimate quality of the manufactured pipe. For a discussion of pipes made of thermoplastic and fiberglass, refer to Part D of this handbook.

Historical Background

The history of pipe manufacturing goes back to the use of hollow wooden logs to provide water for medieval cities. The use of cast-iron pipes in England and France became prevalent in the early nineteenth century. The first major cast-iron water pipeline for Philadelphia was obtained in 1817 and for New York in 1832. Distribution of gas for gaslights was initiated in England, using sheet iron drawn through a die to a cylindrical shape and with the edges welded together. In 1887 the first pipe was made of Bethlehem steel in the United States.

Seamless pipe manufacture was attempted in the mid–nineteenth century by various means; the Mannesmann process was developed in Germany in 1885 and operated commercially in England in 1887. The first seamless pipe mill in the United States was built in 1895.

In the early twentieth century, seamless tubes gained wide acceptance as the Industrial Revolution proceeded with automobiles, oil refineries, oil pipelines, oil wells, and fossil power generation boilers. At that time, the welded tube had not achieved the reliability of present-day electric resistance welded tubes.

The development of pipe and tube production methods, together with the development of steel alloys capable of withstanding the demanding environmental conditions of temperature, chemistry, pressure, and cyclic thermal and pressure load application have enabled pipe and tube to be used reliably in the most critical applications, ranging from Alaskan pipelines to nuclear power generation plants.

World Tubular Product Production Capability

World production and consumption of iron and steel tubular products makes up almost 14 percent of the worldwide crude steel conversion. World production of steel tubular products is continuously increasing to meet the demands of worldwide industrialization and growing population. The production of iron and steel tubular products vary depending on a wide range of worldwide economic factors such as oil exploration, power generation plant construction, and automotive production. For example, in economic climates where oil prices are low, there is less incentive to drill new oil wells. Consequently, the production of steel pipe for oil drilling casings would be reduced. Similar examples of steel pipe production as a function of economic climate can be seen in the power generation and automotive industries. Total world production of pipe is an integration of the effects of the local national economic climates throughout the world.

FERROUS PIPE-MAKING PROCESSES

Iron-Making

The making of steel for ferritic piping begins with the smelting of iron ore found in deposits in the crust of the earth throughout the world in forms such as hematite and magnetite. In preparation for the smelting process, the iron ore may be treated by any of several methods to convert it into a suitable form for introduction into the blast furnaces. One method is sintering, which converts ores into a porous mass called clinkers. Another is smelting, which is performed in a blast furnace. The process involves the chemical reaction of iron ore with limestone, coke, and air under heat, reducing the iron ore to iron. The ‘‘pig’’ iron obtained from the blast furnace is used as the basic component in the steel-making process.

Steel-Making

Steel for piping can be produced in several ways (Fig. A5.1), depending on the facilities available and the desired characteristic of the steel. Generally, steel requires

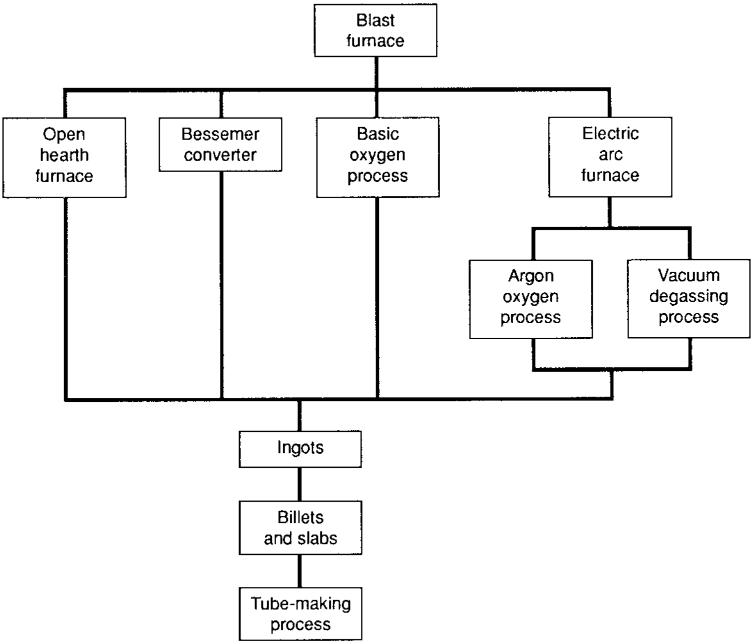

FIGURE A5.1 Piping steel-making processes.

the removal of carbon from the pig iron to a degree required by the carbon steel properties desired. Alloy steel also requires the addition of alloying elements such as chromium, nickel, manganese, and molybdenum to provide the special properties associated with the alloying element.

Bessemer Converter. The Bessemer method of making steel (due to Sir Henry Bessemer in 1856) consisted of blowing a current of cold air through the molten pig iron, thereby using the oxygen in the air to burn carbon and other impurities from the melt. After burning out the carbon in the pig iron, the exact amount of carbon required for the steel is reintroduced into the heat.

Basic Oxygen Process. The basic oxygen process (BOP) is essentially the same as the Bessemer process except that it uses pure oxygen (instead of air) together with burned lime converted from limestone. This process burns out the impurities more quickly and completely and provides for more precise control of the steel chemistry.

Open-Hearth Furnace. The open-hearth furnace is used to produce much of the steel in the United States; however, it is being superseded by the basic oxygen process. Its significant advantage is the ability to use scrap steel as well as pig iron as ferrous stock in producing steel. The open-hearth furnace is a large rectangular brick floor, or hearth, completely covered with a brick structure through which the charge of ferrous stock and limestone is introduced. It is fueled with coke gas, oil, or tar introduced through a burner playing a flame across the hearth while the products of combustion escape through the furnace wall away from the burner. An advantage of the open-hearth process is that testing for carbon content during the heating is possible, allowing adjustments to be made to the feed-stock at that time to control the chemistry of the product.

Electric Arc Furnace. The electric arc furnace is a large kettle-shaped chamber lined with fire brick, into which a charge of steel scrap with coke is melted by means of heat produced by an electric arc. Since no burning of fuel is required, the oxygen of the steel can be controlled and kept to a minimum. Alloying elements can be added without the fear of oxidation. Because of the control of heat time, temperature, and chemistry, the electric arc furnace is used in the production of high-quality alloy steels.

Argon Oxygen Process. The argon oxygen process (AOP) is used in the production of specialty steels with low carbon and sulfur and high chromium content. A charge of steel of almost the desired properties is introduced into a basic oxygen furnacelike vessel, and controlled amounts of oxygen and argon are introduced into the melt. This reducing process conserves valuable chromium.

Vacuum Degassing Process. When exceptionally high quality steel is required, steel can be ''degassed'' in a vacuum environment. This vacuum degassing process provides strong reduction in hydrogen, oxygen, nitrogen, inclusions, and contaminants such as lead, copper, tin, and arsenic.

Ingots, Blooms, and Billets. Ingots, blooms, and billets are the shapes into which the molten metal is solidified before using it in a particular pipe-making (or other) process. An ingot is poured from the molten steel and after solidification goes to the blooming mill to be rolled into square blooms, which are further formed onto bar rounds. Alternately, in the case of large pipe, the ingot may be formed into pierced billets to be used in the seamless tube-making process.

Continuous Casting Process. Although the development of the continuous casting process (Fig. A5.2) began in the nineteenth century, it was after World War II that its use became of great commercial interest. In the continuous casting process, molten steel is poured from the melting furnace to a ladle feeding a reservoir called a tundish. The tundish feeds a lubricated mold that has a cooled copper surface, and the solidifying steel is continuously drawn from the mold. In the case of piping steel, the mold is the shape of the billet or slab used in the tube-making process. There are many types of continuous casting processes, ranging from vertical to horizontal, with variations of bent sections in between. This process is now used in more than half the world's steel production. In Japan, 85 percent of the total steel produced is by the continuous casting process.

Pipe- and Tube-Forming Processes

There are basically two types of pipe- and tube-forming processes, namely, seamless and welded. Each process imparts unique properties to the pipe or tube. Seamless

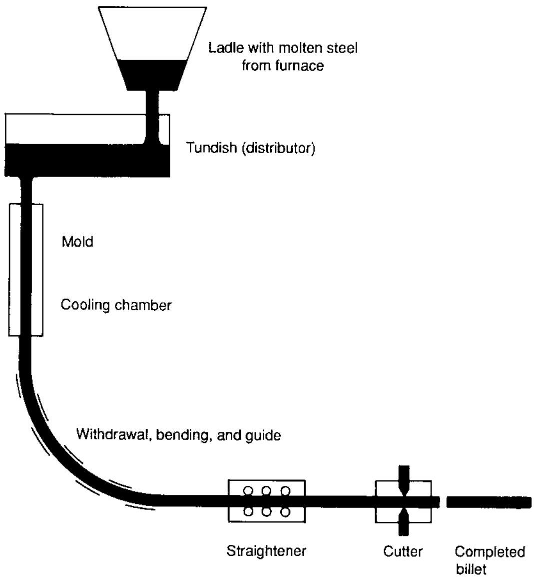

FIGURE A5.2 Continuous casting process.

pipe or tube does not have the presence of a welded seam along the length of the pipe. This seam has traditionally been believed to be a potential weakness. The development of automated welding processes and quality control, however, has made this a virtually nonexistent concern. The control of thickness uniformity and concentricity is relatively easy with welded pipe and tube. In general, the seamless pipe is more expensive to produce. The classification of cylindrical tubular products in terms of either pipe or tube is a function of end use. This is discussed further under Tubular Product Classification.

Seamless Pipe. Seamless tube and pipe (Fig. A5.3) are manufactured by first producing a hollow tube which is larger in diameter and thickness than the final tube or pipe. The billet is first pierced by either a rotary (Mannesmann) piercer or by a press piercing method. For tubes of small diameter, the mandrel mill process is used. For medium outside diameter tubes of carbon or low-alloy steel, the Mannesmann plug mill process is used. Large-diameter, heavy-wall carbon steel, alloy, and stainless pipe is manufactured by the Erhardt push bench process and vertical extrusion similar to the Ugine Sejournet type extrusion process. High-alloy and specially shaped pipe are manufactured by the Ugine Sejournet extrusion-type process. These processes are performed with the material at hot-metal-forming temperatures. Further cold processing may or may not be performed to obtain further dimensional accuracy, surface finish, and surface metallurgical structure.

Mandrel (Pilger) Mill Process. In the mandrel (pilger) mill process (Fig. A5.4), a steel billet is heated to forging temperature and placed between the rolls of a hot rotary piercing mill. A piercing point is placed at the center of the billet, and the rotating rolls are designed to advance the billet over the piercing point, thereby forming a hole through the center of the billet along its entire length as it advances

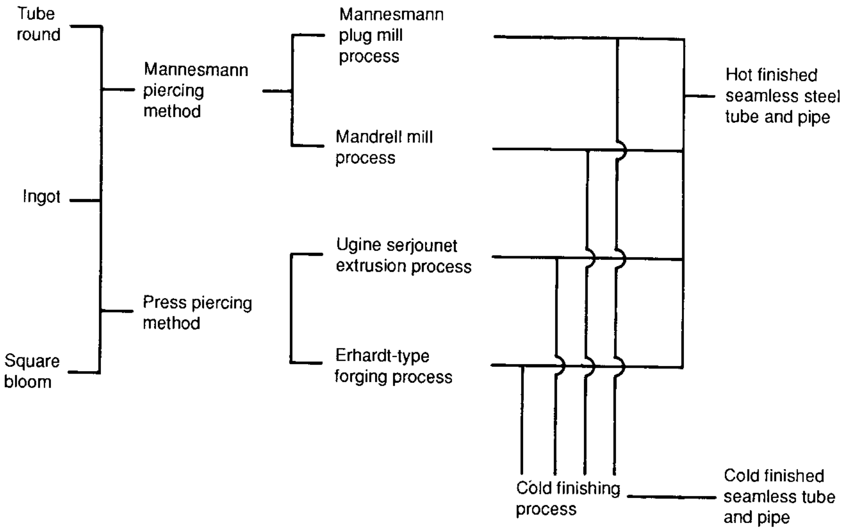

FIGURE A5.3 Seamless tube and pipe manufacturing processes.

into the tilted rolls. A mandrel of outside diameter approximately that of the inside finished pipe diameter is pressed into the pierced hole of the billet. This combination of mandrel and billet is placed between rolls of a pilger-mill having a cam-shaped contour revolving counter to the direction in which the billet is being forced by means of a hydraulic and pneumatic ram mechanism.

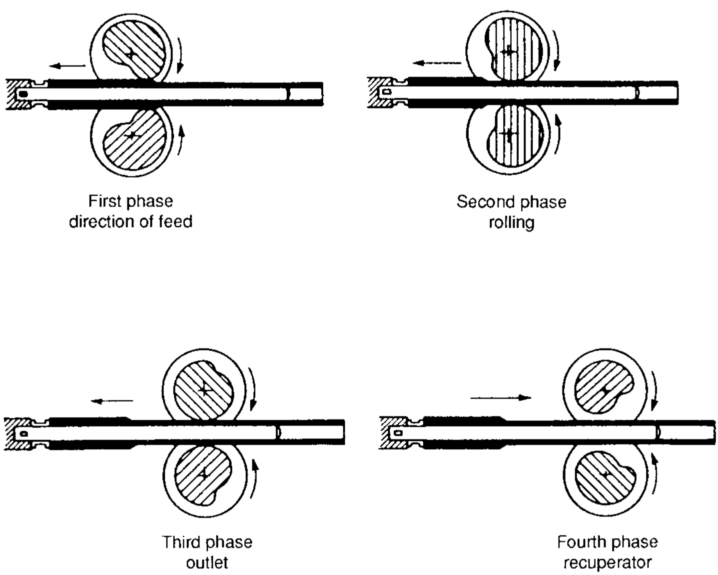

FIGURE A5.4 Mandrel (pilger) mill process.

In the pilger-mill, the rolls first grab the hot billet and after some rotation form a shaft. The pressure of the rolls forces the billet backward, and the resulting tube section is squeezed and smoothed out in the adjacent part of the roll groove. This process is equivalent to forging the billet against the mandrel and driving the billet and mandrel against the ram. After reaching the open portion of the cam shape, the ram mechanism again forces the billet into the rolls. Following the pilger-mill process, the tube is reheated and passed through a reducer or sizer to provide a more uniform diameter. The resulting tube or pipe is called *hot finished seamless*.

The pilger-mill process is slower than conventional drawing. However, since large reductions in diameter are possible in a single pass, the process is applied to the production of tubes of small diameter such as heat exchangers, fossil fuel boilers, and nuclear steam generators.

Mannesmann Plug-Mill Process. In the Mannesmann plug-mill process (Fig. A5.5) the billet may be pierced in two hot rotary piercers because of the greater reduction needed for medium-size pipe and tube. Following the piercing process, the pierced billet is placed in a plug-mill, which reduces the diameter by rotating the tube over a mandrel. Having some ovality, the tube is next inserted between the rolls of reelers which provide for dimensional correction and burnish the inside and outside diameters of the tube. Finally, after reheating, the tube reenters a reeler and sizing rollers to provide for greater dimensional uniformity.

The Mannesmann plug-mill process is a standard process for making large quantities of thin-wall stainless steel tube or pipe of uniform size and roundness throughout its entire length.

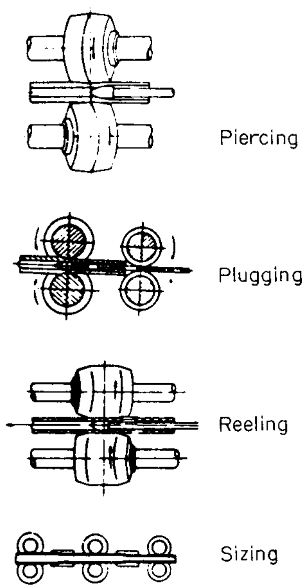

FIGURE A5.5 Mannesmann plug-mill process.

Ugine Sejournet Type Extrusion Processes. The Ugine Sejournet extrusion process (Fig. A5.6) is used for high-alloy steel tubes and pipe such as those of stainless steel and specially shaped pipe. A descaled billet, heated to approximately 2300°F (1260°C), is placed in the vertical press compartment with an extrusion die at its bottom. After applying a hydraulic ram to the billet, a piercing mandrel within the ram punches the billet, producing a cylinder from which the punch piece is ejected through the extrusion die opening. Following this, the ram is activated to apply pressure to the billet, and the billet is extruded through the annulus formed between the piercing mandrel and die cavity. In horizontal presses, piercing is done as a separate operation, or a hollow is used with a mandrel and die. The mandrels and dies are made of high-alloy steels containing tungsten, molybdenum, and chromium having Rockwell C hardness values of approximately 46. Powdered glass is the lubricant used in this process. Heavy-wall pipe in sizes NPS 8–48 (DN 200–1200), having a wall thickness ranging from 1 in (25 mm) to 6 in (150 mm), is extruded vertically to 45 ft (14 m) lengths using procedural steps in the Ugine Sejournet process and a graphite lubricant. These large extrusions of carbon-, alloy-, and

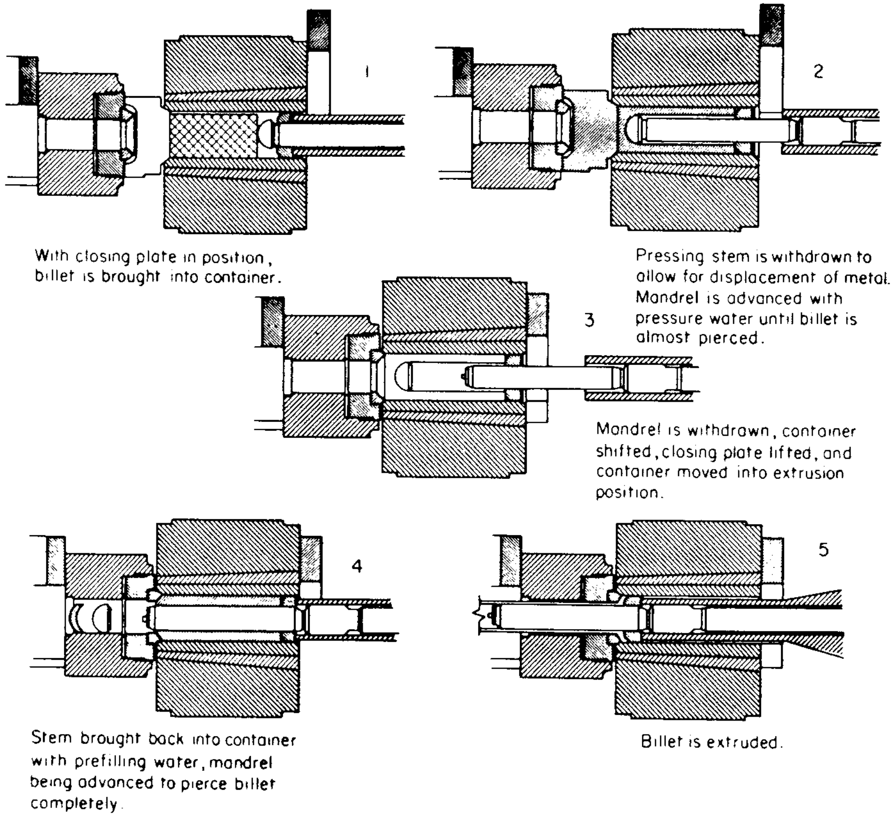

FIGURE A5.6 Ugine Sejournet extrusion process.

nickel-based materials include ASTM specifications A 106, Grades B & C; A 312; A 333; A 335; A 376; B 167; and B407. Heavy-wall pipe per ASTM A335, Grades P11, P22, and P91 is increasingly being used in power generation. In addition, heavy-wall pipe is utilized in offshore oil drilling and production.

Forged Seamless Pipe. Forged pipe is used for large-diameter, NPS 10–30 (DN 250–750), and thickness, 1.5–4 in (40–100 mm), pipe, where equipment availability and cost for other seamless grades are limiting. There are two processes available for the production of forged seamless pipe, namely, forged and bored pipe and hollow forged pipe.

Forged and Bored Seamless Pipe. In the forged and bored process a billet or ingot heated to forging temperature is elongated by forging in heavy presses or forging hammers to a diameter slightly larger than that of the finished pipe. After turning in a lathe to the desired outside diameter, the inside diameter is bored to the specified internal diameter dimensions. The resulting pipe can be made to very close tolerances. Sections 50 ft (15 m) long have been produced by this process.

Hollow Forged Seamless Pipe Erhardt Type Process. The Erhardt process (Fig. A5.7), developed by Heinrich Erhardt in Germany in 1891, consists of heating a

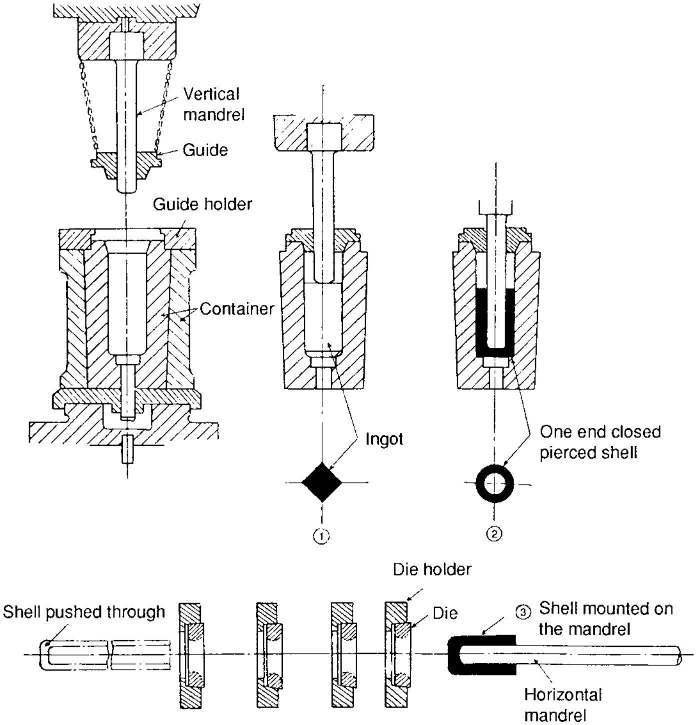

FIGURE A5.7 Hollow-forged seamless pipe—Erhardt-type process.

square ingot to forging temperature, placing it into a circularly hollow die, and incompletely piercing it with a vertical piercing mandrel such that a cup shape is obtained. As a result of the piercing at forging temperature, the square ingot becomes the (circular) shape of the die. After reheating, the cup-shaped shell is mounted on a mandrel and pushed through a series of dies to the desired diameter and wall thickness, after which the cupped end is removed and the inside and outside pipe diameters are machined. This process is used for large-diameter and heavy-wall seamless pipe for boiler headers and main steam line piping. It can be applied to produce low and medium carbon steel pipe (ASTM A53, A106, A161, A179, A192, A210), stainless steel pipe (TP329, TP304, TP304L, TP321, TP347, TP316), and high nickel alloys (A333, A334).

Cold and Hot Finishing of Seamless Pipe and Tube. Pipe that has been produced by the Mannesmann plug-mill, mandrel mill, Ugine Sejournet, or Erhardt forging process can be used as hot finished seamless steel pipe or tube if the application does not require further finishing. If further finishing is required, the pipe or tube may be further reduced by a cold reduction process (Fig. A5.8). If the cold reduction processes are used, the reduced tube must be heat-treated in a furnace such as a bright annealing furnace or in a continuous barrel furnace. Subsequent to the heat treatment of the cold finished pipe, the pipe must pass through a straightening process which corrects any nonstraight sections caused in the pipe by the heat treatment of cold reduced pipe. The straighteners are either a series of rolls

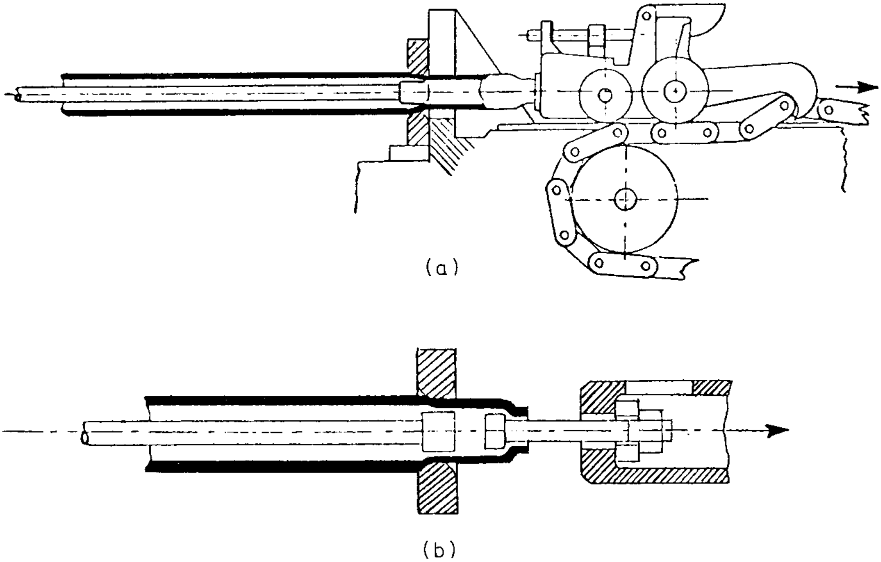

FIGURE A5.8 Cold and hot finishings of seamless pipe and tube.

through which the pipes pass cold or a device which bends the pipe at discreet locations along the pipe. The resulting product is called *cold finished seamless pipe* or *tube*.

In applications of tube to fossil fuel boilers, cold finishing is sometimes specified. Cold finishing improves the surface finish and dimensional accuracy. Some boiler manufacturers, however, consider the hot finished tube surface satisfactory and specify it as such because of its reduced cost.

Welded Pipe. Welded pipe is produced by forming a cylinder from flat steel sheets coming from a hot strip mill. The strip mill takes the square bloom from the blooming mill and reduces it into plates, skelp, or coils of strip steel to be fed into the particular welding process equipment. Butt-weld pipe is made by furnace heating and forge welding or by fusion welding using electric resistance, flash, submerged-arc welding, inert-gas tungsten-arc welding, or gas-shielded consumable metal-arc welding. The welded seam is either parallel to the tube axis or in a spiral direction about the tube centerline.

Furnace-Welded (Continuous or Butt-Welded) Pipe. This is a low-cost carbon steel pipe below 4-in diameter made of steel from open-hearth or basic oxygen Bessemer steel. In this process, skelp is heated to welding temperature in a continuous furnace and passed through forming and welding rolls, welding the strip edges at the same time the tube is formed. Strips can be consecutively resistance-welded to each other to form a continuous pipe.

Fusion-Welded Pipe. Fusion-welded pipe is produced by resistance-welding, induction-welding, or arc-welding.

Electric Resistance-Welded Pipe. In the electric resistance-welded (ERW) pipe process (Fig. A5.9), upon exiting the forming mill, the longitudinal edges of the cylinder formed are welded by flash-welding, low-frequency resistance-welding,

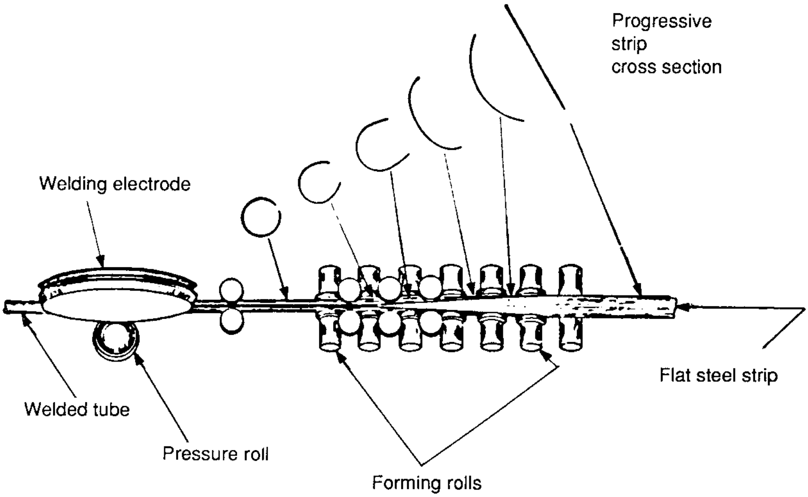

FIGURE A5.9 Electric resistance welded pipe process.

high-frequency induction-welding, or high-frequency resistance-welding. All processes begin with the forming of the cylinder with the longitudinal seam butt edges ready to be welded.

In the flash-welding process, the butted cylinder surfaces are placed in contact; a voltage is applied across the contact, causing metal flashing along the seam length and raising the steel temperature locally to the metal-forming temperature. After this, the seam edges are pressed together and a pressure fusion-weld is formed at a temperature lower than the steel melting point. The upset material along both the inside and outside of the seam is removed with a scarfing tool. This process is used to produce high-strength carbon steel pipe from NPS 4 to 36 (DN 100 to 900).

In the low-frequency resistance method, electric current and pressure are simultaneously applied, and the resulting heat causes melting of the edges. The resulting seam is similar to that from the flash-welding process and requires removal of the upset material. Postweld heat treatment may be desirable for stress relief, tempering, or recrystallization. This process is applied to pipe of outside diameters up to NPS 22 (DN 550).

High-frequency welding process, using an alternating current of more than 400,000 Hz, is similar to the low-frequency resistance welding process. The lower inductance path followed by the current produces a smaller high-temperature band that minimizes the amount of upset material. This process is used for pipe up to NPS 42 (DN 1050).

For production of small-diameter pipe at high rates of production, the high-frequency induction-welding process may be used. In this process, an induction coil raises the seam temperature to welding temperature. The rapid increase in temperature caused by the high-frequency current causes little upsetting because of the resulting control of temperature and fusion.

Several arc-welding processes are used in commercial welded pipe production. These include the submerged-arc-welding process, the inert-gas tungsten-arc-welding process, and the gas-shielded consumable metal-arc-welding process.

In the submerged-arc-welding process, bare wire consumable electrodes are added to the weld metal under a blanket of flux. The melting flux creates a protective atmosphere of inert gas and a slag blanket over the solidifying weld metal. In heavy-wall piping, simultaneous submerged arc seam welds on inner and outer sides of the pipe are sometimes used to build up the weld thickness to the desired level. In modern pipe production facilities, automated equipment is used to control all variables in the submerged arc process, including relative movement speed between pipe and welding heads, wire feed rate, welding current, and flux feed rate. Submerged-arc seam-welded pipe is used in critical high-temperature or high-pressure applications in the electrical power generation process and chemical industries.

For carbon steel and stainless steel pipe of smaller wall thickness, the inert-gas tungsten-arc-welding process is used. The weld is protected by an inert gas such as argon or helium, which forms a blanket over the weld metal. For thicker-wall pipe, a filler wire may be fed into the protective gas blanket. For thin-wall pipe, no filler is used. A number of variations in pipe forming before welding are used, including molding, pressing, or rolling strip into cylinders.

Spiral Welded Pipe. Lightweight pipe for temporary or light operation duty such as in water systems applications may be made by the spiral-welded process. In this process, narrow strips of steel sheet are helically wound into cylinders. The edges of this strip can either be butting or overlapping and are welded by any of several electric arc-welding processes.

Cast Pipe

Cast-Iron Pipe. There are four basic types of cast iron: white iron, gray iron, ductile iron, and malleable iron. White iron is characterized by the prevalence of carbides which impart high compressive strength, hardness, and resistance to wear. Gray cast iron has graphite in the microstructure, giving good machinability and resistance to wear and galling. Ductile iron is gray iron with small amounts of magnesium or cesium which bring about nodularization of the graphite, resulting in both high strength and ductility. Malleable iron is white cast iron which has been heat-treated to provide for ductility.

Cast-iron pipe is extensively used for underlying water, sewage, and gas distribution systems because of its long life expectancy. Specifications for this pipe can be found under Federal Specification W-W-P-421b-Pipe, Cast Iron, Pressure (for Water and Other Liquids). Cast-iron pipe is produced from four processes: vertical pit casting, horizontal casting, centrifugal sand mold casting, and centrifugal metal mold casting.

Vertical Pit Process. The vertical pit process for producing pipe requires a sand mold formed into a pipe pattern of the outer surface of the pipe, into which a separately made core is placed. The molten iron is poured into the vertical annulus between the outer mold and the core. American Standard Specifications for Cast Iron Pit Cast Pipe for Water or Other Liquids are available in ASTM Specification A 377. Pit-cast pipe specifications for the gas industry may be found in American Gas Association (AGA) Standards for Cast Iron Pipe and Special Castings. ASTM Designation A142 provides specifications for pit-cast culvert pipe.

Horizontal Process. In the horizontal cast-iron pipe process, horizontal outer molds are made in halves, with a core formed around a perforated horizontal bar. After the top half is placed on the bottom half, the molten iron is introduced in a manner preventing ladle slag from entering the mold.

Centrifugally Cast-Iron Pipe. There are two types of centrifugal casting machines—horizontal and vertical. Pipe is most commonly produced in the horizontal machine. The centrifugal castings are formed after molten metal is poured into a rotating mold. The mold continues its rotation until solidification of the metal is complete, after which the casting is removed. Molds can be made of sand or, for permanent molds, graphite, carbon, or steel. The centrifugal casting process provides a means of producing high-quality castings which are defect-free due to the absence of shrinking. These castings cool from the outside to the inside, providing a desirable directional solidification which results in cleaner and denser castings than those resulting from static casting methods.

Cast-Steel Pipe. Cast-steel pipe is produced by either static or centrifugal casting processes. In the horizontal centrifugal casting machine, the molten steel is introduced into the rotating mold of sand, ceramics, or metal. Centrifugally cast pipe can be obtained in sizes up to NPS 54 (DN 1350). Application of this pipe can be found in paper mill rolls, gun barrels, and high-temperature and pressure service in refineries (temperatures above 1000°F or 538°C). This process is also used for high-nickel and high-nickel alloy pipes.

Cold-Wrought Steel Pipe. Centrifugally cast stainless steel pipe can be cold expanded subsequent to casting by internally applied pressure to form cold-wrought pipe. The process, called hydroforging, applied to austenitic stainless steels provides for recrystallization and grain refinement of the centrifugally cast material grain structure.

NONFERROUS PIPE-MAKING PROCESSES

Aluminum and Aluminum Alloy Tube and Pipe

Aluminum tubular products include both pipe and tube. They are hollow-wrought products produced from a hollowed ingot by either extrusion or by welding flat sheet, or skelp, to a cylindrical form. General applications are available in alloys 1100, 2014, 2024, 3003, 5050, 5086, 6061, 6063, and 7075. For shell and tube heat exchanger applications, alloys 1060, 3003, 5052, 5454, and 6061 are available. Pipe is available only in alloys 3003, 6061, and 6063. The designation numbers indicate the particular alloying element contained in the aluminum alloy (such as copper, manganese, silicon, magnesium, and zinc) and the control of the impurities. The numerical designation system consists of four numbers, *abcd*, where *a* designates the major alloying element in the aluminum alloy: 1 for 99 percent pure aluminum, 2 for copper, 3 for manganese, 4 for silicon, 5 for magnesium, 6 for magnesium and silicon, 7 for zinc, and 8 for another element. Digit *b* designates an alloy modification for groups 2 through 8 and an impurity limit for group 1. Digits *c* and *d* indicate the specific alloy for groups 2 through 8 and the purity of group 1.

Copper and Copper Alloy Tube and Pipe

Copper tube and pipe have a wide range of application throughout the chemical, process, automotive, marine, food and beverage, and construction industries. Unified Numbering System (UNS) designations (CXXXXX) have been established for many alloys of copper. ASTM and ASME specifications have been developed for copper tube and pipe. Seamless pipe and tube are covered by ASTM B466, B315, B188, B42, B302, B75, B135, B68, B360, B11, B395, B280, B306, B251, B372, and B88. ASME specifications include SB466, SB315, SB75, SB135, SB111, SB395, and SB359.

Tubes and pipe of copper and copper alloys are produced by either of two processes—piercing and extrusion, or welding skelp formed into cylindrical shape. The seamless pipe or tube produced through the extrusion process is the most common commercial form of copper and copper alloy tubular products.

Hot Piercing Process. In the Mannesmann piercing process, a heated copper billet is first pierced, then rolled over a mandrel which determines the inside diameter of the pipe. Following the piercing operation, the pierced shell is drawn through a die and over a plug to obtain the finished outside and inside diameters.

Extrusion Process. In the extrusion process, the heated copper or copper alloy billets are formed into shells by heavy hydraulic presses. The hollowed-out billet is then extruded through a die and over a mandrel to form the outside and inside diameters of the pipe.

Cold-Drawing Process. The cold-drawing process uses mother pipe which is placed on a draw bench which pulls a cold tube through one or a multiplicity of dies and over a mandrel to reduce the pipe gradually to its finished dimensions.

Other Processes. Other processes of significance are the cup-and-draw process for large-diameter pipe and the tube-rolling process which reduces copper tubing by means of cold-working over a mandrel with oscillating tapered dies.

Nickel and Nickel-Alloy Pipe and Tube

Nickel and nickel-alloy pipe and tube, because of their high strength and generally good resistance to oxidation and corrosion, are used in the chemical industry and in steam-generation equipment for nuclear power-generation plants. Applications of nickel are found in tubes and pipe of pure nickel and binary and tertiary alloys of nickel, such as Ni-Cu (Monel 400 and Monel K-500), Ni-Mo and Ni-Si (Hastelloy B), Ni-Cr-Fe (Inconel 600 and Inconel 800), and Ni-Cr-Mo (Hastelloy C276 and Inconel 625) alloys. The alloys are used in applications requiring corrosion resistance to water, acids, alkalis, salts, fluorides, chlorides, and hydrogen chloride. The alloy must be carefully selected to provide for resistance to the specific corrosion media found in the environment.

Nickel and nickel-alloy pipe and tube are produced by the Ugine-Sejournet extrusion process, in which a shell is formed by hydraulic piercing of a billet by a ram and subsequent extrusion. Alternately, the billet may be initially pierced by means of drilling.

Titanium and Titanium-Alloy Tube and Pipe

Titanium and its alloys have provided the engineering designer with an important alternative to aluminum. They are lightweight and have high strength at moderately elevated temperatures, good toughness, and excellent corrosion resistance. Their applications have been found in a wide range of industries, including aerospace, heat-exchange equipment, chemical plants, and power-generation facilities.

There is a wide range of alloying systems to which titanium may be produced. The alloying elements possibly include aluminum, molybdenum, nickel, tin, manganese, chromium, and vanadium. UNS numbers are used to identify the many available alloys and forms of titanium.

Titanium and alloys of titanium pipe and tube are produced from a melt of raw titanium "sponge" and alloying metals in a vacuum electric arc furnace. An ingot is obtained which is reduced to a billet. The billet provides the stock for the extrusion process, from which the tube or pipe is formed. The process consists of initially piercing the billet, then passing a heated shell through a die and over a mandrel.

COMMERCIAL PIPE AND TUBE SIZES

The standard pipe sizes and other pipe properties are given in App. E2 and E2M, and the standard tube sizes and other tube properties are given in App. E3 and E3M.

TUBULAR PRODUCT CLASSIFICATION

Pipe and tubing are considered to be separate products, although geometrically they are quite similar. "Tubular products" infers cylindrical products which are hollow, and the classification of "pipe" or "tube" is determined by the end use.

Piping Classification

Tubular products called pipe include standard pipe, conduit pipe, piling pipe, transmission (line) pipe, water-main pipe, oil country tubular goods (pipe), water-well pipe, and pressure pipe. Standard pipe, available in ERW or seamless, is produced in three weight (wall-thickness) classifications: standard, extra strong, and double extra strong (either seamless or welded). ASTM and the American Petroleum Institute (API) provide specifications for the many categories of pipe according to the end use. Other classifications within the end use categorization refer to the method of manufacture of the pipe or tube, such as seamless, cast, and electric resistance welded. Pipe and tube designations may also indicate the method of final finishing, such as hot finished and cold finished.

Tubing Classification

Pressure tubes are differentiated from pressure pipe in that they are used in externally fired applications while carrying pressurized fluid inside the tube.

Structural tubing is used for general structural purposes related to the construction industry. ASTM provides specifications for this type of tubing.

Mechanical tubing is produced to meet particular dimensional, chemical, and mechanical property and finish specifications which are a function of the end use, such as machinery and automotive parts. This category of tubing is available in welded (ERW) and seamless form.

SPECIALTY TUBULAR PRODUCTS

There are many specialty tubular products designed for special applications requiring unique manufacturing methods for production. Examples are the rifled boiler tube, the finned heat-exchanger tube, the duplex tube, and the double-wall tube.

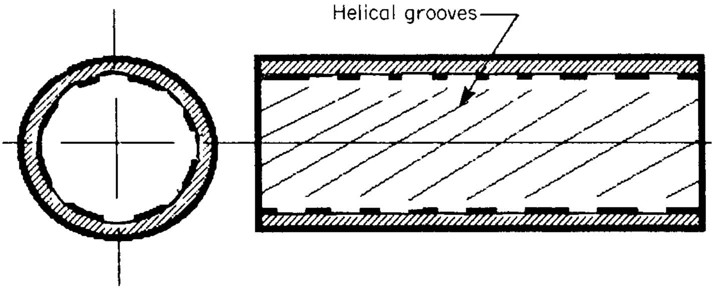

FIGURE A5.10 Single rifled boiler tube.

The rifled boiler tube (Fig. A5.10) is used to provide an improved heat transfer surface on the inner surface of a boiler tube. The rifling twist, similar to that of a rifle, is produced by specially shaped mandrels over which the tube is drawn.

The finned heat exchanger (Fig. A5.11) tube provides improvement in thermal efficiency by providing an extended surface from the base tube surface. The extended surface is produced by turning the tube through special sets of dies which raise fins from part of the base tube material. These fins can be coarse or fine depending on the equipment developed for producing fins.

Duplex or composite tubes have been developed to provide a different material on the inside and outside of the tube to meet the requirements of a different environment on either side of the tube. One method of producing a composite tube is by providing a bimetal mother tube before the extrusion or drawing process. Careful development of this process will yield a composite tube with an excellent bond between the two materials.

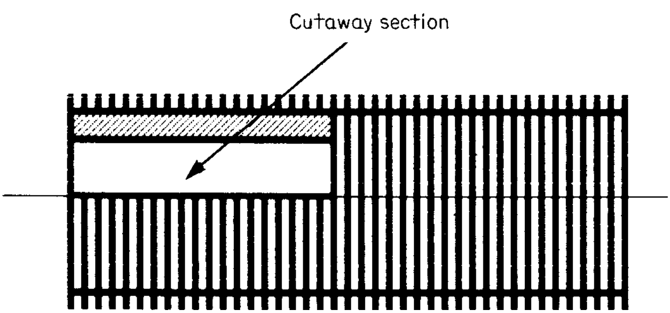

FIGURE A5.11 Finned heat-exchanger tube.

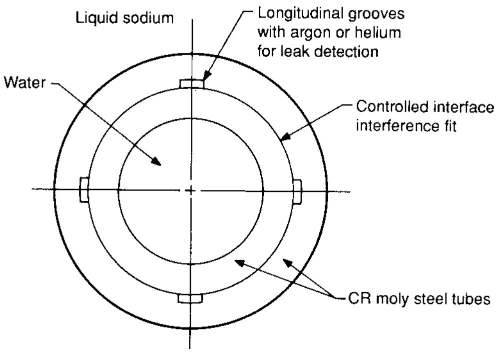

FIGURE A5.12 Double-wall leak-detecting tube.

Double-wall tubes (Fig. A5.12) are used in applications requiring leak detection to avoid a catastrophic mixture of the fluids on either side of the tube. An inert detecting gas can be placed in the annulus between the two tubes to sense very small amounts of leakage from either tube so as to allow careful shutdown of the system. This tube is manufactured by inserting one tube inside the other, then drawing the combined tube through dies or over mandrels which provide a calibrated prestress between the two tubes. This type of tube was developed for application to a fast breeder reactor sodium-water steam generator.

ENGINEERING SELECTION OF PIPE MANUFACTURING METHODS

The selection of the appropriate pipe manufacturing method by the design engineering specification deserves consideration. For many applications, the codes and standards specified in the procurement contract provide for little room to select an optimal manufacturing method. The safest procedure is to obtain the price and schedule from suppliers before firming the piping specifications. At times the selection of the pipe with the best manufacturing process might be tempered by project cost or delivery considerations. In such cases, much is required of the engineer to consider whether lesser quality will be able to meet the desired reliability standard. It therefore is essential that the engineer is aware of the alternates and their operating history of success and failure before an appropriate alternative decision can be accepted. It must also be recognized that choices based on economic considerations alone may prove to be the more costly in the face of the downtime costs of failure.