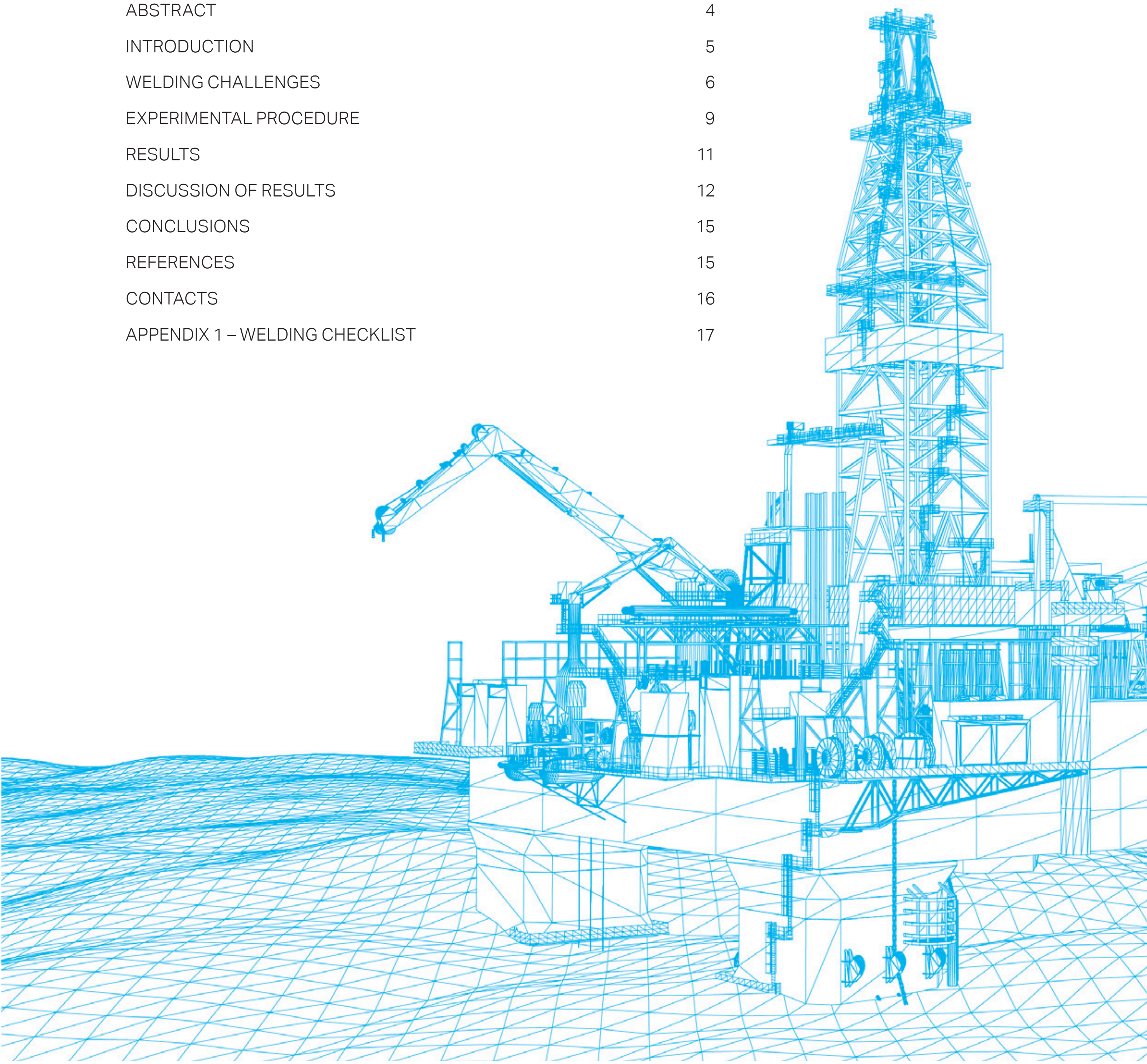
IMPROVED CORROSION PERFORMANCE IN SUPER-DUPLEX WELDS

PRACTICAL ASPECTS OF WELDING FOR DUPLEX AND SUPER-DUPLEX STAINLESS STEELS AND OVERCOMING CHALLENGES IN CORROSION TESTING

CONTENTS



THE CHALLENGE

In the offshore oil and gas industry, achieving good corrosion resistance in the welds of duplex and super-duplex stainless steel pipes, tube and other infrastructure can be challenging. This is especially true for localized repair welding of parts exposed to harsh, chloride-containing environments. The challenge is to maintain the favorable mechanical strength and corrosion-resistant properties of the duplex material while avoiding intermetallic microstructural changes that can arise in the heat affected zone. Not only does this require a skilled welder, but a deep knowledge of joint preparations, filler metals, proper shielding and root gases, welding techniques and even post-weld treatment.

This white paper is part of a series from the Research and Development Department (R&D) within the Sandvik group. It is based on published scientific papers with NACE International and other independent institutes. The content has been slightly modified in agreement with the author to make it more accessible for a broader range of professionals. It is part of our ongoing efforts to open up new possibilities for the oil and gas industry, reinforcing our commitment: WE HELP YOU GET THERE.

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ABSTRACT

For demanding offshore oil and gas applications, duplex (UNS S31803) and super duplex (UNS S32750 and UNS S32760) stainless steels provide excellent corrosion resistance and high mechanical strength.

Duplex steels have heterogeneous microstructures with roughly 50% austenite and 50% ferrite, a micro-structural balance that is achieved by controlling the chemical composition and using special heat treat-ments[1,2]. The high corrosion resistance of duplex steels ensures significantly more uptime than carbon steels and conventional stainless steels, while the mechanical strength allows for lighter constructions, more com-pact system design and thus reduced welding.

FINDING THE OPTIMAL BALANCE

When welding duplex and super-duplex steels, the biggest challenge is to maintain an optimized balance between the austenite-ferrite microstructure in the final weld metal as well as the desired mechanical properties. The purpose of this paper is to share our knowledge regarding the various practical fabrication aspects of duplex and super-duplex stainless steel welding. The paper provides practical advice on how to bring out the best of these complex materials as well as recommendations on how to retain the optimal balance of the duplex / super-duplex microstructure during and after welding.

CORROSION TEST ON 10 WELDED SAMPLES

Ten samples of super-duplex stainless steel pipe in two different sizes were welded and then tested by liquid penetrant test (LPT), radiographic test (RT) and finally ASTM G48 Method A corrosion bath test at 40°C for 24 hours. Based on these tests, this paper provides an overview of which temperatures, shielding and root gas mixes and other parameters are optimal to avoid the formation of any detrimental intermetallic phases or welding defects. The results of these tests are high-lighted in the results section and summary.

Key words: Duplex stainless steel, super-duplex stainless steel, welding, corrosion test, ferrite, austenite

"THE PURPOSE OF THIS PAPER IS TO SHARE OUR KNOWLEDGE REGARDING THE VARIOUS PRAC-TICAL FABRICATION ASPECTS OF DUPLEX AND SUPER DUPLEX STAINLESS STEEL WELDING."
SUKAMAL NASKAR

INTRODUCTION

Over the past decades, duplex stainless steels have built a strong reputation in the offshore oil and gas industry due to a number of attractive features: mechanical strength, corrosion resistance and lighter constructions than those built using carbon steels.

Their two-phase microstructure, with approximately equal amounts of austenite and ferrite, imparts a higher strength than corresponding austenitic grades and provides good resistance to stress corrosion cracking. The lower nickel contents of duplex grades, typically in the range of 5-10% compared with 8-25% in the austenitic grades, gives cost advantages. However, the welding of duplex stainless steels must be handled with care to avoid embrittlement or the formation of impurities in the weld.

BALANCED TWO-PHASE MICROSTRUCTURE

Duplex and super-duplex stainless steels are characterized by a two-phase microstructure that contains approximately 45-65% austenite, which is embedded as islands in a matrix of 35-55% ferrite. Since both phases prevent grain growth, it means that duplex stainless steels have a fine grain structure. What's more, due to a higher concentration of grain boundaries per unit surface area, super duplex stainless steels offer very high strength.

"DUPLEX STAINLESS STEELS HAVE BUILT A STRONG REPUTATION IN THE OFFSHORE OIL AND GAS INDUSTRY DUE TO A NUMBER OF ATTRACTIVE FEATURES: MECHANICAL STRENGTH, CORROSION RESISTANCE AND LIGHTER CONSTRUCTIONS THAN THOSE BUILT USING CARBON STEELS."
SUKAMAL NASKAR

CHROMIUM & MOLYBDENUM STABILIZERS

For the most part, such corrosion resistant alloys (CRAs) are produced using chromium (Cr), nickel (Ni), molybdenum (Mo) and nitrogen (N). Chromium and molybdenum serve mainly as ferrite stabilizers while nickel and nitrogen are used as austenite stabilizers. To obtain the desired ferrite-austenite mix, all these alloying elements need to be in balance in the base materials as well as suitable welding consumables.

PRE MEASUREMENT – A GOOD BENCHMARK

One key benchmark for assessing localized corrosion and checking weld quality is the pitting corrosion resistance equivalent number (PRE), as defined below:

$$PRE = \%Cr + 3.3 (\%Mo) + 16 (\%N)$$

In addition to determining the susceptibility of an alloy to pitting, this formula is widely used as a guide for the usability of corresponding welding fillers. Typically UNS S31803 has a PRE value of 35 whereas UNS S32750 and UNS S32760 have PRE values of 42. Such values provide an indication of the pitting resistance of an alloy in relation to the alloying content. The very high mechanical properties of duplex and super-duplex stainless steels are achieved as a result of the ferrite and austenite structure along with fine grain structure. The tensile properties are governed by ferrite phase while toughness properties are governed by austenite phase in conjunction with fine grain structure.

WELDING CHALLENGES

The welding of duplex and super duplex stainless steel for offshore and subsea operations can present a number of challenges due to the sudden introduction of extreme heat followed by rapid cooling.

During welding or other types of heat treatment, whether isothermal or non-isothermal, several structural changes may occur in the microstructure of duplex stainless steels.

FERRITE PHASE – MORE SUSCEPTIBLE

For the most part, these changes affect the ferrite phase with its richer concentrations of chromium (Cr) and molybdenum (Mo). Another reason the ferrite phase is more prone to structural change is the more compact lattice in the crystal structure, so-called Body Centered Cubic (BCC), which leads to diffusion rates of alloying elements that are almost 100 times faster than those in the austenite phase with its Face Centered Cubic (FCC) crystal structure.

UNDESIRABLE PHASE CHANGES

Slow cooling in the temperature ranges of 550°C to 900°C can lead to the formation of different types of intermetallic phases that are detrimental to the mechanical as well as corrosion properties of duplex and super duplex materials. Essentially, the higher the degree of alloying elements, the greater the possibility to form intermetallic phases and thus the more challenges in the fabrication process.

INTERMETALLIC PHASES – MORE LIKELY IN ALLOYS

Due to the higher alloy content in super duplexes such as UNS S32760 and UNS S32750, they are more prone to the precipitation of intermetallic phases like the sigma phase, chi phase and R phase than a duplex like UNS S31803. Since both duplex and super-duplex stainless steels are rich in Cr and Mo, they are also more likely to form sigma phase than a lean duplex. However, by increasing the concentrations of Cr and Mo, it is possible to shorten the Time-temperature transformation (TTT) curves of the sigma phase, thereby increasing the stability region of sigma phase. A quantitative chemical analysis using electron microprobe analysis (EPMA) shows that Cr, Mo and Si were enriched in sigma[3]. The addition of nitrogen helps to suppress the formation of sigma by reducing the difference between Cr and Mo content in the ferrite and austenite phases.

"SLOW COOLING IN THE TEMPERATURE RANGES OF 550°C TO 900°C CAN LEAD TO THE FORMATION OF DIFFERENT TYPES OF INTERMETALLIC PHASES THAT ARE DETRIMENTAL TO THE MECHANICAL AS WELL AS CORROSION PROPERTIES OF DUPLEX AND SUPER DUPLEX MATERIALS."
SUKAMAL NASKAR

SIGMA PHASE – RISKS OF EMBRITTLEMENT

Sigma phase is a tetragonally close-packed structure that is very brittle in nature and thus has a negative effect on the mechanical properties of the duplex. Since sigma phase is brittle in nature, hardness levels can be used to determine its presence in the base metal as well as weld metal. However, up to 4% presence of sigma phase has no significant impact on hardness[4]; hence hardness measurement is not appropriate to conclude the presence of sigma phase.

> "SIGMA PHASE IS A TETRAGONALLY CLOSE-PACKED STRUCTURE THAT IS VERY BRITTLE IN NATURE AND THUS HAS A NEGATIVE EFFECT ON THE MECHANICAL PROPERTIES OF THE DUPLEX."
> SUKAMAL NASKAR

CORROSION-RESISTANCE CHALLENGES

Apart from reducing mechanical strength, sigma phase also has a negative impact on the corrosion-resistant properties of the duplex. Corrosion properties are reduced at lower temperature due to the formation of secondary austenite. While thermodynamically stable, the austenite formed at low temperature also contains lower amounts of Cr, Mo and, most likely, nitrogen than primary austenite. This altered chemical composition results in lower PRE values at some localized areas on the average matrix, making secondary austenite more susceptible to the formation of pitting.

AVOIDING CHI AND R PHASES

In addition to the detrimental effects of sigma phase and secondary austenite, duplex steels can precipitate chi phase, R phase and chromium nitrides. Tungsten can be used as an alloying element to stabilize the chi-phase and help move the TTT curves towards a shorter time period. The R phase is molybdenum rich intermetallic compound and usually forms at 550-700°C, but its practical importance is less since it takes longer to nucleate.

CHROMIUM NITRIDE ISSUES

The biggest challenge when welding duplex steels is the presence of chromium nitrides and sigma phase together in the weld metal as well as base metal of the duplex family. Chromium nitride is formed during isothermal heat treatment in the temperature range of 700 - 900°C following too fast cooling from high temperature. While the solubility of nitrogen in ferrite is lower, it increases at higher temperatures. However, it has a significantly higher solubility in austenite. At higher temperature, due to increasing temperature gradient for cooling, nitrogen does not have enough time to diffuse in austenite and has limited amount of austenite formation. As a result, when ferrite formations are supersaturated with nitrogen, chromium nitrides form at the ferrite grains or at grain boundaries of δ/δ or δ/γ.

ADVANTAGES OF NITROGEN

With duplex stainless steels, nitrogen is beneficial in the rapid heating and slow cooling occuring in welding operations. Higher nitrogen content increases the reformation rate of austenite in the weld metal and HAZ (heat affected zone), giving shorter distance for nitrogen to diffuse from austenite to ferrite. Nitrogen has 16 times influence on PRE value and hence can significantly contribute to pitting corrosion resistance on weld metal as well as base metal.

BENEFITS OF SOLUTION ANNEALING

When manufacturing duplex and super-duplex base tubes and pipes, solution annealing is part of the final operations to prevent intermetallic phases or defects. However, due to structural integrity and economic feasibility, welded joints do not go through the solution annealing process. As a result, the biggest challenges for duplex and super duplex welding are to avoid intermetallic phases, obtain the desired microstructure and maintain the proper ferrite-austenite phase balance throughout the matrix to achieve the desired mechanical and corrosion properties.

Naturally, tube and materials fabricators in the oil and gas industry must carry out welding in careful accordance with strict guidelines. Repair welding is even more complex since one is not starting with fresh joints. This can present tougher challenges in terms of passing the 24-hour corrosion test for ASTM G48 method A. The fabrication of duplex and super duplex stainless steel tubes and pipes with welding processes and corresponding consumable selection depends on the several project technical requirements.

SELECTING THE RIGHT CONSUMABLES

The selection of suitable welding consumables depends on a number of key criteria: corrosion testing, impact testing, the ferrite number or ferrite percentage requirement on welding metal and HAZ (heat affected zone). The right welding filler material is selected for duplex steels UNS S32205 or UNS S31803, depending on the ASTM G48 Method A corrosion testing requirement at 20°C; 22°C and 25°C. The most suitable consumables for super duplexes like UNS S32750 or UNS S32760 are selected on the basis of corrosion testing temperatures at 40°C, 42°C and 50°C.

Welding consumables are selected on the basis of three welding options:

1. Welding of root pass, second pass (cold pass), fill pass and cap pass by matching weld metal chemistry to base metal.

2. Welding of root pass by over alloying welding consumable followed by cold pass, fill pass and cap pass by matching welding consumables to base material.

3. Welding of root pass, second pass (cold pass), fill pass and cap pass by over matching welding metal chemistry to base metal.

Among the above options, option two is most commonly used for duplex steels to achieve safe welding with optimal results. Since the pipe walls of duplex and super duplex materials are generally thinner than carbon or low alloy steels, the most commonly used welding process is gas tungsten arc welding (GTAW).

"REPAIR WELDING IS EVEN MORE COMPLEX SINCE ONE IS NOT STARTING WITH FRESH JOINTS."
SUKAMAL NASKAR

Gas tungsten arc welding (GTAW), also known as tungsten inert gas (TIG) welding, is an arc welding process that uses a non-consumable tungsten electrode to produce the weld.

Other welding options are as follows:

1. Shielded metal arc welding (SMAW)

2. Submerged arc welding (SAW)

3. Gas metal arc welding (GMAW)

When using the GTAW process, duplex grade materials are welded with AWS A5.9 ER2209 filler while super duplexes are welded with AWS A5.9 ER2594 filler (without Cu & T / with Cu & T). Apart from suitable welding consumables, other important factors in passing the ASTM G48 Method A corrosion testing include the following: shielding gas composition and flow rate; purging gas composition and flow rate; welding technique; oxygen level; heat input; inter-pass temperature; welding position; tube and pipe diameter; tube and pipe thickness; corrosion test sample preparation; and welder skill.

EXPERIMENTAL PROCEDURE

Our corrosion testing of multi-pass welds was limited to two different sizes of super-duplex stainless steel pipe UNS S32750: 1 inch/ Schedule 10 and 2 inch/ Schedule 160.

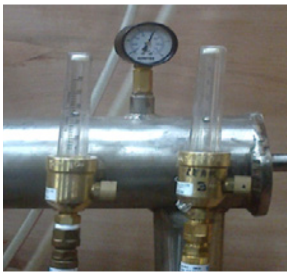
The only welding process used was gas tungsten arc welding (GTAW), with welding consumables matched to the base material: AWS A5.9 ER2594 welding wire. Our main objective was to eliminate possible causes of failure in the super-duplex UNS S32750 pipe, which had been welded with filler ER2594, following corrosion tested in accordance with the ASTM G48 method A for 24 hours at 40°C.

The main variables considered as parameters were: root pass heat input, second pass (cold pass) heat input, interpass temperature, shielding gas flow rate, purging gas flow rate and sample preparation.

1. 6G pipe welding certification test
The welding was done with 6G pipe fixed at a 45° angle to the base position.

2. Clean environment
The welding was carried out in a clean, air conditioned work-shop with wooden floors by a single welder using new hand gloves. Both the 1 inch and 2 inch pipes were cleaned with acetone to remove all foreign particles, paints, oil and other impurities.

3. Calibrated oxygen monitor
With the help of a calibrated oxygen monitor, the oxygen level was kept below 100 ppm on the root side during welding.



4. Premixed gas cylinder
The shielding and purging gas used was Argon+2% nitrogen, supplied from a premixed gas cylinder.

5. Calibrated welding machines
Calibrated welding machines were also used during the welding. Both shielding gas and purging gas was used from root pass to cap pass of the welding. A calibrated digital instrument was also used to check actual welding current and voltage during welding. Inter-pass temperature was kept below 100⁰C during welding.

6. Cleaning TIG rods with acetone
An iron-free grinding disc and power brush were used for the inter-pass cleaning operation while an ASME-qualified 6G welder was used during welding. Proper earth connection to the tubes and the welding machine was checked before and during welding. Welding current and the voltage were measured close to the welding area to reduce amps loss due to resistance from the power source. TIG rods were also cleaned properly with acetone to clean any foreign particles on the surface.

7. Cutting pipes with band saw
All the pipes were cut with a band saw machine.

8. Fit-up procedure
The pipes were carefully calibrated to fit up precisely.

Following welding, a liquid penetrant test (LPT) and radiographic test (RT) were performed on all test coupons to check for any surface and subsurface welding defects prior to sending the samples to the laboratory for the ASTM G48 Method A corrosion testing. The filler metals in all the test coupons had a root-pass diameter of 1.6mm followed by 2.4mm in diameter until the cap pass. The welding trials were conducted in a fabrication yard to simulate the actual fabrication environment for mass production instead of doing them in an R&D facility.

After welding, all ten samples according to the different parameters, we sent them for liquid (dye) penetrant testing (LPT) and radiographic testing (RT). For all the samples, LPT and RT are regarded as acceptable forms of testing according to the American Society of Nondestructive Testing ASNT NDT Level-II certification program. Finally, all the samples were sent to a SAC-SINGLAS accredited laboratory in Singapore for the corrosion testing as per ASTM G48 method A for period of 24 hours.

TABLE 1: SUMMARY OF TEST SAMPLES

Sample number	Dimension	Heat I/P Root	Heat I/P 2nd pass	H/I Fill & cap	Shielding gas flow rate	Purging gas flow rate
Sample 1	1 Inch pipe	2.1	2.0	1.8-1.98	22 LPM	25 LPM
Sample 2	2 Inch pipe	2.2	2.1	1.8-2.0	22 LPM	10 LPM
Sample 3	1 Inch pipe	2.1	2.0	1.8-2.0	22 LPM	25 LPM
Sample 4	2 Inch pipe	1.0	0.58	0.56-0.58	17 LPM	22 LPM
Sample 5	1 Inch pipe	1.23	0.85	0.85-0.90	20 LPM	25 LPM
Sample 6	2 Inch pipe	0.85	0.45	0.72-0.82	22 LPM	25 LPM
Sample 7	1 Inch pipe	1.1	0.98	0.98-1.40	15 LPM	18 LPM
Sample 8	2 Inch pipe	1.2	1.0	0.97-1.4	15 LPM	18LPM
Sample 9	1 Inch pipe	0.72	0.68	0.80-1.3	15 LPM	20LPM
Sample10	2 Inch pipe	0.73	0.70	0.83-1.4	18 LPM	20LPM

All the samples were single V-grove joints with bevel angles of 35° and root gaps of 3-4mm, as summarized in Table 1.
Heat input was calculated as (Current X Voltage X 60)/ (Travel Speed X 1000) and the unit is Kj/mm.

RESULTS

The test results of ASTM G48 Method A, at 40°C with soaking time of 24hrs are summarized in Table 2.

TABLE 2: RESULTS OF ASTM G48 METHOD A CORROSION TESTING

Sample number	Testing Condition	Weight Loss	Pitting Condition	Pitting Location
Sample 1	As welded	42.83 g/m^2	Pitting observed	Root & cap
Sample 2	As welded	22.84 g/m^2	Pitting observed	Root & cap
Sample 3	Pickling & passivation	15.22 g/m^2	Pitting observed	Root
Sample 4	Pickling & passivation	10.25 g/m^2	Pitting observed	Root
Sample 5	Pickling & passivation	12.43 g/m^2	Pitting observed	Root & Cap
Sample 6	Pickling & passivation	8.23 g/m^2	Pitting observed	Root & cap
Sample 7	Pickling & passivation	3.01 g/m^2	No pitting observed	Not Applicable
Sample 8	Pickling & passivation	0.23 g/m^2	No pitting observed	Not Applicable
Sample 9	Pickling & passivation	4.12 g/m^2	Pitting observed	Sample cross section but no pit at root & cap
Sample 10	Pickling & passivation	0.46 g/m^2	No pitting observed	Not applicable

DISCUSSION OF RESULTS

Most of the technical specification and codes referred to in this study are based on the standards of the Norwegian Petroleum Industry (NORSOK M-601) and specifically the international ASTM G48 Method A Corrosion Test, with a temperature of 40°C and soaking time of 24 hrs. The acceptance criteria of the ASTM G48 corrosion test is "no visual pitting at 20X magnification" and a "maximum weight loss of 4g/m2".

SAMPLE 1

Figures 9 & 10 / 1-inch pipe
The first sample was welded with a significantly higher heat input at root pass and second pass, with a very high gas flow rate for both shielding and purging gases. The visual shows the sample following corrosion testing prepared in as welded condition without acid pickling and passivation condition. Here we noted a weight loss of 42.83g/m^2 with visual pitting occurring at the root weld as well as cap location.

Figure 9

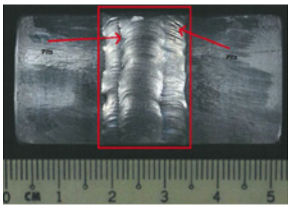
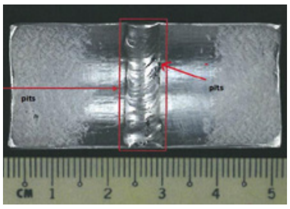


Figure 10



SAMPLE 2

Figures 11 & 12 / 2-inch pipe
This 2-inch super duplex was also welded with a significantly higher heat input at root pass and second pass, with a very high gas flow rate on both shielding and purging gas. The corrosion test sample was prepared in an "as welded" condition without acid pickling and passivation condition. The result of the test showed a weight loss of 22.84g/m^2 with visual pitting at root as well as the cap location.

Figure 11

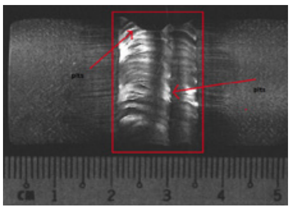
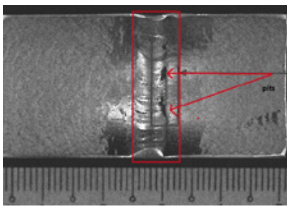


Figure 12



It is worth noting that 1-inch pipes are more difficult to weld than 2-inch pipes due to their greater curvature and thickness to control the correct welding parameters. Both Sample 1 and Sample 2 had very high gas flow rate which evidently did not protect the weld metal especially well on the root side and caused very high pitting with significant weight loss. In addition, samples 1 and 2 were prepared without acid pickling and passivation, meaning it was not possible to remove the undesired oxides, foreign particles, heat tints and other impurities that cause significant weight loss when exposed to aggressive acid media [10% ferric chloride hexahydrate ($FeCl_3.6H_2O$) solution] in ASTM G48 method A testing.

SAMPLE 3

Figures 13 & 14 / 1-inch pipe

For the 1-inch pipe used in Sample 3, we applied similar welding parameters but, during sample preparation, applied acid pickling with nitric acid (HNO_3) and hydrogen fluoride (HF) solution for five minutes. The result shows the weight loss reduces to 15.22 g/m^2 and pitting was not observed on the cap side, although root pitting will still observed.

Figure 13

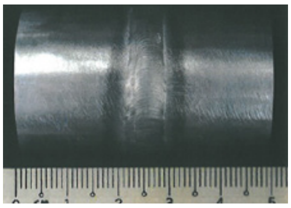
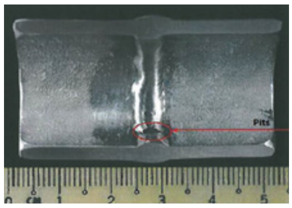


Figure 14



SAMPLE 4

Figures 15 & 16 / 2-inch pipes

The 2-inch pipes in Sample 4 were welded with lower heat input compare to samples 1, 2 & 3 and the shielding gas flow rate was also slightly reduced, while keeping the purging gas flow rate the same. The difference between the heat input at root pass and second pass was noticeable. Pitting was observed at root pass with weight loss but no pitting at cap.

Figure 15

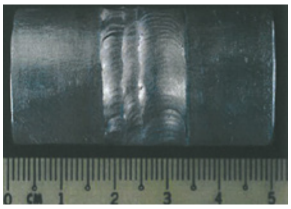
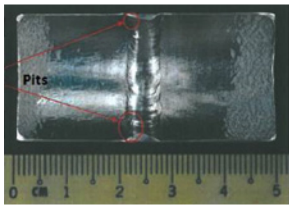


Figure 16



SAMPLE 5

Figures 17 & 18 / 1-inch pipe

The 1-inch pipe in Sample 5 was welded with lower heat input than samples 1, 2 & 3 and kept shielding gas flow rate and purging gas flow rate same as samples 1,2, & 3. The difference between root pass and second pass heat input was significantly different. Pitting was observed at root pass & cap pass with weight loss. The higher gas flow rate caused a negative effect on the shielding of the root weld and hence significant pitting.

Figure 17

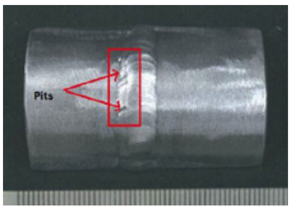
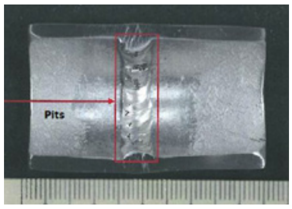


Figure 18



SAMPLE 6

Figures 19, 20, 21

For this 2-inch duplex pipe the heat input on both root pass and second pass were significantly reduced compare to samples 1, 2, 3, 4 & 5. However, the gas flow rate was kept the same. Due to lower heat input, a location was observed with lack of fusion and pitting (Fig. 19) along with a reduction in weight loss, compared to previous samples. However, pitting was still observed on the cap and root areas (Fig. 20, 21).

Figure 19

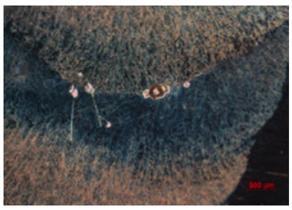


Figure 20

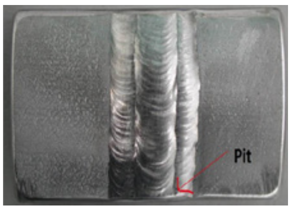
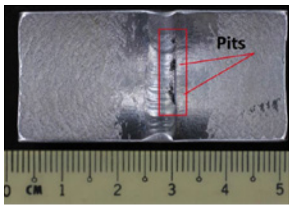


Figure 21



SAMPLES 7 – 8

Figures 22-23 (7) and Figures 24-25 (8)
Samples 7 and 8 were then welded with controlled heat input on root at 1.1-1.2 kj/mm and second pass heat input 0.98-1.0 kj/mm with shielding gas flow rate about 15LPM and purging gas flow rate 18LPM. Both samples showed no pitting and weight loss below 4g/m². Sample 7 (Fig.22 & 23] was 1-inch pipe and due to more curvature with less wall thickness, weight loss was higher compare to Sample 8 (Fig.24 & 25), which was a 2-inch pipe.

Figure 22

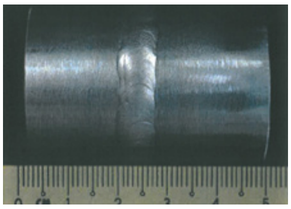


Figure 23

Figure 24

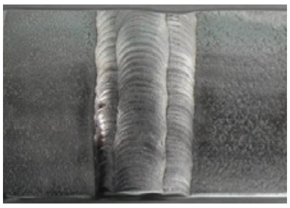


Figure 25

SAMPLES 9 – 10

Figures 26-27 (9) and Figures 28-29 (10)
After the successful corrosion testing achieved with samples 7 and 8, we tried changing the welding parameters for samples 9 and10 to weld at slightly lower heat input on the root pass and second pass. The gas flow rate was maintained at the same level as for samples 7 and 8. However, Sample 9 failed the corrosion test as it exhibited slightly higher weight loss of 4.12g/m2.

A single pit spot was also observed (Fig.26) on the cross section of the sample between the weld beads, although no pitting was observed on either root or cap sides. Sample 10 passed the test without any pitting and with significantly lower weight loss. The cap and root photos for samples 9 and 10 are shown in figures 27-30.

Figure 26

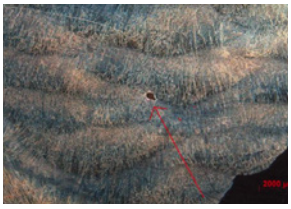


Figure 27

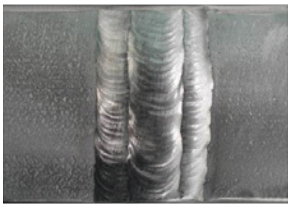


Figure 28

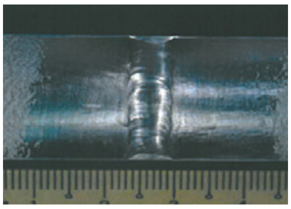


Figure 29

Figure 30

CONCLUSIONS

Based on the results of the above experiment, we can clearly see that proper welding parameters play a vital role in ensuring the integrity of the weld passes during the corrosion testing. Duplex family steels are sensitive to heat input, shielding and purging gas along with other important parameters. For root pass welding, the heat input range of 0.9-1.2 kj/mm is optimal, while for second pass (cold pass) it needs to be 8-10% lower heat input than root pass. This helps to avoid the formation of secondary austenite and hence promote good corrosion properties.

OPTIMIZED HEAT LEVELS

Insufficient heat input is not desirable either since it may cause a lack of fusion between welding beads, leading to failure in the corrosion test. What's more, it may lead to a higher cooling rate, resulting in the formation of chromium nitride. Shielding gas and purging gas of Ar+2% nitrogen is suitable for use in duplex family welding to attain pitting resistance with the austenite-ferrite phase balance.

GAS FLOW RATE AND PREPARATION

Gas flow rate is also an important parameter in order to achieve adequate shielding to protect the weld pool from oxidation. Preparation of the samples also played a decisive role in their ability to pass the corrosion test.

"FOR ROOT PASS WELDING, THE HEAT INPUT RANGE OF 0.9-1.2 KJ/MM IS OPTIMAL WHILE FOR SECOND PASS (COLD HEAT) IT NEEDS TO BE 8-10% LOWER HEAT INPUT THAN ROOT PASS."
SUKAMAL NASKAR

PROPER PREPARATION

Proper acid pickling and passivation provides better anti-corrosion properties that help to protect the final weld joint after fabrication. The skill of the welder is most important for passing any corrosion test and hence the need to use qualified and skilled welders for the fabrication of duplex family.

CHECKLIST FOR FABRICATION

A checklist for fabrication is very useful to have better control of the actual fabrication facility for duplex family welding. Appendix 1 includes a sample checklist as a reference.

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This work is published with the permission of Sandvik Materials Technology AB.
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APPENDIX 1

Welding checklist for duplex and super duplex stainless steel welding & fabrication

WELDING CHECKLIST FOR DUPLEX AND SUPER DUPLEX STAINLESS STEEL WELDING & FABRICATION

Checking Items	Yes	No	Remarks (actual values / comments)
Base material grade			
Base material actual thickness			
Base material form (plate / pipe)			
Base material dia for pipe			
Base material chemical composition			Cr, Ni, Mo, N actual value
Certificate type (2.2 / 3.1 /3.2)			
Base metal cutting machine type			
Cutting machine blade suitability			
Cutting coolant type			
Cleanness of the cutting tool			
Cutting area cleanness			
Tack welding method			
Tack welding process			
Tack welding location			
Tack welding gas			
Tack welding filler material			
Tack welding done by whom			
Root gap			
Root phase			
Bevel angle			
Bevel configuration			
Backing plate used?			
shielding gas composition			
Shielding gas certificate			Other elements composition
Shielding gas flow rate			
Purging gas composition			
Purging gas certificate			
Purging gas flow rate before welding			
Purging gas flow rate during welding			
Purging gas flow rate after welding			
Tungsten dimension for TIG			
Tungsten type			
Tungsten certificate for composition			
Tungsten grinder			
Welding torch type			
Grinding disc type & composition			
Power brush type			
Inter-pass cleaning			
Inter-pass cleaning method			
Welding bevel cleaning inside			
Welding bevel cleaning outside			
Welding consumable type			
Welding consumable size			
Welding consumable grade			
Welding consumable cert type			

APPENDIX 1

WELDING CHECKLIST FOR DUPLEX AND SUPER DUPLEX STAINLESS STEEL WELDING & FABRICATION

Checking Items	Yes	No	Remarks (actual values / comments)
Welding consumable chemical comp			
Welding fit up material			
Welding position			
Welding position each pass cleaning			
Welding position each segment H/I			
Welding travel speed			
Cold pass maintained or not			
Root pass heat input			
Cold pass heat input			
No of total layer			
No of pass on cap			
Location of final pass (center / edge)			
Visual inspection after each pass			
Gas purging equipment			
Welding area cleanness			
Welder's qualification & skill			
Time between all the passes			
After welding cleaning method			
LPT result			
X-Ray			
UT / any other NDE			
Review NDE report / X-ray film			
Selection of proper sample location			
Proper pickling/ passivation			
Correct sample dimension			
Welding machine calibrated			
Calibration date & expire date			
Preheat & inter-pass temp machine			
Calibration date & expire			
Accuracy level			
Welding polarity			
Welding machine earth connection			
Tong tester used or not			
Calibration date & expire			
Welding gloves cleanness			
Total welding time			
Time taken between each pass			
Distortion control			

CONTACT OUR R&D KNOWLEDGE CENTER

Do you have further questions regarding welding, corrosion, temperatures, pressure, pitting and other subsea challenges? If so, we'd be happy to help you – even with basic advice. Having worked with the oil and gas sector for 50 years and serving 100% of all major fabricators and oil companies in all offshore regions, we have a depth of knowledge to share. Please go to our R&D Knowledge Center to get in touch with our experts or to download white papers, case studies and other relevant product information.

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