FABRICATION OF SUPERDUPLEX STAINLESS STEEL FOR OPTIMUM SEAWATER CORROSION RESISTANCE

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Abstract

Super duplex stainless steels are being used increasingly in new build and refurbished SWRO applications around the world. These alloys offer an excellent combination of sea water corrosion resistance and strength, and this combination of properties makes them so attractive as materials of construction for HP sea water feed, brine reject and energy recovery pipe work systems as well as for pumps and valves.

A range of super duplex grades are listed in international codes and standards (ASTM, ASME, ISO) and these cover general requirements for specific product forms, design stresses and design details and general requirements for weld procedure and welder qualification. They may also contain supplementary requirements that can be called for in a customer purchase order should they be required. However, these documents do not provide specific inspection and testing regimes necessary to ensure that components produced on a cast and batch basis are suitable for seawater service. Moreover, the general requirements for procedure and welder qualification cover mechanical integrity and soundness of the joints but not specifics that optimise the process by accounting for the metallurgy of these steels, how they behave when welded and how they are best processed to optimise sea water corrosion resistance.

Companies in other industries have recognised these issues and have addressed the problem by applying their own material and fabrication specifications to be used in conjunction with recognised international codes and standards. The difficulty with this though is lack of standardisation, with each company specification calling for slightly different requirements causing re-grade testing to be necessary before goods can be supplied leading to additional cost and delay. Some SWRO contractors have adopted this approach already but many have not.

Because of the geographic distribution of the SWRO market many of the fabricators and installation contractors have no previous experience with superduplex stainless steels. These companies require support and more robust working instructions if the expected performance of the fabricated spools and vessels is to be realised.

In this paper we propose a set of additional requirements, not currently covered in the codes and standards, which can be applied in addition to statutory requirements to provide a scope of supply from the material manufacturer and fabricator that is optimised specifically for super duplex stainless steels to be used in sea water service. These additional requirements can be applied and used by all and could form the basis of an industry standard to improve the quality and performance of component parts and fabricated spools and vessels.

I. INTRODUCTION

In the last ten years superduplex stainless steels have become firmly established in preference to highly alloyed austenitic stainless steels for a number of applications in reverse osmosis (RO) desalination plants because of their excellent combination of strength, corrosion resistance and their competitive pricing. The composition and properties of the most commonly used high alloy stainless steels are shown in Table 1 and Table 2, along with 316L for comparison and the strength advantage of the grade is apparent. Previous papers have compared the merits of various alloys for this application (1, 2).

The superduplex stainless steels have a two phase structure that consists of austenite and ferrite, ideally in equal proportions to give the best combination of properties. The ferrite phase will give the strength whist the austenite phase the toughness and the ductility. To maintain the optimum combination of properties in the duplex structure it is important to control the phase balance in these alloys as closely as possible to the optimum level. The composition of the austenite and the ferrite phases are different and each is controlled by the bulk composition, the heat treatment temperature and the phase balance. It is important to control all these parameters to give the correct phase balance and hence the optimum composition of each phase to ensure satisfactory corrosion performance.

When ZERON 100 was developed, the aim was to establish the composition limits to obtain the best microstructure that gave the best combination of strength, toughness and corrosion resistance while retaining commercially acceptable levels of weldability and ease of manufacture using all processes. University research into structure/property relationships, thermodynamics and phase equilibria and subsequent production scale trials set the melting range and this is tightly controlled within the broad range that is detailed in the ASTM standards as UNS S32760. We believe that the starting point for many other manufacturers is to formulate the analysis with the lowest cost within the UNS S 32760 range with which they can meet the ASTM minimum levels of specification requirements. These specification requirements are usually significantly lower than can be realised with ZERON 100 on a production basis and have been discussed elsewhere (3).

The authors of this paper show the large variation that can be found in mechanical and corrosion properties between a UNS S32760 alloy and ZERON 100. The authors discussed the tighter controls within the ZERON 100 specifications that ensure a good microstructure with a lack of deleterious phases such as nitride, so optimising the properties of the alloy. They found various amounts of nitrides present in the UNS S32760 alloys and so developed a visual scale to establish the level in each and then investigated the degradation that they caused on all the different properties of the alloy. The graph shown in Figure 1 from the paper shows how the quality of the steel can affect the performance in seawater which is of particular interest to the desalination industry together with performance in the ASTM G48 Method A test as a reference.

The degradation in properties is remarkably similar for both tests and shows that the ASTM G48 Test is a good quality control tool. The authors also found that corrosion initiated by selective attack of the ferrite phase due to the presence of the nitrides and that these precipitates contributed to the reduction in corrosion resistance. A microphotograph of the corrosion is shown in Figure 2.

The additional controls of composition and of heat treatment that are embodied in ZERON 100 ensure that there is a lack of nitride precipitation and so ensures a consistency in corrosion performance of ZERON 100 across all products and this control is not seen in all UNS S32760 alloys.

This paper will also review the typical codes and specifications for using the Superduplex grades and propose minimum testing and specification requirement levels that should be included during the purchasing process and during installation in order to ensure the quality of the steel supplied and also the subsequent fabrication process. It will also identify suitable acceptance criteria that that can be realistically achieved with these steels that will ensure satisfactory performance in service.

The alloys are typically used in the high pressure seawater intake, brine reject lines, energy recovery pipework and also for ancillary equipment such as pumps, valves and filters and the alloys have a history of extremely good performance on a large number of projects for many years now.

As the superduplex stainless steels have become more established in the industry, then this in turn is attractive to many more manufacturers and, consequently, the supply base has grown and purchasers are given more options. However, not all manufacturers have the necessary experience to produce the consistent quality levels required for these products and, with the absence of any industry specifications that require any level of metallurgical or corrosion testing, problems in manufacture may not be found until fabrication or when failures occur in service. The authors have become aware of problems on recent projects that have not been found until the system has been in service that has resulted in failures and costly repair and subsequent down time.

A number of high profile failures in the oil & gas industry have led to concern over the consistency in quality of some duplex stainless steel products being supplied by a number of manufacturers. This has led certain operators to establish an Engineering Equipment and Material Users Association (EEMUA) document with guidelines for the control of the purchasing process and control of manufacturers to try and address this problem. (4)

II. INDUSTRY STANDARDS

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It is common that desalination pipework is designed using ASME B31.3, or in some instances other design codes, such as E1092-1:2001 Annex E have been used. Both these codes are common in the fact that they only specify a size and component geometry to be able to contain the pressure based on the material properties.

It is usual to specify the grade of steel by use of a UNS number as shown in Table 1 but the UNS number only specifies the chemical composition of the alloy within broad ranges.

It has been seen that these high alloy stainless steels are necessary for these difficult applications with highly corrosive conditions and as the alloys become more sophisticated in order to handle the conditions, the metallurgy of the steels also become more sophisticated and so requires a better understanding and technical ability during manufacture. It has been seen that the composition of the steel and the phase balance is important in optimising all the various properties in the alloys. In addition various precipitates can occur if the alloy is not handled correctly in manufacture and/ or if not heat treated adequately after processing. These precipitates (5), such as sigma, chi, laves etc can quickly affect the corrosion resistance markedly (6). The metallurgical and corrosion properties cannot be checked by visual inspection but instead require some destructive or possibly some specialist non destructive techniques to establish the correct quality level.

The ASME code usually requires that products are manufactured to the relevant ASTM standard and these are quite commonly used in other industries as a base specification. However these standards generally only require a tensile test to ensure that the steel meets the minimum levels of strength required by the design code. This does not necessarily ensure that the steel is metallurgically sound and that the corrosion resistance is at the required level for effective service.

III. ADDITIONAL TEST REQUIREMENTS

Additional testing is used in other industries to prove that components have the necessary metallurgical quality. There are a variety of extra tests that can be specified in addition to the mandatory ASTM tests. These are detailed in ASTM A923 or can be by included in an additional proprietary project specification. Any number of the tests can be added, such as a corrosion test, an impact toughness test or a microstructure validity check but it is more sensible to add the test or tests relevant to the properties that are required in service and with reference to the severity of the application.

The metallurgical tests require an experienced operator in order to establish clear pass/fail criteria and access to competent test facilities is not always available and so this test is not considered essential in this instance and this application.

A corrosion test or an impact toughness test is reasonably easy to carry out and only requires access to a testing laboratory and it is usual that many will have the necessary experience to carry out the test to a satisfactory manner. Acceptance criteria are also fairly well established and do provide the necessary clear pass or fail criteria required, but there is still some inconsistency amongst the different specifications in technique and acceptance criteria that can create confusion. As desalination projects do not usually require toughness at sub zero properties then a corrosion test is considered as a suitable quality control test.

UNS S32760 has not yet been included in ASTM A923, yet a similar alloy UNS S32750 has been included but with acceptance criteria at 10 mdd (milligrams per square metre per day) when tested at 40°C. It is considered that this test temperature is too low for these steels. Other specifications, such as NORSOK, require testing in accordance with ASTM G48 Method A at 50°C for 24 hrs with acceptance criteria at 4g/m2. These are generally widely accepted as being the correct acceptance criteria.

The A923 criteria of 10 mdd for a 24 hr test on a standard ASTM G48 specimen size will equate to 1g/m2 and is therefore far tighter than the normal acceptance criteria and is not always readily achievable for all product forms where a weld is required in the production process such as welded pipe and or welded fittings. As welded pipe and fittings are used extensively and make up the majority of a desalination system take off, this is seen as a difficulty.

The NORSOK specifications require the sample for the corrosion test to be additionally pickled prior to testing. There is a danger that this can artificially improve the performance of the sample and can hide potential problems such as poor pickling and surface conditioning that could impact on service performance. It is, therefore, argued that the corrosion sample should be tested in the delivery condition without additional pickling and that this will give a more indicative result of fitness for purpose that is required by these tests.

The UK Welding Institute established best practice for ASTM G48 Corrosion testing a number of years ago to establish working procedures and so obtain some uniformity of testing. This work was published because of its importance to users (7)

For desalination applications, where corrosion resistance is essential, and toughness is not usually a design requirement, it is proposed that a corrosion test is needed on a cast and batch basis to show that the manufacture of the part has the necessary metallurgical quality and is adequate for the intended service. It is proposed that testing to ASTM G48 Method A be employed at 50°C for 24 hrs with an acceptance criteria set at 4g/m2 and testing to be carried out in the delivered condition following the guidelines set out by The Welding Institute (TWI).

3.1 Heat Treatment

Experience from other industries has shown that the condition of components in a batch does not always reflect the test results shown on the test certificate. There have been many examples of components that have failed in service that have contained various levels of sigma although the test certificate has reported excellent properties and the absence of sigma (8, 9)

It has been shown that part of the problem is due to the test sample not being truly representative of the component. The test sample should, where possible, be a sacrificial component or, where not possible due to size limitations, is then truly representative of the component size and section thickness.

It has also been shown that the loading procedure for the components in the furnace is important and that apart from very large single pieces, other items should be in single layers, evenly spaced on a support tray with minimal touching between all components or between components and furnace to allow good circulation and ensure that all surfaces of all the components are evenly heated and cooled. The tray can also be quickly and efficiently transferred from the furnace to the quench.

A furnace should be fully calibrated and surveyed and have a consistency of temperature within the load area as required by ASTM A991. This survey should be conducted on an actual superduplex heat treatment and show uniformity within the tolerance range required by the individual alloy. So for example a furnace to treat UNS S32760 components should be capable of maintaining a soak temperature of 1120C +/- 20C in the furnace working zone.

3.2. Feritscope Testing

There have still been many experiences where the above rules have not always been used or adhered to and there have been instances where individual components have areas of sigma and are not representative of all the batch and these individual components have subsequently failed in service.

The use of a Feritscope at final inspection has been shown to be an effective tool to find items that have not been heat treated correctly. It requires some level of experience from the manufacturer to establish full acceptability as ideally it may also require the ability to perform in situ metallography. This could be required where a clear go/no go differentiation is not established to be able to establish final acceptability, or to ensure good product is not rejected. The techniques are discussed in detail by the authors elsewhere (10).

3.3. PMI

There have been a number of instances where products have been mixed and the wrong alloy has been supplied by mistake to the end client. Where this has been a lower alloyed material that is not suitable for the application, there have been ensuing failures. It is therefore good practice to include PMI for all products to ensure the integrity of all the material supplied.

IV. FABRICATION

It is not the intent here to explain all the detailed parameters that should be used for welding but to consider the choices and the concerns that will enable a strategy to be developed that will allow the correct fabrication specification to be detailed or developed and will allow the best choice of fabricator to be made. This can either be a fabricator with the necessary experience in these steels or alternatively could be a fabricator with no experience but one who has the necessary competence to understand these alloys and who can develop the necessary procedures and can train his welders sufficiently to complete the project to a satisfactory standard.

There is a wealth of work that has been carried out on welding of superduplex stainless steels that has already been published and is readily available (11). Additionally there are many welding guidelines that are published by weld distributors and authorities to establish good weld and fabrication procedures (12, 13). The necessary expertise can be gained by competent fabricators understanding and following these recommendations.

Alternatively a competent material supplier and packager will have the necessary welding experience and should be readily able to supply information through literature and or possibly training to the purchaser or his chosen fabricator, if he is capable and has experience with stainless steels.

4.1. Scope of Fabrication

The intent in fabrication is to achieve a joint as quickly and economically as possible that has adequate properties for service. Generally to achieve these aims then the weld needs a controlled phase balance with an optimum 50% ferrite phase balance being the target, similar to the parent materials. When using a quality steel manufacturer together with a competent weld consumable manufacturer, the composition of the base material and the consumables has been controlled to give the best achievable properties when using recommended fabrication practice.

In practice it is found that it is very difficult obtain a fully homogenous structure due to the high cooling rates and subsequent super cooling found in welds and so large variations in ferrite content can be found within a single weld and so a phase balance of 35% to 65% ferrite is generally accepted.

4.2. Phase Balance

If a phase balance determination is required by the specification then there are two basic techniques available to measure ferrite or austenite content, firstly using image analysis techniques where an image that is homogenously etched is captured and analysed by software to count the percentage of each phase. The advantage of this technique is that a large number of fields can be counted quite quickly and an average value can be quickly established.

However, this technique is not readily usable with welds, as the necessary even etch is not achievable due to the inhomogeneity in the weld. The alternative method is to point count and this is detailed in ASTM E562. If point counting is used, then the magnification should be sufficient to show the features of the structure and the number of fields and the grid size should be selected to get a representative ferrite value based on the recommendations in the ASTM standard based on desired accuracy and the level of the phase to be counted.

This test requires specific experience and again there is a body of opinion that says that if other tests are carried out to show good properties in the weld, then there is no real need to measure the ferrite content as this value becomes secondary. It is again argued that for desalination applications where an ASTM G48 test is an additional test on a WPQR and due to the difficulty in finding experienced laboratories to evaluate the microstructure, the test could be ignored.

4.3. Consumables

There are two types of consumables available for welding superduplex stainless steels; the first is a matching composition type, and this is generally used in the manufacture of components where a post weld heat treatment will be performed. The other consumable is over alloyed and this is generally used in the fabrication of pipework and vessels where the joint will be left in the as-welded condition. The down-stream fabrication of pipe spools will generally use the over alloyed type consumable. This consumable meets the requirements of AWS A5.9. ER2594.Typical compositions of both consumables are shown in Table 3.

4.4. Welding Process

The first choice to be made for fabrication is the choice of process to be used for welding the components, as the choice of process dictates the final properties of the weld. It is common to choose a TIG weld for the root run as this will give proven corrosion performance in the root area where it is needed. The choice of fill is then arbitrary as most processes will give adequate corrosion resistance and the maximum corrosion resistance required in a pipe is usually at the root face.

The most adaptable process, MMA, is widely used for welding duplex stainless steels with electrodes of 2.5–5.0mm diameter. Basic coated electrodes (15 type coatings in AWS terminology) are utilised for positional welding whereas for optimum operability in less critical applications, rutile coated electrodes can be used (16 or 17 types in AWS terminology).
Solid wires are available for GMAW at various diameters from 0.8 mm to 1.6 mm, with the usual size 1.2mm diameter for fill passes. There is a number of proprietary shielding gases available usually based on Argon/ Helium/CO2.

Flux cored wires are used almost exclusively in 1.2mm diameter either as downhand only wires giving good slag release and bead profile, or all-positional wires. Both types of flux cored wire utilise a rutile flux system together with an argon-20% CO2 shielding gas.

4.5. Shielding and Backing gas

One of the major problems when welding duplex stainless steels is to prevent the loss of nitrogen from the weld root. As the backing gas purges air from the root area a very efficient purge has been shown with stainless steels to improve corrosion performance. This is because it reduces air and oxygen at the root face and so reduces oxidation of the weld root. However low oxygen content in the gas purge also means low nitrogen content, as air is a 4:1 mix of nitrogen and oxygen. As the weld root will then have a relatively high nitrogen content compared to the purge gas, nitrogen loss from the weld to the purge gas will occur because of the difference in nitrogen partial pressure. Nitrogen is a very important element in the corrosion performance and losses from the weld root will affect corrosion performance markedly.

There are a number of proprietary gas mixtures available that will help in the control of this and that will improve the corrosion performance of the weld. These are either based on argon/ nitrogen gas mixtures for the shielding gas or the use of formier gas for the purge gas or a combination of both. These will help to control the loss of nitrogen from the weld root and can also improve corrosion performance (14).

4.6. Heat Input Control

The phase balance is controlled by the composition of the weld and by the cooling rate achieved by the combination of heat input, interpass temperature together with the joint geometry. The thicker the parent material, the better is the cooling rate that can be achieved as there is a larger heat sink. This is due to the cooling through the HAZ changing from 2 dimensional to 3 dimensional cooling. Previous internal work has shown a large increase in cooling above 7mm thickness as 3D cooling gets established. 3D cooling becomes well established above 12 mm thick and will give excellent cooling rates naturally (15).

Heat input target ranges for different thickness ranges are suggested in the welding guidelines (12)

It is essential that heat input and interpass temperature are monitored on the weld procedure qualification so that when a satisfactory weld is achieved, the weld parameters can be repeated in production.

4.7. Cold Pass Technique

L Van Nassau et al detailed the effect of the heat input of the second pass, often called the hot pass, on the corrosion performance of the weld root. He established that controlling the heat input of the second pass to 75 to 90% of the value used in producing the root run minimised the heat damage of the root and optimised corrosion performance. He detailed this as the cold pass technique to differentiate from the hot pass conventionally used by welders for other less sensitive materials (16).

4.8. Weld Procedure Qualification (WPQR)

It is common that welds are initially qualified to a code such as ASME but this will only require the use of bend tests, macrostructure examinations and tensile tests in the absence of a sub zero design requirement These tests will only check the weld integrity from a mechanical point of view and confirm the absence of any major welding defects. It does not consider the metallurgical properties or the corrosion resistance of the weld

ASME specifies general thickness qualification ranges, but these are considered too wide for these high alloy steels and it is recognised that tighter ranges are required. These steels are very sensitive to cooling rates in the weld and HAZ and these need to be controlled in order to promote enough austenite reformation in the weld zone but also to prevent the precipitation of deleterious phases. As cooling rates are controlled by heat input, interpass temperature and thickness of the base material it is not adequate to transfer parameters from a procedure to one that has a very different thickness as this will change the cooling rates markedly. This is more of an issue at thinner sections where a small change in thickness, between approximately 1 and 11 mm will lead to a larger change in cooling rate. Additional limits on the ranges in ASME are required and typically as detailed in the Material Data Sheet (MDS) for fabrication (17).

It is also common to use the P groups in ASME for qualification purposes. The superduplex stainless steels are in the same P group as a duplex stainless steel. This means that in theory a weld procedure qualified using a duplex stainless steel can be used to weld a superduplex stainless steel even though the precipitation kinetics for sigma formation are different. It is argued that a superduplex stainless steel weld procedure could be used to weld the lower alloyed duplex steel but it should not be considered good practice to use the lower alloyed duplex procedure to weld the higher alloyed superduplex products.

4.9. Additional Testing

As the codes do not require any testing to establish whether a satisfactory metallurgical quality is achieved during the weld procedure qualification then it is considered that an ASTM G48 Method A test is once again the ideal additional test to establish this. It is a very quick and easy test that can be applied to the WPQR and gives confidence that the parameters used in qualification achieve the necessary performance level required for satisfactory service.

Acceptance levels for welds are generally lower than for parent materials because they are not solution treated. In general testing at 35°C is readily achievable when good welding practices are utilised for heat input control and control of the nitrogen loss effect, and has been shown to give satisfactory service performance over many years.

Other work has been published that reviews the microstructures in the weld zone and the corrosion performance and advises the tolerance of small amounts of sigma formation and suitability when using good fabrication practice (18).

V. WELDER TRAINING

It has been proven on other projects that a fabricator who spends time and effort in a training programme to develop the necessary skills for all welders for these high alloy materials has developed a better level of control in production welding. This involves establishing the need for these steels, the rules for fabrication and practical training.

5.1. Welder Qualification (WQ)

To the relevant ASME code Welder Qualification can be achieved by simple radiography and again this will only check the mechanical integrity of the weld not the metallurgical quality of the weld. It is recommended that an additional ASTM G48 Method A test at 35°C for 24 hrs similar to the WPQR is also carried out for each welder.

VI. PICKLING

It has been shown that post weld cleaning has a marked effect on weld corrosion resistance and that pickling, by either full immersion or by the use of proprietary pickling pastes will improve corrosion resistance in the weld root by up to 10°C (1, 19).

VII. ALTERNATIVE STRATEGY

Where access is not available to an experienced or capable fabrication shop that does not have existing procedures or is not considered capable of development then an alternative strategy is proposed. It is suggested that pipe spools are purchased from an experienced fabricator and Victaulic type couplings or flanges are used to provide an easy assembly and fix on site. The authors' company have used this strategy previously and have supplied spools to a project with excellent results.

VIII. CONCLUSIONS

1) Additional testing in addition to the normal UNS and ASTM specifications should be included for all the superduplex products purchased for use in desalination plant.

2) It is suggested that a suitable additional test is an ASTM G48 Method A corrosion test at 50°C for 24 hrs together with acceptance criteria of no pitting and a maximum weight loss of 4 g/m^2.

3) Additional controls are required for fabrication and a capable or experienced fabricator is required who understands the requirements and controls required to weld these steels.

4) The ASTM G48 test should be added to both the WPQR and the WQ to ensure that the parameters used to weld give the required metallurgical performance in service.

Alloy Grade	UNS No	Nominal Composition wt %							Typical PREn
		Fe	Ni	Cr	Mo	N	Cu	W	
316L	S31600	Bal	17	10	2	-	-	-	24
317L	S31703	Bal	18	10	3	-	-	-	28
904L	N08904	Bal	20	25	4	-	1.5	-	34
6%Mo	S31254	Bal	20	25	6	0.2	0.6	-	43
Z100	S32760	Bal	7	25	3.5	0.22	0.65	0.65	> 41

PREn = Cr % + (3.3 x Mo %) + (16 x N %)

Table 1. Chemical composition of some common stainless steels used in RO desalination.

Alloy Grade	UNS No	0.2% Proof Stress (MPa)	Tensile Stress (MPa)	Elong'n (%)	Hardness (HRC)
316L	S31600	170	485	45	22
317L	S31703	205	515	40	22
904L	N08904	220	530	35	22
6%Mo	S31254	300	650	35	22
Z100	S32760	550	750	25	28

Table 2. Minimum Mechanical properties of some common stainless steels used in RO desalination.

Alloy Grade	AWS 5.9 No	Nominal Composition wt %						
		Fe	Ni	Cr	Mo	N	Cu	W
UNS S32760	-	Bal	7	25	3.5	0.22	0.65	0.65
ZERON 100M	ER2594	Bal	7	25	3.5	0.22	0.65	0.65
ZERON 100X	ER2595-15	Bal	9	25	3.5	0.22	0.65	0.65

Table 3. Composition of weld consumables.

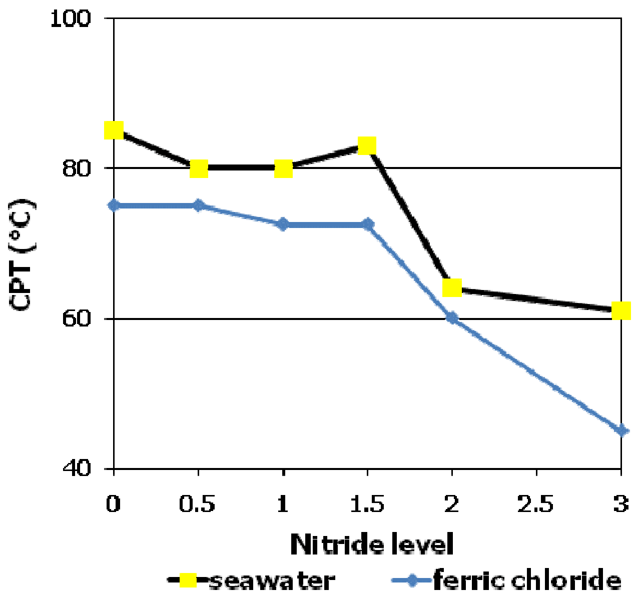

Figure 1. Effect of nitride level of UNS S32760 alloys on corrosion resistance in an ASTM G48 Method A test and in simulated seawater

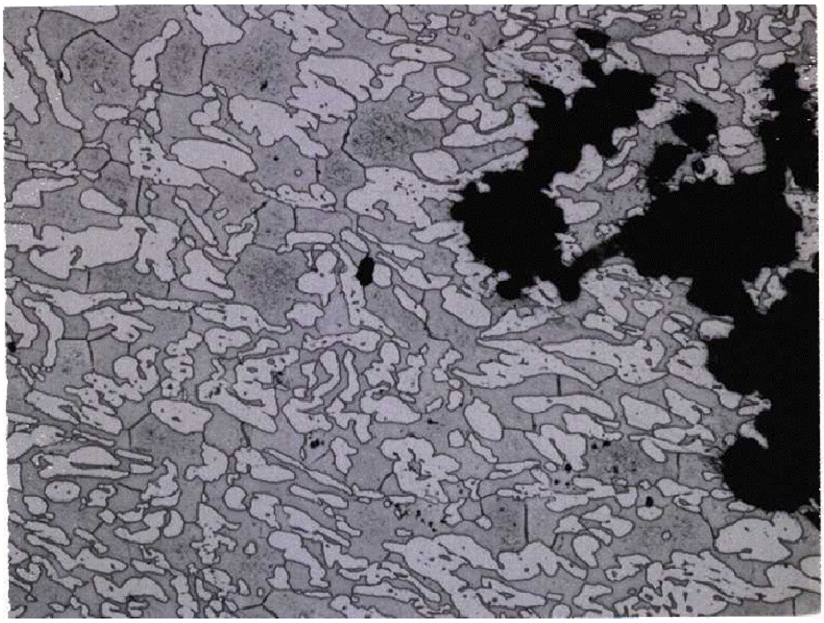

Figure 2. Photomicrograph of a UNS 32760 Alloy showing selective corrosion attack of the ferrite phase as a result of nitride precipitation.

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Appendix 1 - Proposed controls and testing required in addition to international product specifications.

All of the tests are already included either in our current material data sheets for individual products and for fabrication or alternatively in inspection procedures.

Products

1) Addition of ASTM G48 Method A test at 50C for 24 hrs with acceptance criteria of no pitting and maximum weight loss of 4g/m2.
2) PMI of all components.
3) Ferritscope testing with an acceptance criteria >32 and using in-situ metallography to accept or reject product with readings less than 32.
4) Control of heat treatment equipment & procedures to give consistent heat treatments for all products as shown by qualification of the furnace processes and procedures to give consistent and satisfactory results.

Fabrication

1) Use of an experienced fabricator.
2) Use of qualified welding procedures including an ASTM G48 Method A corrosion test at 35C for 24 hrs with acceptance criteria of no pitting and weight loss 4g/m2 maximum.
3) Qualified welders to the production procedures to include an ASTM test as above.
4) Restrictions on the qualified procedure ranges over and above ASME.
5) Welding procedure to be qualified on superduplex material not duplex.