Orbital Welding of Duplex Stainless Steel Tubing and Pipe for Critical Offshore Applications

Soldagem Orbital de Tubos de Aço Inoxidável Duplex e Tubulação para Aplicações Offshore Críticas

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Abstract

Over the last decade or two extremely harsh offshore and subsea environments have mandated the development of improved grades of duplex stainless steels. These newer materials have the ability to retain a good balance of austenite and ferrite and thereby toughness and corrosion resistance in the welded condition. However, in order to retain the desirable properties of these technically complex materials, special care and attention is required for the joining of tubing and pipe.

Orbital GTA welding with preprogrammed weld schedules provides maximum parametric control and repeatability of process and is preferred to manual welding of duplex stainless steel wherever practical. The fine control of heat input makes it possible to meet the highest quality specifications for phase balance, corrosion resistance and mechanical strength. A major advantage of orbital welding over manual welding is that once a procedure has been established for a particular duplex alloy, consistent welds which meet all of the requirements of the qualified test coupons can be achieved with a high degree of repeatability throughout a project.

The use of orbital GTA welding for subsea and offshore applications includes autogenous welding of small diameter 0.250 inch tubing, as well as tubing installations on subsea “Christmas Tree” well heads. Orbital GTA welding with filler metal has also been done successfully on small diameter super duplex 2507 (UNS 32750) tubing for subsea umbilical coils as well as for large diameter headers.

A recent example of orbital welding of larger diameter duplex stainless steel pipe was done for the 800,000 barrel P-52 Platform. Built at the BrasFELS Shipyard in Angra dos Reis, Brazil and owned by Petrobras; this is the largest offshore platform in the world. The installer welded 22 inch Schedule 80 2507 (UNS 32750) duplex stainless steel pipe using two orbital welding power supplies and two full-function weld heads mounted on a single guide ring. The welds were accomplished with low heat input and the radiographic results were excellent. The index of repair over the six months of production welding was so outstanding that the fabricator received a special award from the BrasFELS shipyard for production quality. This project will be described in depth.

This presentation will describe orbital welding procedures and fabrication techniques as well as welding equipment used for autogenous and filler metal applications. The importance of tube and pipe end preparation, joint design, purge gas composition and purging techniques will be discussed.

Resumo

Durante as duas últimas décadas ambientes offshore e submarinos extremamente severos levaram ao desenvolvimento de melhores qualidades de aços inoxidáveis duplex. Estes materiais mais recentes têm a capacidade de manter um bom equilíbrio entre a austenita e a ferrita e, assim, tenacidade e resistência à corrosão na condição de soldado. No entanto, a fim de manter as propriedades desejáveis destes materiais tecnicamente complexos, especial atenção e cuidado é necessário para a união de tubos.

Soldagem orbital TIG (GTA) com horários pré-programados de solda oferece controle paramétrico máximo e repetibilidade do processo e é o preferido a soldagem manual de aço inoxidável duplex sempre que possível. O controle preciso do aporte de calor faz com que seja possível atender às especificações de alta qualidade para a fase de equilíbrio, resistência à corrosão e resistência mecânica. A maior vantagem da soldagem orbital sobre a soldagem manual é que depois que um procedimento foi estabelecido para uma liga duplex particular, soldas consistentes que satisfazem todas as exigências do teste de amostras qualificadas podem ser obtidas com um alto grau de repetibilidade ao longo de um projeto.

A utilização de soldagem orbital TIG para aplicações offshore e submarinas incluem a soldagem autógena de tubos de pequeno diâmetro 0,250 polegadas, bem como das instalações de tubulação submarina "Árvore de Natal" que atuam como cabeças de poço. A soldagem orbital TIG com metal de adição, também foi realizada com sucesso em superduplex 2507 (UNS 32750) de pequeno diâmetro para bobinas umbilicais submarinas, bem como para os cabeçotes de grande diâmetro.

Um exemplo recente de soldagem orbital de tubulação de aço inoxidável duplex de maior diâmetro foi feito para a Plataforma P-52, cuja produtividade é de 800 mil barris/dia. Construído no estaleiro BrasFELS, em Angra dos Reis, Brasil e de propriedade da Petrobras, é a maior plataforma offshore no mundo. A instalada tubulação de aço inoxidável duplex 2507 (UNS 32750) de 22 polegadas de diâmetro, Schedule 80, foi realizada com duas fontes de energia de soldagem orbital e duas de solda de guia montadas em um anel único. As soldas foram realizadas com baixo aporte de calor e os resultados radiográficos foram excelentes. O índice de reparação ao longo dos seis meses de soldagem de produção foi tão notável que o fabricante recebeu um prêmio especial do estaleiro BrasFELS para a qualidade da produção. Este projeto será descrito em detalhes.

Esta apresentação irá descrever os procedimentos de soldagem orbital e as técnicas de fabricação, bem como os equipamentos de solda utilizados para a execução da soldagem autógena e soldagem na qual se fez uso de metal de adição. A importância do tubo e preparação final da tubulação, o projeto conjunto, a composição do gás de purga e técnicas de purificação serão discutidos.

Introduction

As the development of engineered duplex stainless steel alloys for the offshore, subsea, and deepwater industries has advanced, so has the need for advanced welding technology for these materials. Orbital welding, which is defined as “automatic or machine welding of tubes or pipe in-place with the electrode rotating (or orbiting) around the work,” has been shown to offer many advantages compared to manual for welding the new generation of duplex stainless steels. The following examples show the range of applications and range of orbital welding equipment used for welding of duplex stainless steels:

In the early 1990’s, orbital welding technology was used by Cameron Forged Products Division of Cooper Ltd. (Great Britain) to fabricate a super duplex (UNS S32760) test manifold for Philips Petroleum (Henon, 1992). A full-function track-mounted Model 15 weld head was used to join the specially forged tees to form the manifold used for a high-pressure application on an offshore platform in the North Sea. (Figure 1.)

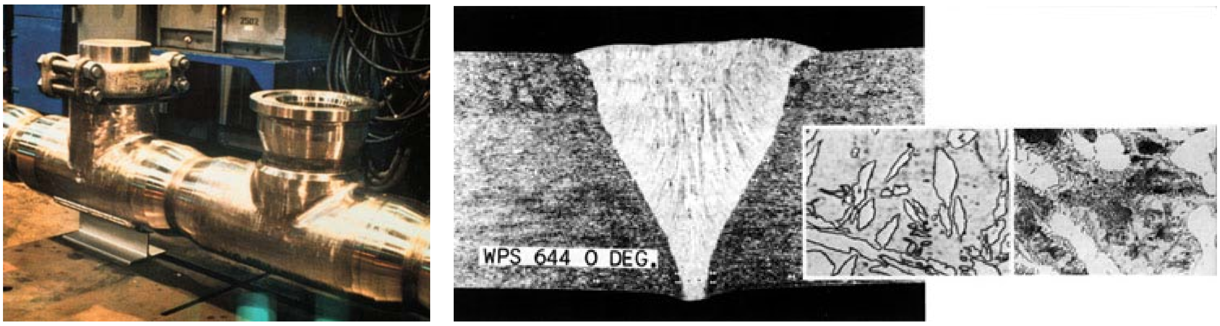


Figure 1. The Embla Test Header built by Cameron from forged super duplex tees using orbital GTA welding[11]. The Weld Procedure Specification (WPS) required preparation and examination of metallographs for sigma phase and ferrite counts.
(Photos from Henon, B.K., December, 1992)

Sandvik Chomutov Precision Tubes in the Czech Republic was one of the first companies to develop the combination of orbital welding technology with an advanced duplex grade, SAF 2507 super duplex (UNS 32507), for the fabrication of umbilical tubing used in today's remote deepwater fields (Henon, B.K. 2001). Arc Machines, Inc. Model 227 Power Supplies and Model 95 weld heads were used for this orbital wirefeed application. (Figure 2.)

Figure 2. Left: Sandvik orbital welding set-up with orbital welding power supply with cooling unit and orbital weld head. Orbitally welded lengths of super duplex tubing were wound onto large coils for umbilical tubing. 100% radiography of the orbital welds was performed. (*Photos from Henon, B.K., 2001)*

Acute Technological Services (ATS), a well-known petroleum industry support company, based in Houston, Texas USA, made an early decision to specialize in welding engineering, consulting and fabrication of duplex stainless steels. ATS has developed highly specialized manual and automatic orbital welding procedures for these materials (Hayes, M.D. and B.K. Henon, 1993).

Material and Methods

Material. Duplex stainless steels consisting of iron alloyed with chromium, nickel, molybdenum and nitrogen are engineered and manufactured to produce a material with a balanced phase microstructure of approximately 50% face centered cubic (fcc) austenite (γ) phase and 50% body-centered cubic ferrite(α) phase in the annealed condition. The balanced phase structure combines the favorable properties of austenitic and ferritic stainless steels when welded properly.

Weld procedure qualification of duplex materials usually requires corrosion testing of the weldments. Ferrite counts, either point counts from sections which are destructive tests, or ferritscope measurements which can be done on tubing in the field or between passes on pipe welds are commonly made. For weldments to be placed in low temperature service, low temperature Charpy impact testing may be required as a test for ductility. The NORSOK Standard M-601 used by the BrasFELS Shipyard requires 100% positive material identification (PMI) for stainless steels and nickel-based materials to be used in subsea applications. This standard also requires the use of matching the consumable with enhanced Ni content compared to base metal in order to promote the formation of austenite during welding.

*Equipment***.** For orbital GTA welding there are basically two types of equipment: equipment for autogenous welding used to weld tube, and pipe welding equipment with the capability of adding filler wire to the weld.

Orbital tube welding equipment. Orbital tube welding is a nearly automatic process in which the operator installs the tubing or components to be welded into an enclosed weld head, selects the appropriate welding program or schedule from the power supply memory, sets the ID purge flow and initiates the weld sequence. The power supply controls weld parameters. There is no operator intervention during the weld sequence in which the electrode, and thus the arc, completes a single pass weld with full penetration. Water cooling of weld heads is strongly recommended, especially for wall thicknesses greater than 0.049 inch or for high production welding. The end preparation for tube welding is typically a square butt weld (no groove) with the ends precision squared by machine.

Orbital pipe welding equipment. Orbital pipe welding power supplies generally provide higher welding current than tube welding power supplies and have the ability to feed wire into the weld. In addition to controlling the parameters for tube welding, they may also have electronic arc length control (AVC) and controls for torch oscillation for weaving the torch back and forth across the weld seam. For both tube and pipe systems, the weld program or schedule is stored in the memory of the microprocessor-controlled power supply, but with pipe welding power supplies, weld parameters such as AVC, welding current and torch centering may be adjusted or modified by the welding operator during welding.

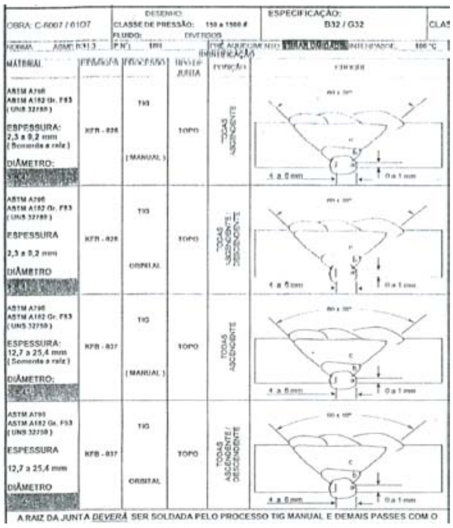
There are several types of pipe weld heads. The most basic is an open-frame head such as the AMI Model 95 with wire feed that clamps onto the pipe and uses mechanical arc length control. The Model 79 is a similar head which also has AVC and oscillation functions in addition to wire feed. Also available are large full-function track-mounted heads such as the AMI Model 15 for welding pipe from 4 inches nominal diameter and larger. These heads move around the weld joint on a track while the pipe remains in place. Other heads for limited clearance are used for boiler tubes and heads and torches exist for a large variety of applications.

Orbital Pipe Welding at BrasFELS Shipyard in Brazil

The Offshore Standard DNV-OS-F01 Appendix C Welding used by the BrasFELS Shipyard specified that mechanized and automatic welding systems where previous experience is limited or where the systems will be used under new conditions *shall* be subject to a more extensive prequalification program or documentation before they may be used. The Contractor was required to prove and document that the welding systems were reliable and that the process could be continuously monitored and controlled.

Installers at BrasFELS used two AMI full-function track-mounted Model 15 orbital weld heads mounted on the same track for welding up to 22 inch schedule 80 2507 (UNS 32750) duplex stainless steel pipe. A Model 79 open frame head was also used for welding smaller diameters up to 4 inch pipe in the pipeshop. At BrasFELS, there were two different joint configurations, pipe-to-pipe using a modified J end preparation and pipe-to-fitting which was a standard V groove with a 37 ½ ° bevel. The preferred end preparation for pipe welding up to about 0.500 inch wall thickness is the modified-J preparation with a land of about 0.065 to 0.095 inches (Figure 3.) The land extension may be adjusted depending on the material. The fittings at BrasFELS were received with a 37 ½ ° end prep which could not be machined or modified.

The PQR reflects the distribution of weld sizes and joint configurations for fully orbital welds or manual root passes combined with orbital welding. Pipe-to-elbow or tee fitting welds were done with a manual root followed by orbital filler passes, while pipe-to-pipe welds with a J end preparation (Figure 4.) were completely orbitally welded. In the pipeshop the pipe was segregated by ODs larger and smaller than 4 inches. (Figure 4.)



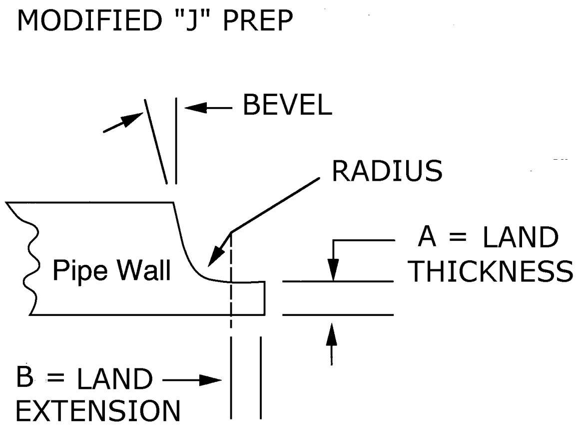


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Figure 3. Left: Detail from BrasFELS' PQR showing separation of duplex stainless steel pipe by sizes over 4 inches and 4 inches and less. It also shows manual root passes for pipe-to-fitting welds and complete orbital welds for pipe-to-pipe joints. Right: A modified "J" end preparation is recommended for orbital welding of pipe.

Arc Machines employee, Eng. Angel Brond, worked closely with BrasFELS to develop their PQR according to the requirements for limiting the heat input in duplex stainless steel welds listed in Offshore Standard DNV-OS-F101, Submarine Pipeline Systems, October 2007, App. C. This standard requires the control of heat input to avoid detrimental weld cooling rates. In order to achieve optimum control of heat input they recommend faster welding times and higher welding currents. Stringer beads are recommended to ensure a constant heat input and any weaving of the weld bead was limited to a maximum of 3 times the filler wire or electrode diameter. In this case the wire diameter was 0.035 inches supplied by Sandvik. The heat input for girth welds was limited to a range of 0.5 – 1.8 kJ/mm, with the lower end of the range specified for thinner wall pipe. It was also required that welding be continuous for an entire pass rather than stopping and starting the arc or performing a split pass.

Appendix C of DNV-OS-F101 required that welding personnel be qualified to ISO 14732 and EN 1418. Qualification of welding operators was done by BrasFELS with AMI consulting on site. As specified by this standard, the qualification tests were done on the actual equipment and premises that were used during production welding.
An additional standard DNV-RP-F112 Recommended Practice - Design of Duplex Stainless Steel Subsea Equipment Exposed to Cathodic Protection October 2008 was used as a Recommended Practice to asses the quality and repeatability of the ferrite and austenite composition of the base metal before welding and after welding.

NORSOK M 601 Standard, Edition 5, April 2008 is also referenced with respect to 4.4.4 Heat Input and 5.1 Welding Requirements. The maximum variation allowed in heat input is +/- 15%. Table A.3 lists acceptance criteria for welds including the amount of weld bead reinforcement or internal protrusion. A normative annex was added in this edition with color photos for acceptable oxidations/coloration on the I.D of pipes. Color ranges from no color (good) to heavy black, brown and blue discoloration which is unacceptable. Loss of corrosion resistance has been shown to be proportional to the amount of color (Hansen, J.V. 1997). To assure minimal discoloration, gas purity and dewpoint had to be certified and monitored at the point of use with an oxygen analyzer. NORSOK M 601 requires the use of filler metal in root passes of Type 25Cr duplex and Ni-alloys for seawater service. Filler metal on 4 inch 2 lbs spools was supplied by Bohler. A separate welding procedure (WPS) was required for repair welds. NORSOK M-601 allows only one attempt at repair in the same area. Re-welding must include complete removal of the original weld and HAZ.

Results

BrasFELS welding of super duplex pipe

The BrasFELS Shipyard was very successful in orbital welding of all of their sizes of super duplex stainless steel pipe. Their welding operation lasted for 1-1/2 years welding two shifts per day. The results of radiographic examination were excellent with a very low reject rate. BrasFELS passed the very stringent maintenance audit of the ISO 9001:2000 certification conducted by Bureau Veritas Quality International (BVQ1) with flying colors. They received an award from Petrobras for their excellent welding.

Figure 4. Left: Orbital welding of 2507 (UNS 32750) 20 inch duplex pipe with the AMI Model 15 and 4 inch pipe with the Model 79 weld heads in the prefabrication environment in the pipeshop at the BrasFELS Shipyard in Brazil. Right: Some orbital welds on pipe and fittings for the Petrobras P-52 Platform. *Photos from Arc Machines, Inc.*

Discussion

In deepwater installations, defined as over 1,000 feet or more beneath the surface, materials are expected to perform under higher pressures (15,000 psi) and to withstand higher temperatures (300° Fahrenheit) than ever before (Chater, J., 2007). To satisfy the requirements for deepwater applications, the use of stainless steels, especially duplex and super duplex have become nearly indispensible. Since proper welding of these materials is essential for maintaining their corrosion resistance and mechanical properties it is absolutely critical that good welding procedures be developed and carried out in a repeatable manner throughout a project.

Each application of duplex and super duplex material is unique and weld procedures must be developed accordingly. The steel tube umbilical must be manufactured to meet the requirements of the specific subsea application which varies with environmental conditions. Material selection and welding procedures must be determined independently for each individual project.

It is generally agreed that duplex stainless steels benefit from the addition of filler metal overalloyed in nickel and nitrogen. However, for some small bore tubing, acceptable ferrite counts and corrosion resistance have been achieved with autogenous welding. This has been accomplished by the use of shield gas containing helium, argon and 2% nitrogen (Hayes, M.D. and B.K. Henon, 2002).

Orbital welding of duplex stainless steel for subsea umbilical tubing is continuing. Several manufacturers of coiled tubing have told AMI, that this would not be possible without the use of orbital welding. Umbilical tubing is typically welded with a Model 95 or a Model 79 weld head feeding wire. AMI has recently been active in assisting with the development of the PQR/WPS for umbilical tubing in Brazil.

Petrobras in Brazil is a major player in this industry. The P-52 platform, recently commissioned, is largest in the world. BrasFELS Shipyard was given an award by Petrobras for their excellence. Weld criteria for duplex stainless steels must include ferrite counts or evaluation of the mechanical properties of the weldment since a good looking weld alone does not assure a good weld. A weld can have a good appearance while still have unacceptable ferrite numbers or deleterious phases that result in embrittlement. In order to accomplish repeatable welds with all of the favorable properties of the qualification welds, there must be proper and repeatable end preparation, joint configuration, purging techniques, and operator training.

Installers must be aware of the unique properties of the material and to understand the need for strict adherence to the qualified weld procedures (WPS). Precise, consistent control of heat input is essential. In addition, purging with inert gas is even more critical for duplex than for austenitic stainless steels for the retention of corrosion resistance. The recommendations for cleaning, end-preparation, welding environment, purging for manual welding of duplex stainless steels (Messer et. al, 2010) apply to orbitally welded duplex stainless steel as well.

The PQR for the Petrobras duplex stainless steel pipe made specific requirements for welding of duplex stainless steel, as outlined in the Sandvik and DNV Standards that would be very difficult to achieve by manual welding. To our knowledge this is the first time that a specification has gone so deeply into the details of a welding procedure. Compliance with the requirement for stringer beads or limiting the amount of oscillation of the weld bead, the upper and lower limits of heat input per pass with a maximum of 0.5-2.5 kJ/mm (10-65 kJ/inch), and the requirement for continuous welding virtually demanded the use of mechanized or orbital welding equipment.

Orbital welding with a proven WPS is the most reliable method for welding of duplex alloys. Unfortunately, installing contractors using manual welders working in the pipeshop or field environments are not always able to consistently meet the same quality requirements as those of the qualification welds that were done under ideal conditions. There have been several occasions when manually welded duplex and super duplex weldments have failed in service. It should be apparent that working in the deepwater environment drives up cost of repairing welds and weld failures may be catastrophic. However, there is very little in the welding literature to document the causes and effects of weld failures.

In an article on CalEnergy's use of corrosion resistant alloys (Van Wijngaarden, M., and J. Chater, 2006) they stated "With failures we reach a topic that is sometimes overlooked: welding." The authors interviewed Project Manager for CalEnergy, George Furmanski who indicated that in the United States there are not many companies that can provide proper welding specialists or welding equipment. Mr. Furanski is quoted as saying "The majority of the stress corrosion cracking failures that we have seen occurred in the weld or the heat-affected zone. We therefore now tend to favor companies that use *fully automatic welding machines*. Our biggest technical challenge right now is to find people who can weld 2507 duplex."

The use of duplex stainless steels for deepwater applications is increasing worldwide and this trend likely to continue as most new oil and gas discoveries are in deepwater fields. Michael Hayes of Acute Technological Services, Inc. estimates that presently about 60% of umbilical tubing for subsea applications is joined by orbital GTA welding, while only about 20-25% of heavier wall duplex and super duplex pipe are joined with this technology. Orbital welding is becoming more and more indispensible for welding these critical materials.

Conclusions

1. Orbital GTA welding is uniquely suited for the joining of advanced duplex stainless steel materials due to the precise control of welding parameters.

2. A wide range of orbital GTA welding equipment is available for welding of small diameter, thin-wall tubing to large diameter heavy wall pipe and all sizes in between.

3. Whether the alloy is duplex or superduplex and, whether the size is small bore or large diameter, these materials and applications have in common the requirement for welding procedures that are optimized for the specific material. Precise control of heat input, shield gas composition and filler metal chemistry are critical for achieving weldments with balanced phase microstructure and minimal deleterious phases so as to retain the favorable mechanical properties and corrosion resistance that were designed into the alloy.

4. Installers of duplex stainless steel pipe must understand the properties of these complex materials and welding operators and technicians must be aware of all of the requirements of the WPS in order to carry out the weld procedures consistently from joint-to-joint with a high degree of repeatability throughout a project.

5. Companies that began orbital GTA welding of duplex stainless steels for offshore applications in the 1990's are still using this technology and have expanded their operations worldwide.

6. The recent installation of pipe sizes up to 22 inch schedule 80 2507 duplex pipe with orbital GTA pipe welding equipment at the BrasFELS Shipyard was highly successful. The fabricator received an award from the Shipyard for completing the welding with a very low index of repair. This installer was clearly aware and focused on all of the details of the WPS.

7. Orbitally welded duplex and superduplex stainless steels will be critical in expanding the exploration and recovery of gas and oil from deepwater fields.

Acknowledgements

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