Penn Machine Presents
Understanding
Carbon and Stainless Steel Pipe Fittings

Carbon Steel Pipe Fittings

Stainless Steel Pipe Fittings

This information is for general training purposes only and is not intended for Design Application

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QQS 763 Properties of Stainless Steel

- Federal Specification for Forged Steel Fittings which was developed by the United States Government as a guide to definitions on when to use 300 and 400 series stainless steel for specific applications

- Specification restricts copper (Cu) and Nitrogen (N) in 300 series stainless for better after welding properties

- Makes a Corrosion Test mandatory in order to assure the material was properly solution annealed

- Makes a Macro-Etch Examination mandatory in order to assure the material has no major imperfect- ions from the steel making process

Color Coding of Stainless Steels

Stainless Steel is color coded to each end user's specification requirement. Some users color code 304 Gold and others use Orange. Each user has a specific purpose or preference for why they use a certain color code. The most widely used pipe, valve, and fitting color code standard is the Pipe Fabricator Institutes Engineering Practice ES-22. Hopefully, the future will show us all that only one standard makes sense. The main caution of color coding stainless steel is that the paint be free from "chlorides". Remember, chlorides attack stainless steel and are harmful to this material. Until the industry uses one color coding standard, all Penn Fittings are color coded (when required) with Vendor certified chloride free paint.

What Are The Main Carbon Grades In Our Industry

Forged Steel Fittings	- A105, A181(Grade 1 & 2), A234 (Grades WPB & WPC)
Branch Outlets	- A105 & A694(Y50, Y60, Y70)
Swage Nipples	- A234 (Grades WPB & WPC)
Pipe Nipples	- A106 (Grades B & C) & A53

What Are The Main Stainless Grades In Our Industry

Forged Steel Fittings	- A182 (example : F304/304L) A403 (example : WP304/304L)
Branch Outlets	- A182 (example : F316/316L)
Swage Nipples	- A403 (example : WP317L)
Pipe Nipples	- A312 (example : TP321)

What is HOT DIP Galvanizing?

This process involves dipping the fittings in a molten bath of Zinc (Zn). Items are processed and certified to ASTM-A153 which is actually a hardware spec for items such as wrenches and crane hooks.

The normal practice for fittings is to rechase the threads in the fitting after galvanizing which adding extra costs into the product.

This galvanizing is performed to provide a strong, corrosion-resistant coating to the fitting for protection from underground or strong atmospheric corrosion.

What is Electro Deposited Galvanizing?

This process puts the fittings in a bath of zinc cyanide. Zinc adhesion to the part takes place because the fittings are negatively charged in the processing cycle. After the parts are zinc coated, a clear chromium lacquer solution is applied.

The fittings are processed and certified to ASTM-B633 and must withstand 96 hours of salt spray to be considered capable for service.

Normally, these parts are used where either atmospheric or surrounding corrosive environments would be a factor in destroying carbon steel fittings.

What's the difference between SA105 and A105?

SA105 is defined as the material spec for ASME Section II Code Part "SA"

A105 is defined this way as the material spec for ASTM under Volume books 1.01 and the material is governed by the ASTM A-1 committee

Are they the same? Yes, in most cases. However if there is a change to the specification, it will be changed in ASTM first and can take up to 18 months before it changes in ASME.

Why is Liquid Penetrant or Magnetic Particle Examination invoked on the product form of CAPS in ASTM-A234?

All caps made from bar in A234 must be tested to ensure there are no inclusions in the material. The reason ASTM invokes this is because some time ago defective foreign source bar entered the United States. Manufacturers were producing caps from this carbon steel bar that were full of inclusions. One can only imagine what an inclusion would do on a product that stops fluid or gas as part of the product's function (i.e. a cap). ASTM prevented many catastrophic disasters by imposing an inspection of the caps to be mandatory and to be certified to A234.

Liquid Penetrant Examination required on the product form of CAPS made from bar in ASTM-A403

All caps made from bar in A403 must be tested to ensure there are no inclusions in the material. The reason ASTM invokes this is because some time ago defective foreign source bar entered the United States. Manufacturers were producing caps from this carbon steel bar that were full of inclusions. One can only imagine what an inclusion would do on a product that stops fluid or gas as part of the product's function (i.e. a cap). ASTM prevented many catastrophic disasters by imposing an inspection of the caps to be mandatory and to be certified to A403.

How does each element effect your Carbon Steel?

- Carbon
- Manganese
- Phosphorus
- Sulfur
- Silicon
- Copper
- Nickel
- Chromium
- Molybdenum
- Niobium
- Aluminum

Carbon (C)

This element is the principal hardening ingredient in steel. The higher the content subsequently the higher the hardness and the lower the ductility and weldability of the steel.

Manganese (Mn)

It contributes to strength and hardness, but to a lesser degree than the element of Carbon. The amount of increase in the properties that manganese can yield depends upon the carbon content. The higher the carbon, the more effect the manganese has on its properties. It is also beneficial to surface quality in all carbon ranges, whether high or low.

Phosphorus (P)

This element is present in all steels in small amounts as an impurity. Generally, increased amounts result in increased strengths and hardness, and decreased ductility. It also improves resistance to atmospheric corrosion.

Sulfur (S)

This element is present in small quantities as an impurity. It decreases ductility, toughness and weldability, but improves machinability.

Silicon (Si)

This element in one of the principal deoxidizers used in the steel making process. It increases the strength and hardness, but to a lesser degree than Manganese. In lower carbon steels, Silicon is detrimental to surface quality.

Copper (Cu)

This element is detrimental to surface quality. In appreciable amounts, it can be detrimental to hot working operations as well. It has no significant effect in small amounts on mechanical properties.
In large amounts, it can have a beneficial effect on atmospheric corrosion resistance. It's mainly in steel when scrap metal is used as the main ingredient to produce a new batch of steel.

Nickel (Ni)

This element increases strength and hardness without sacrificing ductility and toughness. It increases resistance to corrosion and scaling at elevated temperatures when introduced in suitable quantities. A main property of this element is improving the surface quality via appearance and cleanliness of the steel.

Chromium (Cr)

This element increases tensile strength, hardness, hardenability, toughness, resistance to wear and abrasion, resistance to corrosion and scaling at elevated temperatures.

Molybdenum (Mo)

This element increases hardenability and strength in steel. It also improves machinability, resistance to corrosion and it intensifies the effects of other alloying elements in steel.

Vanadium (V)

This element improves the resistance to softening at elevated temperatures. It also aids in hardening and grain structuring during heat treatment. In higher concentrations, this element can improve the ductility of the steel.

Niobium (Nb)

This element is sometimes referred to as Columbium (Cb) in the United States. In fact, the element is the same in chemical international references (Cb = Nb). Niobium is used in addition to Vanadium as a grain refiner. It acts as a carbide precipitation inhibitor in very high concentrations when added to the steel.

Aluminum (Al)

This element is used as a deoxidizer during the steel melting process. It may also be used as a grain refiner in high concentrations. It appears in some carbon steels simply because Aluminum is contained in scrap metal, such as crushed automobiles, being used as the basis for a main ingredient in steel remelting.

What does Carbon Equivalency (CE) mean?

- CE was developed by the American Welding Society (AWS) to show a preferred chemistry in Carbon Steel for ease of welding.

- CE is measured on a hot melt ladle analysis for chemistry purposes to determine an "Index" of individual elements in Carbon Steel.

- This "Index" is based on Carbon (C), Manganese (Mn) and alloy elements contained in the steel.

- The actual formula is :

$$CE = C + \frac{Mn}{6} + \frac{(Cr + Mo + V)}{5} + \frac{(Ni + Cu)}{15}$$

What type of CE value is specified for products?

- The actual formula is published in Carbon Steel ASTM A-Specs and ASME Section II SA-Specs under A105, A106 and A234 as a supplement so users of the product form can order to a specification as a supplement if needed.

- ASTM and ASME specs call for a .47 Max CE

- API specifications call for a .43 Max CE

- Normally users specify a .45 Max CE

- As a rule, the lower the CE value, the better the weldability results

Penn Machine's Inventory of Carbon Steel

In 1990, Penn Machine started to stock inventory with a range of .35 to .43 CE

Through consultation with end-user welders and welding engineers, it was found that CE values of less than .43 yielded better weldability of product, less dependacy on post weld heat treatment in sour service applications and a reduction in field service cracking in prolonged service. In one case, a 50 percent reduction in annual weld rod usage (based on a five year study) was realized.

Why should Carbon Steel be Hardness Tested

Hardness is the physical property of steel which controls the steels mechanical properties.

Forging Hardness of A105 material has a maximum hardness of 187 Brinnell. Why not 350 Brinnell? Typically, a material which is too hard lends itself to be too strong and very brittle. In such a state, fatigue and cracking will result when the material is used under extreme stresses, pressures and/or temperatures.

Stainless Steel Main Menu

General Stainless Steel Information

Chemical Elements of Stainless

5 Main Attributes of Stainless Steel

4 Basic Types of Stainless Steel

4 Micro Structures of Stainless Steel

Stainless Steel Material Grades

LP Testing of Stainless Steel

Liquid Penetrant testing (sometimes called dye penetrant examination) is an inspection method in which the product is covered in a fluorescent dye and examined under an ultraviolet light. Under this light, any inclusions or surface defects are high-lighted. In most cases, the specification calls for the evidence that "no defects" are discovered in this examination process. After this LP exam is performed, the parts are cleaned to remove the fluorescent dye. The qualification of the examiner is usually a certified eye exam plus both class room and hands-on inspection certification. Stainless Steel is LP rather than Magnetic Particle Examined because stainless cannot be magnetized well enough to hold metal particles.

Sour Service Hardness Requirements of Steel

A Sour Service Environment is one containing hydrogen under partial pressure. The most common specification requirement of Carbon Steel to be used in such an environment is to be in accordance with NACE-MRO-175.

NACE requires that Carbon Steel products be supplied with:

a) a Nickel content of less than 1 percent
b) Hot formed or Heat treated
c) a Maximum Hardness of 22 Rockwell C.

3 restrictive requirements on Hardness

Remember, Nickel (Ni) contributes to how hard the steel will be. The more Nickel in steel, the harder it becomes. By restricting Nickel, lower hardness values are maintained.

Carbon Steel which is hot formed or Heat Treated will be in a state of uniformity with a consistent hardness throughout the end product form.

The 22 Maximum Rockwell C Hardness comes from extensive lab testing where Carbon Steels subjected to Hydrogen under partial pressure and cracked severely at a range between 24 to 27 Rc.

Penn Machine's Carbon Hardness Compliance

A105 is supplied with a hardness range between 137 to 187 Brinnell. This meets the supplementary requirement of the specification for users who need a consistent hardness from fitting to fitting.

A234 items are supplied with a maximum hardness of 197 Brinnell. Though not required by the spec, Penn reports this hardness as a help to the user for determination of post-weld heat treatment requirements.

Penn Carbon Fittings are supplied with under a 22 Rockwell C, so the user can meet NACE-MRO175 requirements and use Penn fittings for sour service environments.

Carbon Steel Hardness Main Menu

Why Test for Hardness in Carbon Steel?

Sour Service Requirements on Carbon Steel

3 Reasons why Hardness is Important in Steel

Penn Product's Hardness Requirements

Major Chemical Elements of Stainless Steel

Chromium

Nickel

Manganese

Molybdenum

Copper

Nitrogen

Niobium,Tantalum, and Titanium

Chromium (Cr)

This element is the major element in Stainless Steel that gives the steel its corrosion resistance. Chromium combines with Oxygen (O) to form a colorless chrome-oxide film on the surface of the metal. This makes the
steel passive.

Nickel (Ni)

This element combines with Chromium (Cr) and alloys the steel. The Nickel alloying is what gives Stainless Steel its valuable mechanical properties. The addition of Nickel to Chromium extends the corrosion resistance of the steel when added over 6 percent. Corrosion resistance is best when Nickel increases from 6 to about 15 percent.

Molybdenum (Mo)

This element is added in amounts of over 2 percent to increase the pitting corrosion of the steel. It is also used to increase the surface corrosion to a number of acids including sulfuric and phosphoric.

Manganese (Mn)

This element is added to give the material higher tensile and yield properties. In most stainless steels, Manganese is less than 2 percent. The manganese is increased to conserve Nickel (Ni). For example, going to a Mn closer to 2 % will conserve Ni to the 10 % level. Most steel mills will tend to melt Nickel on the low side for purely economic reasons. In this case, the steel's Manganese level will be closer to 2 percent.

Copper (Cu)

This element is added to increase the stainless steel's corrosion resistance to harsh acids such as sulfuric acid. Copper has also been noted to help stainless hold up against corrosion in sea water and brine environments.

Nitrogen (N)

This element has only been added into Stainless Steel during the last two decades. The purpose of nitrogen is to mistake proof the material once it has been welded. Many stainless steels are never heat treated after they are welded. By adding Nitrogen, usually up to 0.1 percent into the steel, it was found that microstructure impurities were eliminated after the material was welded without taking a subsequent solution anneal. The Nitrogen in the steel is said to be a welder's hidden treasure.

4 Types of Stainless Steels

Austenitic
Ferritic
Martensitic
Duplex

Austenitic

Iron, Chromium, and Nickel combine to have more than 16 percent Chromium, over 6 percent Nickel and to show an austenitic structure of the steel. Austenitic structure is a certain type of metallurgical picture which shows the intertwining of Chromium and Nickel to Iron Atoms. This type of structure is non-magnetic. However, a certain amount of magnetic properties can be added to an austenitic structure through cold working the material. This type of structure gives good corrosion resistance, oxidation resistance, certain types of acid resistance and good mechanical strength at elevated temperatures.

Ferritic

This type of stainless steel has just Iron and Chromium, usually containing between 11 to 30 percent Chromium with no other alloying elements. The material with over a 11 percent Chromium forms with Iron Atoms to become a Ferritic structure. This metallurgical picture of the material is highly resistant to chloride stress-corrosion cracking. The main properties of a Ferritic Structure are magnetic, good ductility and resistant to corrosion and oxidation.

Martensitic

This steel is used when high strength mechanical properties are required. They generally contain between 11 to 18 percent Chromium. The only other major elements in the material, beside Iron, is Carbon. The structure of Chromium and Iron atoms forms what is called Martensitic. The metallurg-ical picture here adds a structure to the steel of very high strength, hardness, impact strength, and corrosion resistance.

Duplex

This steel has over 18 percent Chromium, over 4 percent Nickel, and added Molybdenum plus Nitrogen and added corrosion and pitting resistance properties. Duplex refers to possessing the properties of both Austenitic and Ferritic structures.

The picture here is of very strong material with the properties of Ferritic such as mechanical strength and impact properties and the austenitic properties of corrosion and pitting resistance.

Stainless Steel's 5 most Common Characteristics

- Corrosion Resistance
- Strength
- Appearance and Cleanability
- Fabrication
- Passiveness

Corrosion Resistance

The steel combines Chromium, Nickel, and some grades Molybdenum as the major elements to provide corrosion resistance to the entire cross section of the metal. The need of painting, coating and plating is eliminated with the corrosion resistance being the main characteristic of all stainless steel.

Strength

Due to the high alloy contents of Nickel in stainless steel, the material has a higher strength than carbon and low alloy steels. The material can maintain strength at elevated temperatures.

Appearance and Cleanability

The steel provides a pleasing appearance. Some even say stainless steel gives an ornamental look in appearance. The steel cleans easy and is why the material is used in the food, beverage and pharmaceutical industries where cleaning the lines after producing one batch from another has to be completed in a timely as well as a clean manner.

Fabrication

The material can be fabricated by most conventional methods. These include stamping, forming, drawing, stretch forming, forging, casting and welding. The material is quite clean to process and requires only annealing as the primary heat treating practice to add the corrosion resistance back into the material after fabrication is completed.

Passiveness

The element of Chromium in Stainless Steel combines with Oxygen to form a colorless Chrome-Oxide film on the surface of the material. This film is extremely non-porous, tightly adhering and self-sealing. If broken, the film tends to re-form immediately, affording continuing protection to the metal underneath. To insure this reaction, the surface of the stainless enables oxygen to have free access to it. This is called the "passive" condition of Stainless Steel.

Passivation

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Different Types of Stainless Steels

Low Carbon Grades

Straight Grade Material

High Carbon Grades

Stabilized Grade Material

L-Grade Stainless Steel

"L" means LOW CARBON. These grades of stainless steel are manufactured with carbon at less than .035 percent. The material is melted with a low carbon concentration to give the material a fine to medium grain. This enables the material to be used in a wide range of corrosion resistant applications. The main property for L-Grade is that they hold up well after being welded and not receiving a post weld heat treatment. For this reason, many fabricators like the ease of welding L-Grade material and not having to post weld heat treat it.

Carbon Steel Main Menu

Chemical Elements	Hot Dip Galvanizing
Carbon Equivalency	Electrodeposited Galvanizing
Carbon Products	A234 Cap Testing
Hardness Properties	SA105 vs. A105

Carbon Equivalency Main Menu

Carbon Equivalent Formula and Definition

Industry Specifications of CE

Penn product's Carbon Equivalent

Straight Grade Stainless Steel

"Straight" means not "H-grade" and not "L-Grade". Straight grades are produced with a carbon content of .08 percent maximum. Years ago, before the wide use of L-grade stainless, most steel mills only made straight and h-grade stainless steel. Today most L-grade material is dual certified and manufactured as straight and L-grade material. The only difference in straight grade to L-grade is slightly higher mechanical properties. With modern steel making practices, straight grade stainless has become known as dual grade stainless with the slightly higher mechanical properties to enable the user to use dual grade stainless where the ASME Code permits.

H-Grade Stainless Steel

"H" means HIGH CARBON. The H-Grades are produced with a concentration of .04 to .10 percent Carbon (C). This high amount of carbon coarsens the grain structure of the material. The large grain sizes produced make the material ideal for use in high temperature applications (over 1000 deg. F) where creep rupture properties are needed.
Think of an H-Grade as "stone" compared to "sand" for an L-Grade. If you walk on sand your feet sink. If you walk on stone your feet don't sink. Creep rupture is like sinking in sand. At these over 1000 deg. F temperatures H-grades don't bulge (creep) whereas an L-grade could bulge as much as 20 % in 2 weeks.

Stabilized Grade Stainless Steel

"Stabilized" refers to certain intentionally added alloying elements (usually Titanium, Niobium or Tantalum) that have been added to stainless steel material to minimize the tendency of carbide precipitation. Stainless steel, when used at very hot temperatures, (normally over 1250 F) tends to break down and sensitize. The grain structure allows the solution annealing to revert back to active chromium carbide activity, resulting in severe intergranular corrosion and a rapid breakdown of the material. At these hot temperatures, the Titanium, Niobium, and Tantalum strengthen the grain boundaries and prevent sensitization from happening, keeping the solution annealed state of the material in tact.

Different Properties of Stainless Steel

Charpy Impact (Toughness)

Hardness/NACE-MRO175

QQS-763/Properties

Corrosion Testing (A262)

Stabilized Heat Treatment

Non-Contamination

Solution Annealing

LP Testing

Magnetic Permeability

Passivation

A403 Caps

Color Coding

Titanium (Ti) Tantalum (Ta) Niobium (Nb)

These elements are intentionally added into some grades of Stainless Steel to stabilize the steel. Each element, whether it be Ti, Ta or Nb, binds with Carbon (C) precipitates randomly in the grain boundaries instead of forming continuous patterns in the grain boundaries. This random forming improves the corrosion resistance of the stainless steel and lends itself to be used at very high service temperatures where stainless steels absent of Ti, Ta or Nb could not be used.

Stabilized Heat Treatment of Stainless

This is called the "corrective heat treatment" for titanium bearing stainless (such as 321) and niobium bearing stainless (such as 347 or 348).

This annealing takes place after the material has been solution annealed. The material is held at a temperature between 1550 and 1650 F for up to 5 hours depending on thickness of the material.

The corrective heat treatment assures the formation of austentite and protects the material against carbide precipitation when the service temperature of the material will be in the 1600 F range. Without this heat treatment, Intergranular Corrosion would occur at about 1400 F service.

Solution Annealing Stainless Steel

When the temperature of Stainless Steel is over 1850 F, carbides which decrease the resistance to intergranular corrosion are dissolved. Usually the manufacturer tries to anneal at the highest possible temperature (over 1900 to 2000 F). At this high annealing temperature, all the carbides, when dissolved, go into a solution form. Once they are in solution the steel is rapidly cooled, usually by water, quenching to freeze the state of solution. Think of cooking chocolate and then you want to make a candy. In order to get the it in the most uniform shape, you freeze or cool the candy rapidly. Solution annealing has other benefits like limiting grain growth and restoring maximum softness and ductility to the steel. Once this solution state is captured, the steel is now stainless.

A262 - Corrosion Testing of Stainless

If the stainless steel was properly solution annealed, the material will be free from preceipitated grain boundary carbide networks which result in "Intergranu-lar Attack (IGA)".

The most common test to see if the steel is free from IGA is the ASTM-A262 corrosion test. The two most common tests are Practice "A" and Practice "E".

Practice "A" which is a Oxalic Acid Etch Test of "etch structures of 300 series stainless" and Practice "E" is a Copper Sulfate/Sulfuric Acid Test for detecting the susceptibility to IGA

Magnetic Permeability of Stainless Steel

The metallurgical structure of austentetic stainless steel makes chromium/nickel non-magnetic and gives the material added properties. Cold working stainless steel, such as rolling, may change the structure slightly leaving some trace of being magnetic. Magnetic Permeability is a measure of the magnetic force in the metallurgical structure of the steel. Most 300 series stainless steels are under a 3.0 u permeability. Why is this important ? There are certain piping systems which require a very low nearby magnetic interference, such as piping components near a radio tower or in a submarine to block radar signals. Penn fittings fall below a 2.0 u, assuring the user's magnetic permeability is met for the design requirement.

Non-Contamination of Stainless Steel

Stainless steel has a chromium oxide layer which enables the steel to be corrosion resistant. In order for the steel surface to maintain a "passive flow", it must not be contaminated from outside sources such as dirt or the main culprit, iron. Such contamination comes from many sources such as carbon steel wire brushes, carbon steel inventory containers and metal strapping on steel bundles. A second form of contamination is chloride attack which can result from sprayed salt from snow/ice removal during outdoor transporting functions. Also, this chloride attack may come from paints used to color code material, as many paints have chlorides in them. Penn Fittings are stored with protection against iron surfaces and are free from salt environments.

Fittings when color coded are done so with "chloride free" paints.

Charpy Impact (Toughness) Testing of Stainless Steel

Stainless Steel's most common grades can be used in services to -325 Degrees F without being charpy impact tested. Why? Because specifications such as ASTM/ASME-A312 permit it as well as the ASME Code B31.1. The real answer is that stainless steel as a material in the austentic structure is very strong, but very elastic. Its like freezing a rubber band and then pulling it and not being about to break it. Stainless Steel acts like the "rubber band effect" at temperatures down to -325 F. The ASME Codes have found that the charpy (toughness) test is not really required for the stainless grades until the temperature goes below this point, at this time charpies would be required to show what impact would be placed on the material at these lower temperatures.

Stainless Steel Hardness Testing &

NACE (National Association of Corrosion Engineers is the professional organization that provides a specification called MRO-175. This specification covers materials that are used in sour service environments where hydrogen under partial pressure is the normal operating condition of the process. This organization has proven that Ausentitc Stainless Steel will crack in these types of environments when the materials hardness exceeds a Rockwell 22 C Hardness value which is about a 237 HB (Brinnell). Penn Machine's 300 series stainless is provided to the user at BELOW a 22 C Hardness to assure that any inventory or user requirement is met for sour service environments.