ASPECTS OF TUBE AND PIPE MANUFACTURING PROCESSES: METER TO NANOMETER DIAMETER

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ABSTRACT

The use of tubes and pipes has a long history in different industrial applications. New methods for manufacturing tubes and pipes are developing and improvement of the existing manufacturing methods is continuing. Broadly speaking, the manufacturing methods of metal tubes and pipes can be divided as seamless and welded. Tubes and pipes manufactured through different routes have their specific advantages and disadvantages. Depending on the application requirements, tubes and pipes are manufactured in different sizes and shapes. The outside diameter of tubes and pipes could be several meters to even few nanometers. The tube and pipe industries face many challenges to produce high-quality tubing in a cost effective and productive way in today's marketplace. Some of these challenges are requests for tube products in a wider variety of shapes and sizes by the end users, applications that require special materials, and demand for improved product quality from manufacturer. In this paper, different aspects of manufacturing, processing, design, utilization, quality control, handling, cost and safety in tube and pipe production are briefly reviewed to offer a general idea relating to these issues.

Keywords: Tube, Pipe, Seamless, Welded, Manufacturing, Nanotube, Finite element.

1. Introduction

Tubes refer to any shape of hollow material of uniform wall thickness and defined by the outside diameter and wall thickness dimensions. On the other hand a pipe is one type of tube with the specific circular shape. Tubes can be of different shapes in cross-section like square, rectangular, oval, circular, conical or any special shape (e.g., hexagonal). In general, tubes and pipes refer to hollow sections with smaller and larger outer diameter respectively. The outer diameter of tubes and pipes could be as large as several meters and as small as few nanometers. In today's technology tubes and pipes play an important role in many applications primarily for conveying of fluids and are made of diverse materials and dimensions according to the purpose for which they are intended, metal pipes being of the greatest consequence. Tubes and pipes have also found their way as structural elements in buildings, bridges, and automotive and aerospace industries. Modern materials for constructing tubes and pipes are principally divided into metallic and non-metallic. Metallic materials can also be divided as ferrous (e.g., cast iron, wrought iron and steel) and non-ferrous (e.g., copper, aluminum, brass, lead or alloys of copper, aluminum, titanium and magnesium). Whereas non-metallic materials include plastic, concrete, clay, wood, glass, paper and many others.

The tube and pipe industry faces many challenges in today's marketplace. Firstly, the end users are demanding tube products in a wider variety of shapes and sizes. The manufacturers of tubes and pipes face the complexity when the shapes required are other than regular ones and sizes become either very small or very large. Secondly, applications that require special materials such as titanium alloy are becoming more common and special techniques are needed to process them. Finally, improved product quality with reasonable cost is being demanded from every manufacturer. To meet these challenges, it is necessary to use optimized tooling and advanced manufacturing and quality control techniques. This paper briefly outlines different aspects of manufacturing tubes and pipes.

2. Tube and pipe manufacturing processes

Promising developments have been made over the past decades to master the manufacturing processes in terms of product quality, process quality, automation etc. Various methods of manufacturing tubes and pipes from different materials are briefly described in the following sections.

2.1. Metallic tubes and pipes

The manufacturing processes for metal tubes and pipes can be divided into welded (seamed) and seamless.

<u>Seamless tubes and pipes</u>

The production process for seamless pipe begins by heating a metal billet at high temperature. The red-hot billet is rotated and drawn by rolls over a piercing rod or mandrel. The action of the rolls causes the metal to flow over and about the mandrel to create a hollow pipe shell. The shell is then moved forward over a support bar and is hot-rolled or cold-rolled in several reducing/sizing stands to obtain the desired wall thickness and diameter (Fig. 1(a)).

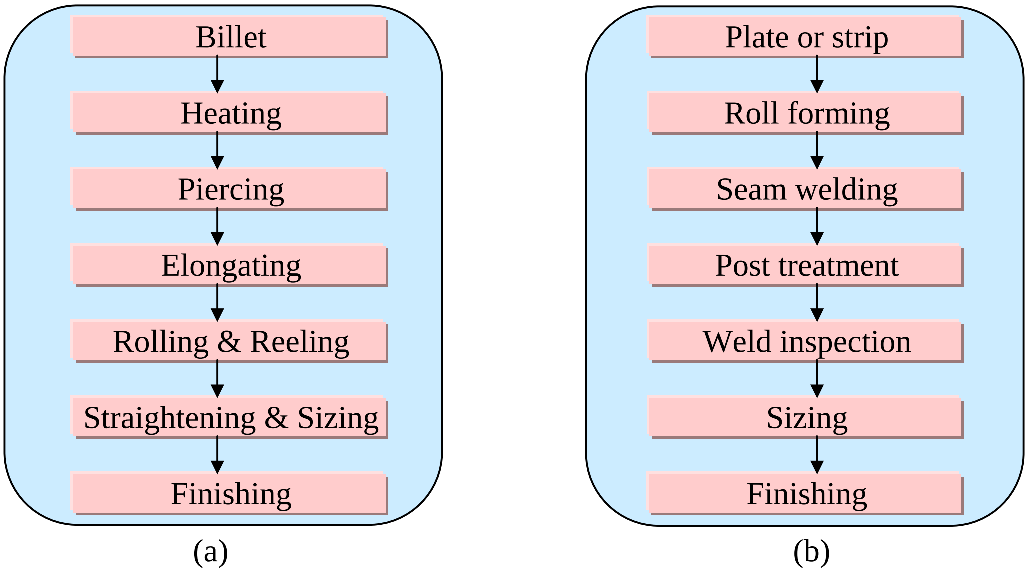


Figure 1. Basic steps in manufacturing (a) seamless and (b) welded tubes and pipes.

Seamless tubes are produced mainly for the applications where the ranges of wall thickness extend from small to large with the diameter range up to approximately 650 mm [1]. Hot extrusion process is also used for producing seamless tubes of approximately upto 230 mm outside diameter. Another method of manufacturing seamless tubes is casting, centrifugal casting being the most common method used to manufacture tubes and pipes from cast iron either grey or ductile [2]. Seamless pipe has outstanding homogeneity in the circumferential direction and is thus highly resistant to internal pressure and torsion. In the seamless tube manufacturing process, the life of mandrels is an important factor for producing quality tube consistently. While the advances in optimization of the mandrel position, roll geometry, rolling speed etc. is continuing to reduce the wear of mandrels, deposition of advanced hard coatings on the mandrel also have significant effect on the extension of mandrel life.

Welded tubes and pipes

Welded pipe is made by bending metal strips (skelp) or plate into the form of a tube by roll forming and welding the seam by various welding processes (Fig. 1(b)). The diameter of welded tubular product ranges from approximately 6 to 2500 mm with a wall thickness from 0.5 to approximately 40 mm [1]. Currently around two thirds of the steel tube production in the world are accounted for by welding processes. Depending on the forming method, the manufacturing of welded tubes and pipes are classified as longitudinal and spiral (helical) seam. In contrast to longitudinally welded pipe production where each pipe diameter requires a certain plate width, spiral pipe production is characterised by the fact that various pipe diameters can be manufactured from a single strip or plate width with a ratio of pipe diameter to width of between 1:2 and 1:2.2. Large diameter pipe ranging from approximately 500 mm to 2500 mm is the current state-of-art in spiral welded pipe production [1]. Welding methods are improving for faster operation and controlled quality welding with laser-based vision and guidance systems and automated welding machines. Optimisation of edge shape is required to obtain a sound welding zone without any deformation and thickness reduction at the edge during the roll forming of thick plates [3].

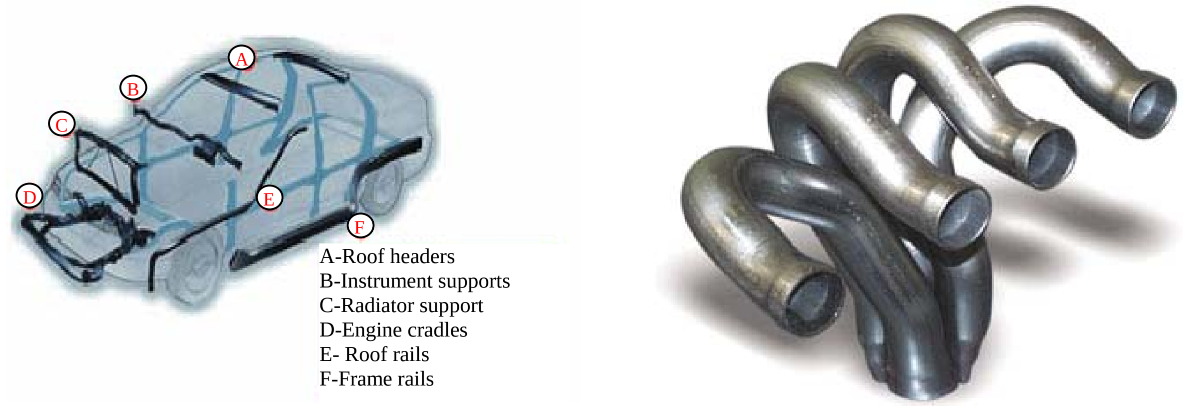


Figure 2. (a) Hydroformed tubular parts for automotive applications [4] and (b) rotary draw bent tube [5].

After manufacturing tubes and pipes are processed through several operations such as annealing, coating deposition, cutting, bending, straightening, forming etc. to make it suitable for any particular end applications. Tubes and pipes are cut into required sizes using sawing, lathe cutting, rotary cutting etc. Laser cutting is becoming popular where high precision and smaller cutting width is necessary. Tube hydroforming [6] is achieving increasing acceptance in the automotive industry for making a wide variety of components including suspension frame, body structure, power-train components and exhaust pipes (Fig. 2(a)). Laser forming [7] have also been developed to make a precise and complex shape of tube by a controllable laser beam without pre-processing. CNC (Computer Numerical Control) bending is being used for automatic operation with precise control of shape and size (Fig. 2(b)).

2.2. Non-metallic tubes and pipes

Plastic tubes and pipes are constructed using many different plastic compounds such as polyvinyl chloride (PVC), polyethylene, polytetrafluoroethylene (PTFE), polypropylene (PP) etc. for flow lines of liquids and gases in pneumatic, hydraulic, household, medical and many other specialized applications. The basic manufacturing processes of plastic tubes and pipes are moulding, casting, forming of sheets, and extrusion being the most common. Composite tubes reinforced with organic

(e. g., synthetic) or inorganic (e.g., glass) fibers in polymeric matrix are becoming more popular due to their higher stiffness and lower weight [8], and are manufactured by moulding (resin transfer moulding, lapped moulding etc.), casting and pultrusion techniques. Concrete pipe is one of the most versatile, durable and economical conduits for the transportation of water, industrial wastes and sewage since the start of civilization. Today, there are three commonly used processes for producing precast concrete pipes: dry cast, packerhead and wet cast [9]. The traditional concrete pipes are reinforced by metal or a large volume of fly ash is being used as a replacement for cement to make it long, strong and better [10]. Paper tubes are manufactured through spiral winding by automatic winding machine, glued by glue device and cut into specified length by auto cut-off units for applications in textile, paper and packaging industries.

3. Recent developments

Last few decades have witnessed several new developments in tube and pipe manufacturing industries in terms of new material, sizes and shapes, manufacturing process and quality control, and improvements are still ongoing to meet further challenges. Tubes and pipes required for high and low temperature applications like power plant, and gas and oil exploration in cold areas (e.g., Alaska, Arctic) and deep seas are steadily progressing. Tubes and pipes with higher wall thickness (several hundreds mm) have been made from the material with high mechanical strength and corrosion resistance. Multilayer tubes consisting of different materials bonded together have been developed to meet the application demands where the conditions outside and inside the tube require properties that cannot be made from a single material [11], for example superheater in boilers. Stainless steel is the dominating material in such applications.

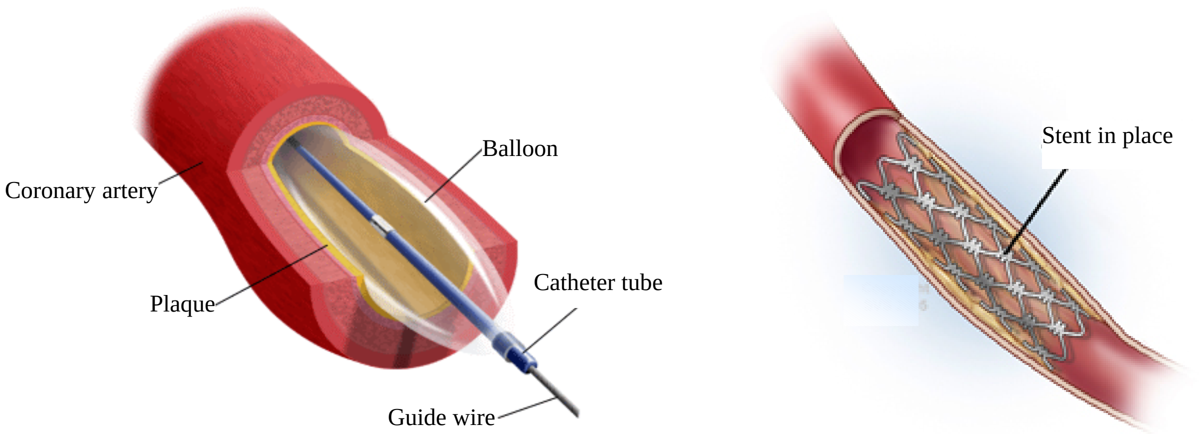
(a)

(b)

Figure 3. Large diameter (a) steel [12] and (b) concrete pipes [9].

The development of large diameter pipes ranging from several hundred millimeters to few meters will continue to meet stricter clean water mandates, to rehabilitate aging and obsolete sewer and drainage systems owing to stringent environmental regulations, to transport natural gas due to increased energy demands and to construct building and transportation. Concrete pipes, either metal or fiber reinforced, will reign over underground applications due to its durability, corrosion resistance, strength, tapping ease and versatility. Large diameter spiral welded pipes are usually chosen for oil and gas pipelines, petroleum product lines, industrial and process pipelines. Plastic pipe will grow at the fastest pace as a result of broadened sewer and water distribution uses due to the improvements of plastics in pressure tolerance and crush resistance. Fig. 3 shows pictures of large diameter steel and concrete pipes.

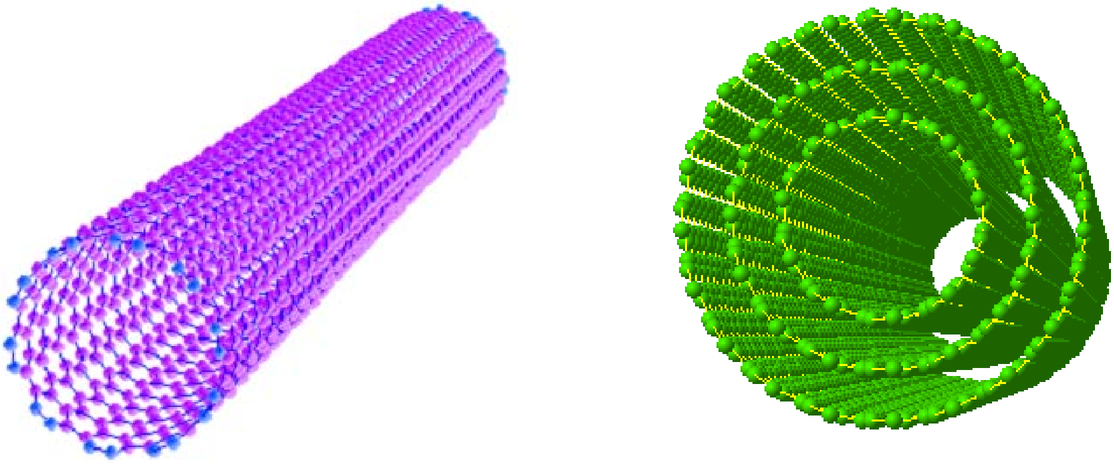
Precision tubings with very small-bore diameter and very smooth internal and external surfaces have been developed for very special demands such as nuclear, aerospace, automotive and medical applications. High precision seamless steel tubes are usually prepared by cold working which ensures all the necessary requirements such as close tolerance and good surface finish. Much attention has also been paid to laser welding for welding very smaller diameter tubes with minimum heat affected zones. As the demand for smaller diameter continues, smooth bore with wall thickness control still remains a challenge especially where precise dimensional control is necessary. Continuous monitoring of the wall thickness with state-of-the-art machinery and controls can reduce the wall thickness variation. Polymer material has also recently turned the attention of manufacturers to produce precision tubes in biomedical industries including catheters, endotracheal, and tracheostomy tubes [13]. Fig. 4 shows the picture of a catheter tube and tubular stent used in coronary angioplasty operation.



(a) (b)

Figure 4. (a) Catheter tube [14] and (b) tubular stent [15] used in coronary angioplasty operation.

Tube and pipe production is not only progressing towards the upper dimensions but also in the lower dimensions. Nanotubes belonging to a group of nanostructured materials with the diameter of few nanometers have been developed. Although other nanotubes based on boron nitride, copper sulphide and molybdenum have been reported, currently, carbon nanotubes are by far the most important group [16]. Carbon nanotubes consist of hexagonally arranged carbon atoms in the form of a cylinder with a diameter measured in less than a nanometer and a length of several microns. Ideally, carbon nanotubes are mainly of two types: a single cylinder of carbon (single-walled nanotube, SWNT) and several concentric tubes or cylinders (multi-walled nanotube, MWNT) as shown in Fig. 5. The carbon nanotube is the subject of most intense research due to their multidimensional properties such as high mechanical strength, good electrical and thermal conductivity, high thermal stability etc.



(a) (b)

Figure 5. (a) Single-wall and (b) multi-wall carbon nanotubes [17].

In general, there are three ways to produce carbon nanotubes: electric arc discharge (EAD), laser ablation (LA) and chemical vapour deposition (CVD). All these methods use high temperature ranging from 700 to 3000 ^{o}C [18]. Researches are continuing to produce nanotubes using even further low temperature processes such as microwave plasma (below 520 ^{o}C) [19]. Several post treatments including ultrasonic cleaning, liquid phase treatment and annealing at high temperature (2700 ^{o}C) are necessary to produce pure and defect free carbon nanotubes. Carbon nanotubes have been considered for some fascinating potential applications such as in semiconductor, automotive, aerospace, and biomedical industries. Although carbon nanotubes have been tested positive in several potential applications due to their excellent properties, the current barriers to mass-market use of these materials include, a lack of commercially available material of consistently high quality, higher cost (€ 400 /g) and successfully expressing the basic properties of the raw material in the end applications. Although it is very difficult to predict when the nanotubes will make its way for commercial application, the next decade will see the whole new development of nanotube both for research and commercial applications. Interested readers are suggested to read the references [18,20,21] for further information on nanotubes.

The use of numerical simulation such as Finite Element Analysis (FEA) in tube and pipe manufacturing industry to optimise the tool design, manufacturing processes parameters and finally the performance of the tubular product is advancing at higher pace. The current applications of the FEA in piercing, drawing, extrusion, bending, roll forming, welding and hydroforming are very common [22-27]. There is no doubt that industry cannot survive without the computer-based simulation and optimization of some of the key manufacturing processes with which it is working. Specialized software dedicated to tube manufacturing, tube forming, and heat transfer analysis will be more popular in future.

To consistently produce high quality tube and pipe products, automatic on-line quality control system through computer at every stage of the operation and proper maintenance of tooling are vital. Laser visual alignment measurement techniques have been developed for 100 percent on-line and non-contact measurement with high measurement precision [28]. Moreover, minimization of testing error and an operational standard should be established for all employees to follow. With the time and requirement, the size and weight of the tubes and pipes have increased, which in fact have increased the problems in pipe handling. Specially designed robots using sophisticated algorithm for an industry specific requirement can handle this kind of repetitive operation with minimum engagement of workers, enhanced safety, improved reliability, increased productivity, and higher precision and accuracy [29]. But the most significant side effect to implement this process is that it sets an upper limit on the tube lengths, diameter and weight.

Several safety procedures such as proper guarding of different equipments, proper condition of working environment and standard work practices are vital for tube and pipe manufacturing industry from manufacturing and workers point of view. Due to the increased concern of global environment, complex scheme of environmental rules and regulations must comply by considering recyclability and disposal of waste material, energy efficiency operation, indoor/outdoor air quality, resource conservation, noise and vibration, and other environmental considerations [30]. The potential waste management areas identified are pretreatment (i.e., pickling), processing (i.e., cutting, sawing, bending or tube forming) and post treatment (i.e., coating) operations where environmentally harmful chemicals, coolants and liquid lubricants are regularly used. Strategies for managing environmental risk by implementing an environmental audit or pollution prevention measures (e.g., reducing waste generation) should have to be taken into considerations [31].

4. Concluding remarks

The basic manufacturing processes for tubes and pipes are known for decades and have always undergone constant improvement. The great advances made in the field of electronics, control and automation will exercise an enormous influence on tube and pipe manufacturing. Tubes and pipes used in oil and gas exploration and production, and chemical and petrochemical industries will play a greater role in supplying the total steel tube market. However, the tubular products in structural engineering such as buildings, aerospace, automotive industry etc. will continue to grow. The requirement of high-strength and high-toughness materials will lead to the development of new materials driven by diversifying design, operating conditions, evaluation methods and cost reduction. Tubes and pipes made with conventional materials such as iron, steel, copper, concrete and plastic will control the mass market for all sorts of applications in societal infrastructure, while precision tubes made with special materials or nanotubes will cover a very small market by volume. Tube manufacturers will be more dependent on finite element analysis in simulating tooling design, process optimisation and performance evaluation of tubes and pipes. Through continuous monitoring and documentation of data from the start of the manufacturing process and different mechanical, chemical and non-destructive tests will effectively guarantee the production of constantly high quality tubes and pipes.

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