The Development of Steels and Their Uses

Research Paper Prepared By

John R. Curry
Pressure Vessel and
Steel Fabrication Industry Expert
2011

Development of Steels and Their Uses

The steels of the late 19th century and early 20th century were not what we have in use today. Early steels were simply molten iron with a small amount of carbon melted in the heat. Hence the term carbon steels. The carbon gave the steel strength, hardness, and the ability to stand stresses, but it also gave the steel a course grain structure and with too much carbon, a brittleness to the steel. Early steels contained impurities such as sulfur and phosphorus that adversely affected the quality of the finished product.

Prior to World War II, two major steels were used in pressure vessels. The first was A-285C, a 55,000 psi tensile steel that was easy to weld and fairly “soft” to fabricate. Forming was easy and this steel found wide use in the industry. The other was A-212B Firebox, a 70,000 psi tensile steel with a course grain structure and high hardness. It had the tendency to suffer brittle fracture in thicker materials during severe service.

Both of these steels were essentially replaced by A-516-70 in the mid-1960’s. A-516-70 is a fine grain, 70,000-psi tensile steel that is silicon-killed in the ladle. The addition of a small amount of silicon during the melting process promotes the fine grain properties. Fine grain steel is easy to cut, form, and weld. These properties, along with the higher tensile strength, have made A-516-70 the steel of choice for carbon steel pressure vessels today.

Fabrication Methods in the Post World War II Era

A century ago, welding, as we know it, had not yet been developed. Great structures, such as the Eiffel Tower and giant steamships were held together with rivets. Arc welding was developed in the 1930’s and was in wide use in World War II. With a very few exceptions, all large diameter pressure vessels manufactured today are made using flat plates, roll formed into cylinders or shell cans and welded together. There are plate rolls here on the Gulf Coast that can roll cylinders up to 14” thick and 120” wide when using hot forming. Pressure vessel shells are generally roll formed rather than using a press-brake to minimize stresses in the shell walls. The heads for pressure vessels are generally manufactured by a handful of companies that specialize in that business. Heads can be hot pressed or cold spun, starting with a circular blank of steel. After the vessel shells are welded together, openings for nozzles are cut and flanges or forgings are welded into the assembly. Supports are added, the vessel is trimmed out, finished, painted, and shipped to client. There are several welding methods in use today. Arc welding using a stick electrode (SMAW) is used for small nozzles and vessel attachments.

The heliarc, tungsten inert gas (TIG) is used for very fine welding typically in root passes for alloy metals. Short Arc (MIG) is a wire feeder using an inert gas as a shield. It can be used for root passes for small diameter welds. Flux Core (FCAW) is the newest process. It is a cored wired that initially was used for non-pressure fillet welds but has improved in quality to the point that it is being used in pressure retaining welds. Submerged Arc (SAW) is the old standby in welding of vessel seams. This process uses a wire that ignites beneath a flux at the point of contact on a vessel weld joint, long seam or girth seam. This method allows the maximum amount of weld deposit per minute and is the most widely used method in use today for vessel seams.

Development of Steels and Their Uses

Refinery and Petro-Chemical Plant Building in the 1960's and 1970's

During the 1960's, our nation experienced one of the longest economic expansions ever seen. Inflation was modest, growth was widespread, consumption increased dramatically. New refineries and chemical plants were built along the nation's Gulf Coast and to a lesser extent in other areas of the country. The EPA and OSHA were not yet in place.
Environmental concerns were not at the forefront of each construction project. In this business climate, plant building proceeded at steady pace.

In 1973, the Arab Oil Embargo changed the face of the Oil industry forever. In October of 1973, the price of a barrel of crude oil was $3.39. Twelve months later, it was more than $11.00, a more than 320% increase. This dramatic increase in the price of crude produced shock waves through the global economy for the next dozen years.

During this time, the energy industries of our nation experienced an unbelievable bonanza. The exploration and production equipment business soared to new highs. Inflation began to appear at all levels of life. The consumer price index grew more than 14% annually during the mid-1970's.

The metal fabrication industry in the United States reached its zenith during the late 1970's. The third world was not yet a threat to the supremacy of the American grip on the world's fabrication needs. The company I founded grew from 6,900 ft.^{2} and 15 shop employees in 1973 to over 40,000 ft.^{2} and 90 shop employees by 1980. Expansion was the rule of the day. We were an arrogant and cocky bunch in our industry.

The Bust of the 1980's

The pendulum began to swing in the early 1980's. Business was booming in 1981, but the signs of a major downturn were beginning to show up. Inventories were growing. Lead times were dropping. An economic correction was at hand. Major contractions in the demand for all things associated with oilfield production and supply rapidly spread through the industry in the early 1980's. By 1984, a substantial percentage of the industry had disappeared. In 1979, Wyatt Industries, the largest pressure vessel shop in the country, had 1370 shop employees. In 1984, Wyatt closed their doors. Belmas, Metal Arts, Delta Southern, Wilson Industries, Smith Industries, Allied Industries, and Graver Tank all closed their doors.

The Recovery and Decline of the 1990's

In the early 1990's, conditions within the industry were favorable. New refinery and chemical plant expansions and offshore production platform work grew steadily. The remainder of the fabrication industry began to recover from the bust of the previous decade. The industry was in good health until 1998, when a decline in the price of crude oil took its toll on the construction budgets of the major oil companies. Crude oil was priced at $10.73 per barrel in February 1999.

Development of Steels and Their Uses

From 1999 until the end of 2003, the industry was in serious decline. More closures of old line firms such as Engineers and Fabricators Company, and G. A. Mosites occurred.

Strong Growth from 2004-2008

The year 2004 saw a dramatic rebound in the fabrication industry due to several factors. The first was an ever-increasing price for crude oil, due mainly to greatly increased consumption in China and India. The second was a 104% increase in the price of steel. This too was fueled by demand from China. Worldwide steel production had flattened out. The cruel steel market of the last few years had done things that no one would have ever considered possible twenty years ago. Bethlehem Steel is no more; United States Steel no longer makes plate of any kind. It sold its last plate mill to the International Steel Group (ISG) in early 2003 in exchange for a sheet mill. ISG was purchased by Mittal, Inc. which became Archelor Mittal, the largest steel mill in the nation. As the price of crude oil climbed to $147.00 per barrel in July 2008, the industry boomed. Gasoline was over $4.00 a gallon and diesel was even higher. The fabrication industry prospered by ever higher energy prices. The collapse in late 2008 was not felt by many fabricators in the industry because of strong backlogs going into 2009. By the end of 2009, a bust was in full swing. There were some strong contractions within the industry, but most fabricators weathered the storm. By mid 2010, crude was once more climbing and generating ever stronger business.

The Deepwater Horizon Drillship tragedy and the BP Macondo well blowout in April of 2010 brought offshore drilling operations to a halt, but by the end of 2010, activity was again on the upswing. Crude oil prices ended 2010 above $90.00 a barrel.

Development of Steels and Their Uses

Classifications of Metal Fabrication

Field Fabrication and Construction

Fifty years ago, any vessel or tank larger than 12’ 0” in diameter was considered to be a field erection and construction job. Most highways, bridges, and underpasses were not designed for the movement of large, heavy objects. For a Process Column 14’ 0” or larger in diameter, the approach was to roll the plates in arc segments and assemble the vessel in the field just like a jigsaw puzzle. Since labor was still relatively inexpensive, versus steel, this was a cost effective approach to constructing a large vessel. As field labor became ever more expensive, larger and larger vessels began to be manufactured in vessel shops. Shop labor rates are much cheaper than field construction rates and shop fabrication is not subject to weather related delays.

Shop Fabrication

Sheet Metal Fabrication

Sheet metal fabrication is generally a precision operation using press brakes, roll forming, punching, plasma burning, and laser cutting tools. Typically, sheet metal shops work to a maximum thickness of .250” or less. It is a rare sheet metal shop that does ASME Code fabrication.

Structural Fabrication

This includes skids, various structures made from beams, channels, angles and ladders and platforms. Generally, the labor rates in a structural shop are less than a vessel shop. Therefore, ladders and platforms are subcontracted to structural shops.

Atmospheric Tanks

The steel tank industry builds non-pressure, non-ASME Code, flat or cone bottom or top tanks. Typically, the thicknesses are .375” or less and the tanks are made with commercial quality steels, such as A-36. The labor rates in this industry are much less than a pressure vessel shop.

Pressure Vessel and Exchangers

The pressure vessel industry manufacturers almost all of their products as ASME Code items, designed and stamped to The ASME Boiler and Pressure Vessel Code, Section VIII, Div. 1. Their principal pieces of equipment are plate-forming rolls, vessel turning rolls, and heavy welding machines and machine tools in exchanger shops.

Fabricated Piping

The pipe shops employ the most highly skilled and expensive welders. Pipe shops have jigs and fixtures and use a wide variety of welding processes. Their work is generally more precise and subject to tighter tolerances than vessel shops. Most of their work is pipe size up to 24” diameter, and 100% radiography of their welds is often required.

Development of Steels and Their Uses

Metallurgy

Carbon Steels

A-36 This commercial quality steel has wide uses in all fields **except** pressure vessels and exchangers. Although it can be used for a pressure-retaining vessel, it is limited to a thickness of .625”. We do not see this steel specified for vessel work. A-36 is the standard specification for all structurals and flat bars. Most of it comes from the melting and casting of steel scrap.

The A-516 family of steels

A-516 can be produced to Grades 55, 60, 65 and 70. A-516-70 is the most common and will be what is offered in steel warehouses worldwide. Originally, the Grades 55, 60, and 65 were designed to be used in those applications requiring lower hardness levels and therefore, better ductility. As a practical matter, when buying one of these lower grades, the mill test reports will have dual or triple certified the plates as conforming to the requirements of all three specifications. This steel is made in specific heats or melts in electric furnaces to be able to control the chemistry or the finished product.

Normalized A-516-70

A heat of steel is made into ingots, which are then rolled into slabs. When made into the finished plate, the steel is heated again and rolled out to the required thickness, width, and length. These plates are then called “as rolled”. Because they have been rolled out to the required thickness, they have a certain amount of stress inherent in the plate. By reheating the plate to 1650° F, we have “normalized” the plate and removed excessive stresses. These stresses in the steel are undesirable and many of the liquid steams in a refinery react with stressed steel promoting corrosion and possibly failure in service.

Vacuum Degassed and Normalized A-516-70

By vacuum degassing a heat of steel and adding calcium to the mix, minute impurities such as sulfur and phosphorus can be removed, giving the steel the ability to resist hydrogen induced cracking, and stress corrosion cracking.

There are other carbon steels that are used, such as A-537, but they are for specialized small market applications and we shall not take them up at this time.

Stainless Steels

A-240 is the broad category for the manufacture of stainless steel plates. This specification describes the chemical and physical properties of a test specimen taken from the finished product.

The 300 series stainlesses are known as “Austenitic”. They contain chrome and nickel.

The 400 series stainlesses are known as “Martensitic”. They contain chrome only.

Development of Steels and Their Uses

A-240-304 is the most common stainless in use today. It is called 18-8 stainless for its chrome and nickel percentages. It has a small amount of carbon and usually some trace elements such as molybdenum, which are not intentionally added to the heat. The balance of the heat is ferrous or iron. The chrome is a high hardness element and gives the metal strength. The nickel gives it toughness and ductility. This is the alloy of choice for low temperatures (down to -320ºF) and can be used in certain high temperature applications.

Look at your specification for A-240.

Notice the chemistries. Look at the carbon ranges.

A very small amount of carbon in the heat gives the finished product some strength.

There are several grades of 300 series stainlesses, such as 316, 321, 347, and 310, which is used in high heat applications because of its high nickel content.

In the 400 series stainlesses, we only find 410 and 410S in common use today. Both of these are straight chrome steels. They are hard, difficult to work, and very crack sensitive.
410 stainless was in wide use 40-50 years ago because of its lower cost, but we rarely see it in use today. 304 has come to be used where 410 was a generation ago.

Higher (Non Ferrous) Alloys

Exotic metals have a special place in the petrochemical industry, primarily in high heat, corrosive, or erosive atmospheres within chemical plants. Names such as Hastelloy, Carpenter 20, Incoloy, Inconel, Monel and are all made for specific applications.

Development of Steels and Their Uses

Choosing The Steel For Your Application

A-516-70 is the most widely used pressure vessel steel. It maintains its strength to temperatures of 650º F and can be used to -50ºF if normalized and impact tested. It is commercially available in thicknesses from .250" to 1.500" in the "as rolled" condition. For thicknesses in excess of 1.500", the plate must be normalized to prevent potential cracking in forming or in service. A-516-70 plates are commercially stocked in warehouses today in widths of 96" and 120" and lengths of 480". Of course it can be ordered to any width and length and thickness, but it is rare to find stock plates that are longer than 480"or wider than 120".

The Austenitic stainlesses are the 300 series metals. All of the 300 series stainlesses contain chrome and nickel. Some contain molybdenum, vanadium, or a very small amount of titanium. These metals do not rust or corrode in normal conditions. The metals we are talking about are 304, 316, 310, 321, and 347. Each of these has specific applications. A century ago, when the specifications were first being written and steel making was still fairly primitive, all of these 300 series stainlesses had L grades, straight grades, and H grades, low, normal, and high carbon contents. Three decades ago, warehouses had to maintain multiple stocks of L grade and straight grade materials. Sometime in the 1970's, steel makers perfected the technique of controlling the chemical and physical properties of the stainlesses to make a product that met both specifications, with low carbon for service and normal carbon for strength. This meant that warehouses no longer had to carry multiple stocks of L grade and straight grade materials. For the fabrication industry, this was a revolution. We could design a pressure vessel using the higher stress values of straight grade material and still meet the clients need for low carbon. It allowed for a substantial weight reduction in the design and fabrication of 300 series pressure vessel.

The Martensitic stainlesses are the 400 series metals. These items, notably 410 and 410S are straight chrome materials. They will actually rust. Some 40 years ago, 410 was in wide use as a cladding material in high temperature, corrosive refinery process equipment. At the time, 410 was significantly cheaper than the 300 series stainlesses. A clad reactor in the 1960's was designed using 410 stainless because it was much cheaper than using 304. This is not true today. Manufacturing techniques have made the production of 304 stainless plates to be as low as 410 or 410S. If you buy a piece of 410 stainless plate today, it will be comparable in price to the same item in 304.

Development of Steels and Their Uses

Mechanical Design Facts You Need To Know

By far and away, the most common plate rolls owned by the vast majority of fabricators in the nation today are capable of handling either 96” or 120” wide plates. Plate rolls are rated as .500” x 8’ 0” or .750” x 10’ 0” up to 1.500” X 10’ 0”. The largest plate roll in use in the nation today is at Navasota, Texas. It can roll 8” thick x 10’ 0” cold and 14” hot. Tex-Fab Inc. owns it here in Houston.

Since plate is stocked in warehouses in 96” and 120” widths and generally 40’ 0” lengths, you need to know that this means that any pressure vessel larger than 12’ 6” I.D. cannot be fabricated from a single shell can using stock plate. It is acceptable to weld two plates together, but then we have to deal with flatness issues, and a second long-seam. Because of the 120” wide plate issue, a vessel with a seam length of 11’ 0”, 21’ 0”, 31’ 0” etc. is not a fabrication friendly idea.

Wind Loads on Tall Towers

Since most of the petrochemical plants are located on the Gulf Coast of the United States, wind loading from hurricanes is a significant design factor. Over the years, maps have been developed giving us expected maximum wind loadings for any specific location in the nation. We use this resource in determining what wind load to input in the design of a tall tower. A general rule of thumb is that when the total height of the tower exceeds the diameter by a ratio of 10 to 1, then the wind load may indeed affect your design. We have prepared a few examples to show you the effect of different wind loadings.

As the tower height increases, and the wind speed increases, the thickness at the bottom of the tower and the skirt increases accordingly. Base plates can end up being very thick.
It some cases, the typical anchor bolt stress of 15,000 psi may have to be elevated using high strength anchor bolts. Another method of approaching this problem is to flare the skirt, obtaining a larger bolt circle, effectively reducing the L/D ratio. In calculating the wind load, we must add in factors for insulation, ladders and platforms, and external piping.