# WELDED STAINLESS STEEL TUBES & PIPES VS. SEAMLESS

## *COMPARAÇÃO ENTRE TUBOS DE AÇO INOXIDÁVEL COM E SEM COSTURA*

Elin M. Westin[1], David Garrett[2], Asko Kähönen[2], Hans Storbacka[2] and Sören Nytomt[2]
Outokumpu Stainless – Avesta Research Centre, P.O. Box 74, SE-774 22, Avesta, Sweden
Outokumpu Stainless Tubular Products, P.O. Box 16377, SE-103 27, Stockholm, Sweden

**ABSTRACT**
Welded tubular products play a vital role in virtually every industrial segment supporting our daily lives. Stainless steel pipe and tubes have good to excellent corrosion resistance and high quality surface finish characteristics, and are for these reasons used in demanding applications such as food processing and pharmaceutical production, for the conveyance and processing of liquids, gases and semi-solids in solution. Their high strength makes them ideally suitable for pressure applications within the oil & gas, petrochemical, chemical, energy, pulp & paper industries, etc. Initially all stainless steel tubular products were of seamless construction, but with improved metallurgy and welding processes, the benefits of welded products have diminished the use of seamless. Most tubes are produced from strip material or plate and can be 100% non-destructive tested (NDT) to ensure best possible weld quality. By choosing the optimum welding procedure followed by heat treatment and chemical cleaning (pickling) the corrosion resistance of the weld equals that of the base metal. The main advantages of welded tubes and pipes are their lower inherent cost, narrower tolerances for wall thickness, concentricity (OD/ID) and internal surfaces that can be checked prior to manufacture. They also allow larger diameters and longer lengths to be produced. Although welded tubes dominate the market, seamless tubes and pipes are still used. The main reasons other than conservatism are that some very heavy wall sizes can sometimes be too thick to form to the required profiles and that some traditional standards still specify seamless. The long term future and growth of stainless steel tubular products will without a doubt lie in welded production.

*RESUMO*
*Produtos tubulares soldados desempenham um papel vital em praticamente todos os segmentos industriais auxiliando nossa vida. Tubos de aço inoxidável têm boa resistência à corrosão e excelente acabamento com características de alta qualidade de superfície, e são por estes motivos utilizados em aplicações exigentes, tais como processamento de alimentos e produção farmacêutica, para o transporte e tratamento de líquidos, gases e semi-sólidos em solução. Sua alta resistência mecânica o torna idealmente adequado para aplicações de alta pressão nos setores de petróleo e gás, petroquímica, química, energia, indústrias de papel e celulose, etc. Inicialmente, todos os produtos tubulares de aço inoxidável eram fabricados sem costura, mas a metalurgia e os processos de soldagem foram melhoradas e os benefícios dos tubos soldados produtos causaram a o declínio do uso dos tubos sem costura. A maioria dos tubos são produzidos a partir de lâminas ou placa de material e pode ser testado 100% com ensaios não-destrutivos (END´s) para garantir melhor qualidade de solda. Ao escolher o melhor procedimento de soldagem seguido por tratamento térmico e limpeza química (decapagem) a resistência à corrosão da solda é igual ao do metal base. As principais vantagens dos tubos soldados são seu baixo custo inerente, tolerâncias estreitas para a espessura da parede, concentricidade (DExt / DInt) e superfícies internas que podem ser verificadas antes da fabricação. Eles também permitem maiores diâmetros e comprimentos mais longos a serem produzidos. Embora os tubos soldados dominem o mercado, os tubos sem costura ainda são usados. As principais razões para este fato prendem-se principalmente para grandes espessuras de parede, que às vezes podem ser muito difíceis para formar os perfis exigidos, além do fato de que algumas normas tradicionais ainda especificam os tubos sem costura. O futuro a longo prazo e crescimento de produtos de aço inoxidável tubular irá, sem dúvida, reside na produção de produtos com solda longitudinal.*

## INTRODUCTION

There is a never-ending debate whether seamless is better than welded. The arguments typically centre on structural integrity and corrosion resistance of the weld, severity of the intended service, NDT and inspection requirements and delivery time [1]. In reality, both production methods can provide the necessary quality and service life, corrosion resistance and reliability. Generally welded tubes are less expensive, have narrower tolerances, thinner nominal wall thickness, better concentricity (outer/inner diameter OD/ID), higher internal surface quality and are often chosen since they can be produced in longer lengths with larger diameters. Seamless tubes are needed where heavy wall thickness is combined with small diameters making forming of plate or strip complicated and where the standard specifically specifies seamless.

Viewed over the history of stainless steel tubular production, welded products can be considered relatively new arrivals to the market, as production originally was limited to seamless manufacturing only. This was due mainly to restricted welding technology and availability of only high carbon pre-material in strip and plate. The advent of modern AOD melting technology and precision cold-rolling/slitting processes combined with rapid technological leaps in welding techniques resulted in welded tube supplies soon becoming the dominant market supply. In 2007/2008, the stainless steel tube and pipe consumption was approximately 4 million metric tonnes of which welded products account for some 3.4 million metric tonnes and increasingly welded tubes and pipes are gaining market share from seamless [2].

Longitudinally welded stainless steel tubes for pressure applications are fusion welded with inert gas protection with or without filler metal. The corrosion resistance of the weld is of the same level as the base metal and the strength higher than the base metal. When produced by an approved manufacturer, authorities allow a strength factor of 1.0 under certain codes, for instance when 100% NDT is performed. Processing and testing advancements on the welded and cold worked tubing have created many technical and commercial advantages over the seamless product [3]. One improvement has, for instance, occurred within heat treatment where a strictly controlled annealing process eliminates residual stress from welding and forming.

This paper focuses on the benefits of welded stainless steel tubular products and how the integrity of the weld is guaranteed by means of NDT and destructive testing (DT), in addition to covering welding processes and corrosion aspects for both welded and seamless pipes.

## HOW TO MANUFACTURE TUBES AND PIPES

Tube manufacturing starts in the steel mill where either slabs or billets are cast. Production of seamless tubes starts from billets. Large diameter and heavy-walled pipes are made from hot-rolled plate, while strip welded tubes are mainly produced from cold-rolled or hot-rolled slit pre-material.

### MANUFACTURING WELDED TUBES

Depending on the outer dimension, wall thickness and final application, there are different ways of manufacturing welded tubes and pipes. Strip welded tubes are typically made in accordance with the production route shown in Figure 1. The material is decoiled, preferably into a strip accumulator which then enables continuous tube production. The strip edges may be precision-trimmed in order to create perfect joint geometry before welding. Cold forming is performed step by step from flat strip into a round profile and the edges are welded together as they approach the welding rolls at the welding station. Typical welding methods for strip welded tubes are traditionally autogenous

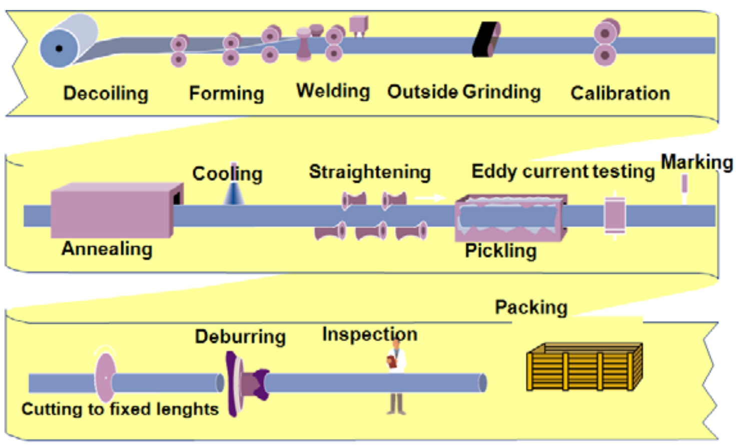

Figure 1. Typical production route for inline strip welded tubes.

tungsten inert gas (TIG) and plasma arc welding (PAW) or combinations of these. The tendency is that more and more tube manufacturers now are using the more productive laser welding method. Welding can be carried out with filler metal when this is a requirement in the product standard. Outside grinding of the weld seam follows welding. Solution annealing or stress relieving may be necessary by code or application requirements. Today, most of the modern welding lines are equipped with inline induction annealing. Such heat treatment homogenises the weld to be structurally indiscernible from the rest of the tube and improves properties and reduces residual stresses of the cold formed tubular product. After annealing the tube is calibrated to nominal diameter and straightened. The tube is normally 100% eddy current tested (ET), marked, cut to standard or special lengths, de-burred, visually inspected and finally packed. The cleaning with acid pickling as part of the process can be performed either inline or offline.

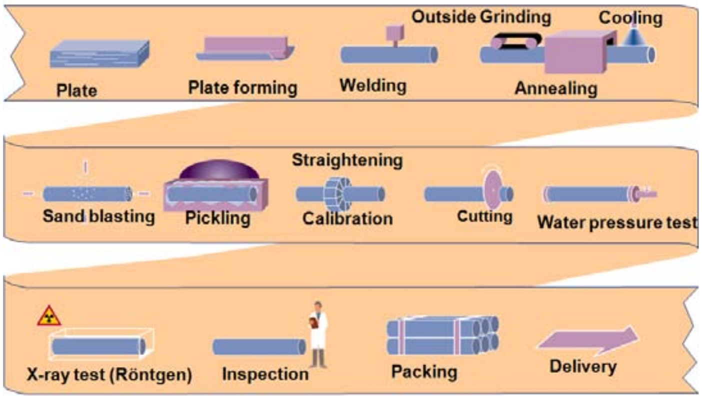

Figure 2. Typical production route for heavy-walled pipes.

*Heavy-walled pipe*, typically thicker than 6 mm, and pipes *with large OD*, typically larger than 500-600 mm are made piece by piece from plate or sheet (Figure 2). Depending on thickness, the forming is done in a roller bending machine or in a hydraulic press. Welding is commonly performed in I, Y or X shaped joints with PAW and (tandem) submerged arc welding (SAW) or combinations of these in specially designed welding machines. TIG welding is frequently used for dressing (remelting) of the root. All welding is normally done with filler metal, except when welding under codes that do not allow use of filler metal. After welding, the weld seam can be ground and the pipes can be annealed and water quenched as specified in the applicable standard or customer specification. The pipes are calibrated to fulfil specified dimension tolerances, followed by possibly sandblasting and acid pickling. The pipes are finally tested with hydrostatic (HT), radiography (RT) or other NDT methods like dye-penetrant testing (PT), but also DT in accordance with actual product standards.

## MANUFACTURING SEAMLESS TUBES

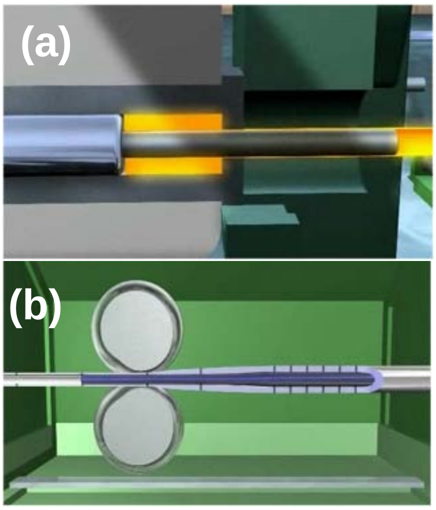

Figure 3. (a) Extrusion of a seamless tube and (b) pilgering cold work [4].

Seamless tubes are generally made in multiple steps starting with hot extrusion to form the tube hollows from billets, Figure 3a. The extrusion billet has typically a drilled hole and is pushed through a die and over a mandrel followed by air cooling or water quenching. The ID of the extrusion die determines the OD of the extruded tube and the OD of the piercing ram determines the ID. The gap between the piercing ram and the extrusion die defines the tube wall thickness. The wall thickness uniformity (concentricity) is difficult to control and it is difficult to achieve good surface quality. The surface of the extrusion billet is initially machined in order to remove any surface defects that otherwise would have a negative effect on the surface quality of the finished product. Further reduction of the tube hollows down to the required tubing sizes is done cold using pilgering (Figure 3b) to final finish and size of the tubes [1]. Cold work improves the mechanical and tolerances. Cold pilgering is the preferred production process since this technique provides a high forming rate, narrow tolerances and good productivity yields, but cold drawing gives narrower tolerance ranges and better surface quality [4]. In general both seamless and welded tubes receive some type of finishing treatment and heat treatment after completion of the manufacturing process. For example, ASTM A269, Standard Specification for Seamless and Welded Austenitic Stainless Steel for General Service, states the tubing may be hot finished or cold finished and that all tubing shall be supplied in the heat treated condition [1].

## WELDED AND SEAMLESS PRODUCTS

Many beliefs, which limit the use of welded tubular products are based on thinking originating from the world of carbon steels or a time before the carbon could be strictly controlled in the analysis of the stainless grade, and are no longer appropriate arguments against welded stainless products. As discussed by James and O'Donnell [1,5] detrimental defects are not exclusive to welded tubing. Seamless tubing can also have defects in the base metal that result from the manufacturing process. These include laps, scratches, tears or laminations. Seamless tubing should consequently also be inspected similar to welded tubing as part of the quality control process. Typically seamless tubing is inspected using HT and ultrasonic testing (UT).

### ADVANTAGES WITH WELDED TUBES

Welded tubes and pipes are generally more cost effective than the equivalent seamless alternative. They are significantly more available both from distributor and mill stocks and from a mill production lead time perspective.  With longer lead times seamless tubes can be exposed to unknown alloying price extras that can fluctuate substantially, hence it can be difficult to plan and predict the true costs for the material. Therefore in addition to faster delivery times for welded tubes, there is the added advantage of lower economical risk. Welded tubes generally have better surface quality on both the OD and ID as compared to hot-finished seamless materials. Welded tubes offer the advantage that the internal surface can be checked prior to manufacture. Since either the top or bottom surface of the pre-material will ultimately become the ID of a tube, the possibility of a casting defect being present on the ID of a welded tube is essentially non-existent under good production process control conditions. The use of cold-rolled strip for the production of welded tubes also results in better OD/ID concentricity and inherent surface finish. Low residual stress is obtained by solution annealing. High quality welds can be confirmed using stringent ET, UT, X-ray and HT. There are specialised ASME specifications for specific applications. The specification requirements for welded tubes are equal to or greater than seamless tubes. The performance of welded tubes and pipes in demanding applications can be generally considered to be equal to that of seamless materials.

### ADVANTAGES OF SEAMLESS PIPES

Despite many advantages with welded tubes, seamless tubes are still widely used and the two products generally complement each other. Tubes made of austenitic stainless steels, duplex and special grades can often be found in both seamless and welded construction, while seamless tubes dominate in non-weldable and highly specialised grades [1]. While some very heavy wall sizes are too thick to form to the required diameter in a welded construction, seamless tubes are available with very thick walls (i.e. $D/t < 8$). Other reasons for not specifying welded material could be that the design code, company or authorities have specified seamless pipe for the application. However, more commonly it is subjective reasons such as habit, limited experience and lack of trust in longitudinal welds that leads to seamless being chosen. When comparing seamless tubes to welded, the following arguments are often used as benefits of seamless tubes: Not having a heat-affected zone, better corrosion resistance, more homogeneous grain structure, no extra weld integrity testing, no problem with weld-seam orientation and no need for pressure de-rating. However, these are often very application and standard dependant issues and can be dealt with through the appropriate selection of manufacturing and finishing processes for welded products. Most of these arguments are discussed in this article.

BUTT WELDING OF WELDED AND SEAMLESS TUBES

Regardless whether the tube is welded or seamless, most are connected with circumferential welds to one another, fittings and flanges. Longitudinally welded tubes are produced in stable conditions (indoors, no wind, clean atmosphere) with automatic welding and excellent backing gas shielding. The process is continuous; the tubes can be annealed and pickled inline and are mostly tested with 100% NDT. Circumferential welds are made under less perfect conditions and instead often become the weakest link in both welded and seamless piping systems. These welds can in the main not be annealed and pickled after orbital welding and this increases the need to use over-alloyed filler metal and proper gas shielding. The residual stress level may also be higher than for welded or seamless tubes. Consequently, these issues are often more important than the initial selection of seamless or welded products.

Most stainless steels have good weldability, but some may require special welding procedures (bevelling, heat input, interpass temperature, filler metal). The most commonly used welding methods for manual girth welds are TIG and MMA for the root run. For filling and capping, the same methods can be used, but higher productivity methods are also an alternative. Orbital TIG welding is nowadays often used for butt welding of tubular products. In many cases, welding of pipes and tubes can only be performed from one side. It is important to perform such welding with full penetration and mostly with over-alloyed filler metal. For this reason, this type of manual welding requires qualified welding procedure specifications (WPS) and skilled welders and operators.

Weld oxide/discoloration formed on the root may decrease significantly the corrosion performance of the joint and should be removed after welding. If no, or inadequate, protection is provided, the penetration bead and surrounding parent metal will, at the very least, be badly oxidised. Other probable consequences are that the penetration bead will not form correctly and will have unacceptable porosity. The net effect is serious impairment of the corrosion performance of the weld zone and structural stability. As pickling of the inside rarely is an option, backing gas must be used for best corrosion resistance when TIG welding. The most common root gas is pure argon, but for duplex stainless steel and high-alloyed austenitics, nitrogen-based backing is recommended (e.g. 90% $N_2$ + 10% $H_2$). Root paste is not a viable option. When welding pipes, purge inserts are often used to help minimise oxygen levels. Alternatively, the pipe ends are sometimes closed using special fixtures or even cardboard and tape. To minimise the oxygen content in the enclosure, it should be flushed at least ten times with a volume equal to that of the enclosure. Preferably, there should be a flow of backing gas throughout the whole welding sequence until the weld has cooled down below 200°C. This applies even when welding multiple runs. It has been shown that an oxygen content of 60-100 ppm can leave a dark oxide on the weld. This can reduce corrosion resistance of the weldment significantly. In all cases, a maximum of 50 ppm should be seen as a target. If there is any doubt about the fitness for purpose of an oxidised weldment, it should be pickled before being put into service. With the increased access on the topside, weld oxides can be removed by using appropriate cleaning methods such as a mechanical method (brushing, grinding, blasting and polishing) followed by chemical cleaning (pickling).

Seamless tubes are also circumferentially welded together with the same requirements, but the orbital welding conditions are normally more demanding due to larger wall thickness variations. Welded tubes and pipes are mostly cheaper to weld (time, filler metal, bevelling, etc.) and the chemical composition is typically optimised for seal welding which make them easier to weld. For example MKS HPS® Products [6] notes that when producing seamless tubing in austenitic stainless steel, lower ferrite numbers are beneficial for the extrusion process. When connecting such seamless tubes, the lower ferrite number increases the possibility of hot cracking in the welds.

## WELD PROPERTIES

It is in general desirable that the properties of the weldment are on a par with those of the parent material. A correctly performed and cleaned weld can approach base material properties. Welding may cause changes in microstructure, corrosion resistance and affect the mechanical properties; hence it is important to verify good performance by suitable testing.

The hardness, yield and tensile strength of the weld are mostly somewhat higher than for the base material, while the impact toughness and ductility often are lower. Residual stresses, which develop as the weld solidifies and cools, can be reduced significantly by solution annealing.

The corrosion resistance of weldments can be equal to the base metal for heat treated products (recrystallisation and homogenisation of the microstructure) or products welded with filler metals, if optimum procedures are employed. However, the corrosion resistance may be affected by the choice of welding method, filler metal and shielding gas. The resistance of weldments to uniform corrosion is normally at the same level as the base metal, as in many cases over-alloyed fillers are used. The resistance to localised corrosion in chloride-containing environments may be somewhat lower than for the base material. One reason can be segregation of chromium and molybdenum in the weld metal. The pitting corrosion resistance of the longitudinal weld is improved by using an over-alloyed filler metal and/or by a heat treatment, which evens out the segregations and give the weld equal corrosion resistance with the base metal. The resistance to stress corrosion cracking, which typically occurs in warm chloride-containing environments and hot alkaline environments, may be lower compared to the base material as welding introduces stresses in the material. If stress corrosion cracking is a great concern, solution annealing may reduce the risk. Intergranular corrosion is normally caused by precipitation of chromium carbides in the HAZ. However, welding modern low carbon stainless steels, and stabilised steels, normally does not increase the risk for intergranular attack.

The taking of tube samples during production is common practise to evaluate for intergranular and uniform corrosion, and local weld corrosion. If the weld does not show preferential corrosion and the overall corrosion rate of the sample is acceptable, this is confirmation that the heat treatment was sufficient to impart good corrosion resistance [1]. The quality of the surface is important for the corrosion performance and in general, welded products have smooth surfaces since these are produced from coil or plate with strict surface quality control. Seamless tubes often have surface defects that could represent potential sites for subsequent localised corrosion. If a smooth surface is needed on seamless tubes, this can only be achieved at a higher cost. Corrosion evaluation can also be used for seamless tubing to ensure it was subjected to proper cold work and heat treatment and has adequate corrosion resistance [1].

## QUALITY ASSURANCE & TESTING

To ensure high-quality products, tube mills have a third-party certified quality assurance system, qualified welding methods and operators who carry out visual inspection and qualified NDT and DT. The final testing is determined by the actual product standards and customer specifications.

### NON-DESTRUCTIVE TESTING

Eddy current testing (ET) is the most dominating NDT method for testing strip welded tubes produced inline from coil. It is a fast, efficient and accepted method of testing in EN 10217-7, ASTM A 312, A 790, etc. ET is the base for welding factor 1.0 in Europe and a substitute for hydrostatic testing (HT). It is, however, normally limited to tubes with wall thickness of less than 6 mm. Radiography (RT) is a highly effective and sensitive method for thick walled welded pipe. RT is accepted in all standards and when 100% of welds are RT, the tubes also qualify for a welding factor of 1.0 and thereby fully correspond to a seamless pipe. Dye-penetrant testing (PT) is a supplementary requirement in the EN, and ASTM standards. Normally, the method is used in combination with other NDT such as RT. HT, also called leakage test, is an alternative to ET testing and is mandatory according to e.g. A 358 and A 928. The surfaces and welds are visually inspected before the pipes are delivered to the customer. The products are also checked to ensure correct tolerances of outside diameters, wall thickness, length and straightness before delivery are made.

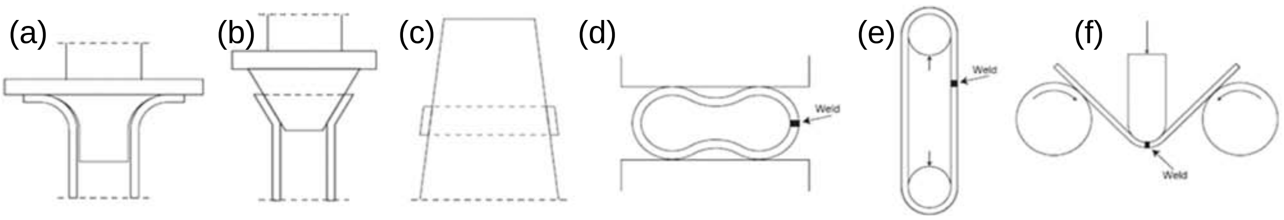


Figure 5. Some examples of technological testing of tubes (a) flange test, (b) flaring test, (c) ring expansion test, (d) flattening test, (e) ring tensile test and (f) root bend test.

DESTRUCTIVE TESTING

Technological tests, well described by Janikowski and Roth [3], are designed to specifically test the ductility of the weld in various directions. The weld is bent in a manner to strain a specific surface (OD or ID) in a specific direction (in the direction of the weld or transverse to the weld). The tensile test, also known as tension test, is probably the most fundamental type of mechanical testing that can be performed. Some technological tests, typically used for tubes are shown in Figure 5. Most high quality welded tube producers will perform such testing very frequently, in addition to the ASTM required certification tests on the final product [3]. Other relevant tests may be hardness and notch impact testing, and microstructure examinations. Hardness is the resistance of a material to permanent indentation and the most common use for this is to verify the heat treatment of a part. Notch impact testing is used to determine the energy absorbed in fracturing a test piece at high velocity at certain temperatures. It may be used to select a material and to verify suitable welding procedures. The goal of the microstructure inspection, performed using metallographic methods is to check that welding and heat treatment have been correctly performed. Grain size, grain boundaries and weld microstructure are typically checked.

Stainless steel is mainly chosen for corrosion resistance and several types of corrosion test options are available to ensure that the requirements of the specification can be met. The most common method to rank the resistance to pitting corrosion of different stainless steel grades and their weldments is to determine the critical pitting corrosion temperature (CPT) according to ASTM G48 Method E. This involves 24 h or 72 h exposure in a 6% $FeCl_3$ + 1% HCl solution. The test is repeated at different temperatures until the lowest temperature to cause pitting is determined, i.e. the CPT. For qualification/acceptance purposes the test can be performed at a single specified temperature. Another useful standardised method for pitting corrosion evaluation is electrochemical determination of the CPT in a 1 M sodium chloride solution. This is described in ASTM G150, and involves rather sophisticated test equipment with a flushed port cell.

Intergranular corrosion tests are tests specified in ASTM A 262, EN ISO 3651-2 (Strauss and Streicher), EN ISO 3651-1 (Huey). In addition ASTM A 763 and A 923 are designed to detect sensitisation from slow cooling rates, insufficient annealing, or carbon contamination, and can thus, be used to check if an alloy is correctly solution annealed, dissolving chromium carbides, which ensures that the chromium is available to keep the stainless “stainless” [3].

## DESIGN & TYPICAL STANDARDS FOR TUBULAR PRODUCTS

As a basis for the dimensioning of pressurised process piping systems in Europe, EN 13480-3 is used for design and the tube standard EN 10217-7 defines the technical delivery conditions and stress values for standardised grades. Outside Europe, the ASME standards dominate e.g. ASME B31.3 describes dimensioning rules on how to calculate internal design pressures for pipelines.

There are three main tubular piping systems used for describing dimensions; ANSI, ISO and Metric. The North American ANSI system is a national system applied all over the world, particularly within the petrochemical and offshore industry. The outside diameter is constant and expressed in inches, the wall thickness is expressed in schedules (Sch.), designed to withstand different inside pressures classes. The European ISO system is also OD based; it provides almost the same OD as the ANSI system, but in millimetres, and with a lot more choices for different wall thickness. The Metric system also use millimetres and also offers a wide range of different gauges, it has constant ID and has its roots within the Scandinavian pulp & paper industry. In Europe, stainless steel tubes used for pressure purposes are mainly manufactured according to EN 10217-7, while tubes for general applications are manufactured according to EN 10296-2. These standards cover both austenitic and duplex grades. The rest of the world often uses the American standards, where fusion welded austenitic stainless steel pipes serving in corrosive environments or at high temperature (or both) are mainly manufactured according to ASTM A 358. The standard ASTM A 312 is used for austenitic welded pipes intended for high temperature and general corrosive service. The corresponding standards for duplex grades are ASTM A 928 and ASTM A 790.

Table 1. The joint coefficient (z used in EN standards) or joint quality factor ($E_j$, used in ASME standards) used for calculation of the wall thickness for welded tubes. The type of welding process, amount and type of NDT decide the factor.

| Type of weld | EN 13480-3 | | ASME B31.3 | | | |
|---|---|---|---|---|---|---|
| process and NDT | EN 10217-7 / EN 10253-4 | EN 10296-2 / EN 10253-3 | A 312 | A790 | A358 | A 928 |
| EFW, 100% ET | 1.0 | - | 0.8 | 0.8 | 0.8 | 0.8 |
| EFW, 100% RT | 1.0 | - | 1.0 | 1.0 | 1.0 | 1.0 |
| EFW, spot RT | - | 0.85 | - | - | 0.9 | 0.9 |
| EFW, double butt | - | 0.7 | 0.85 | 0.85 | 0.85 | 0.85 |
| EFW, single butt | - | 0.7 | 0.8 | 0.8 | - | - |

EFW = electric fusion welded ET = eddy current test RT = radiographic test

A “strength coefficient in the longitudinal weld (Z or V)” is included in the standard design rules for calculation of pipe dimensions (Table 1). Standard EN 10217-7 describes 100% NDT. This gives a possible design utilisation of 100% and a weld factor Z = 1.0 for pressure calculation under EN 13480-3. This means that the welded tube is considered to have the same strength as a seamless tube for design purposes. The code for pressure piping ASME B31.3 is used by the process engineers worldwide. ASME is often combined with ASME/ASTM in material specifications. The pressure tube design in Europe is regulated by the European Community. The pressure equipment directive (PED 97/23/EC) harmonises national laws of the member states regarding the design, manufacture, testing and conformity assessment and assemblies of pressure equipment.

When designing tubular piping systems, there is a potential for weight savings by reduction in wall thickness by choosing a welded pipe or tube. Standard sizes can be produced with a thinner, more appropriate wall for welded pipes when compared to seamless tubes with the same diameter, thanks to the smaller steps in wall thickness in both ISO and Metric systems compared to ANSI (e.g. between Sch 10S to Sch 40S, the step increase of wall thickness can be 30-100%). Additional weight savings are possible by using high-strength materials, such as duplex grades instead of standard austenitics 304 or 316, with at least the same high corrosion resistance. Paijkull et al. [7] show some case studies where stainless steel grades have effectively been used in tubular products.

## MATERIALS & APPLICATIONS

When selecting a material grade for an application, a number of considerations have to be made. The grade needs to have sufficient corrosion resistance combined with suitable mechanical and physical properties. Tubular products are available for most stainless steel grades and are used in a wide range of applications and industrial segments; standard austenitics and austenitics for high temperature applications (e.g. 1.4307 (304L), 1.4541 (321), 1.4845 (310S) and 1.4948 (304H)), standard austenitics with molybdenum for improved corrosion resistance (e.g. 1.4404 (316L), 1.4571 (316Ti), 1.4438 (317L)), superaustenitics (e.g. 1.4539 (904L), 1.4547 (254 SMO®)), duplex (e.g. 1.4462 (2205), 1.4362 (2304), 1.4162 (LDX 2101®)) and superduplex (e.g. 1.4410 (2507)). The largest tonnages of welded process pipes are found primarily in chemical, petrochemical, energy, pulp & paper, water treatment and desalination industries. This could involve acidic or caustic environments, high pressure, abrasive conditions and both high and low temperature. The need for stainless tubing increases in more corrosive, low maintenance and high risk (failure) applications. Within offshore, welded tubes are used below the sea level in flowlines, umbilicals and riser pipes. Above the sea level, they are often found in process piping, seawater and service systems. Welded tubular products are frequently used in LNG plants, terminals and tankers, GTL plants, regasification and for storage. Other oil & gas applications are refineries and methanol, ammonia, ethylene, propylene and urea plants.

## CONCLUSIONS

The global need of stainless tubes increases steadily. Due to improved and cost-efficient production technologies, more than 80% of the tubes are today welded. Quality assurance systems have been developed where all welding procedures and welders are qualified by a notified body and the material and weld properties certified with established test methods. Seamless tubes are mostly used where the standard specifically specifies seamless, but current product standards are continually being revised to suit modern welding manufacturing technology. By choosing a welded tube over seamless, from the ANSI dimension system to ISO and Metric, and from the traditional austenitic to the duplex steel grades, there is large potential to save weight and cost when planning the pipe system of tomorrow.

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Corresponding authors: elinwestin@outokumpu.com and david.garrett@outokumpu.com