

The Use of a Lean Duplex Stainless Steel, UNS S32101:

Thermal Dimple Jackets on Vessels for High Purity Applications.

Dear Reader

Many thanks for the interest you've shown in our technical magazine Acom, not least by all comments I've got in the past. However, the old man is getting older and I've now reached a point in life where I'm slowly speeding down, letting younger colleagues do what I used to do, including being the editor of Acom.

My successor has been appointed, a far more qualified researcher than myself and with this issue of Acom he has taken over all the worries and subjects for rejoicing I have experienced during more than 10 years.

He is Claes Olsson, PhD, associate professor at Uppsala University, and I just want to congratulate you readers to have him as your contact person in the future and I also want to wish Claes good-luck to this part of his job at the Avesta Research Centre.

Yours sincerely

Jan Olsson, ex-editor of Acom.

Dear Reader

It is a great pleasure for me to take over the responsibility for Acom from Jan Olsson. Although we share the same last name, we are not related, explained by the fact that Olsson is the 7th most common Swedish family name.

When taking over, I look back at more than 20 years of scientific publications concerning stainless steels. Looking forward, I hope I can continue the good work of my predecessors by finding articles for the journal that have a combined practical and scientific interest. In this issue, you will find a paper showing the versatility of the lean duplex stainless steel LDX 2101, illustrating its corrosion resistance, mechanical and physical properties in the real-life application of dimple jackets.

Your sincerely,

Claes Olsson, Acom editor.

The Use of a Lean Duplex Stainless Steel, UNS S32101:

Thermal Dimple Jackets on Vessels for High Purity Applications.

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Abstract

Most vessels and thermal dimple jackets for use in high purity applications, such as the pharmaceutical, biotech, food, dairy, and beverage industries, are constructed from type 304 (S30400) and mainly 316L (S31603) stainless steel. In these industries an embossed dimple jacket attached to the outside wall of the vessel usually performs product heating and cooling. With a dimple jacket either steam, cooling water or other media is passed through the interconnecting channels created by a network of dimples. The design typically involves a thin sheet of stainless steel shaped to create a network of dimples that is welded to the much thicker vessel wall. The severity of the thermal stresses and strains during rapid heating and cooling along with the corrosive conditions makes 316L dimple jackets susceptible to premature failures. This paper discusses the possible failure modes of type 316L dimple jackets including chloride stress corrosion cracking (SCC), crevice and pitting corrosion, thermal fatigue, and possible fabrication defects. The improved performance of S32101, a lean duplex stainless steel, is discussed and the results of qualification tests comparing 316L (S31603), S32101, and alloy 625 (N06625) are presented.

Key Words: Stainless Steel, Lean Duplex, S32101, Dimple Jacket, Vessels, Low Cycle Fatigue, Chloride Stress Corrosion Cracking

Introduction

Design and Fabrication Details

The basic design of embossed dimple jackets is covered in ASME Section VIII, Division 1, Appendix 17[1]. There are several methods for design and fabrication of these jackets. The method investigated in this study is the embossed dimple jacket welded to a plain (back-up) plate using a semi-automatic GMAW plug weld with filler metal (reference ASME Section VIII, Division 1, Appendix 17, 17-1(b)(3) figure 17-5)[1]. With this design, the dimple jacket is pre-formed from thin gauge sheet material and welded to the vessel shell or head using a GMAW plug weld utilizing filler wire. See Figures 1–3.

Fig. 1 3-dimensional cut-away drawing of thin-gauge dimple jacket on vessel sheet/plate with a 'Half-Pipe' Inlet/Outlet Header.

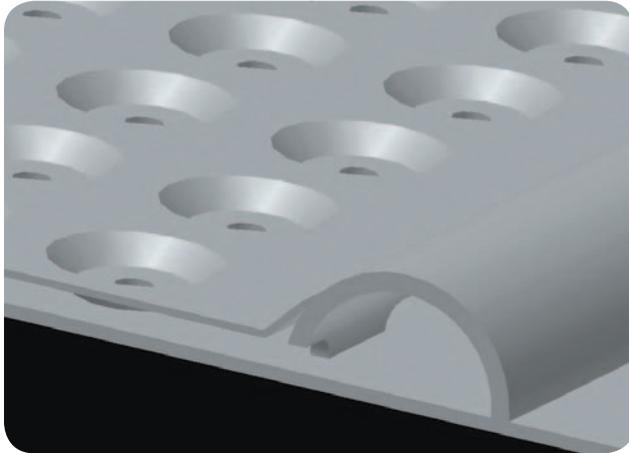


Fig. 2 Formed and rolled dimple jacket sheet prepared to install on vessel shell.

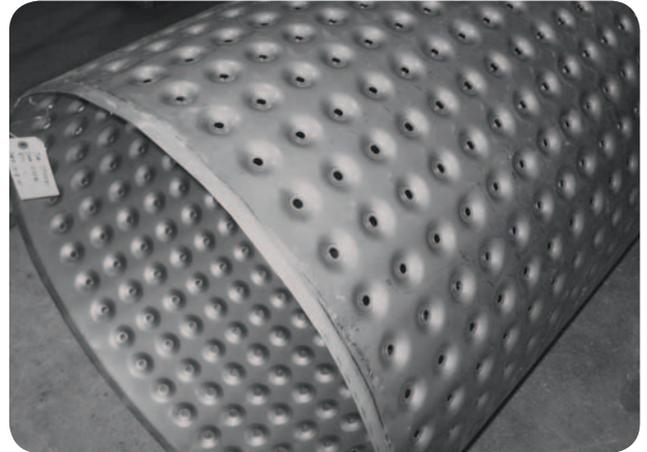
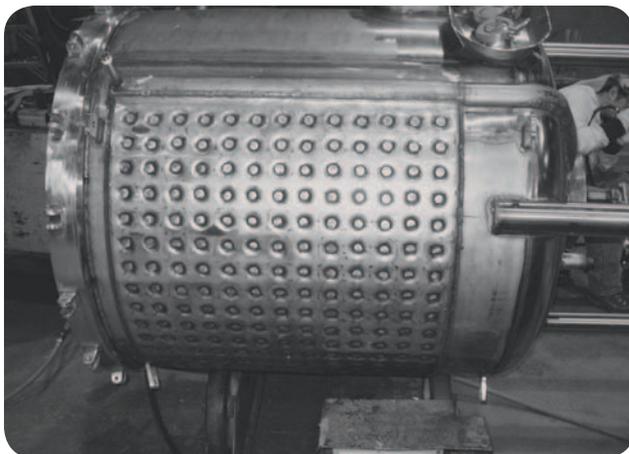


Fig. 3 Dimple jacket and 'Half-Pipe' headers welded on vessel.



Design Environment/Application Requirements

The dimple jacket interior sees various kinds of heating and cooling media, including water, steam, and water-glycol. Some media are corrosive, such as chlorinated city water and some are not. The dimple jacket exterior is usually insulated and then covered with a sheathing barrier. The dimple jackets are exposed to many heating/cooling cycles as the vessels are run through the numerous production processes.

Possible Failure Modes

The design and manufacturing techniques can be a factor in the longevity of a dimple jacket. Every fabricator has their own designs, fabrication techniques, testing plans, instructions and policies to guarantee long-term life of the dimple jackets.

Most failures occur at the inlet and outlet 'headers' (see Figures 1, 3) because these are the areas that see the most drastic temperature changes and have higher stress concentrations, therefore special attention to these areas can increase the service life.

Generally the dimple jackets will last for a long time when used properly; however, they can see some adverse conditions. Chloride stress corrosion cracking is a common mode of failure with types 304/304L (S30400/S30403) and 316/316L (S31600/S31603) stainless steel dimple jackets, mainly due to the chlorides in the media or chloride contamination from the insulation, even if it is 'chloride free' insulation [2]. Due to the nature of the design, which inherently has tight crevices near the plug welds, crevice corrosion and pitting on the interior of the dimple jacket can also be a problem in the presence of chloride contamination.

In addition to corrosion mechanisms the jackets can fail due to fatigue. The crevices in these systems are stress risers that can promote failures over time, especially if used incorrectly. The most common incorrect use of dimple jackets on vessels involves heating and cooling procedures that result in 'thermal shock'. This occurs when the process actually 'shocks' the vessel/dimple jacket assembly causing extreme thermal stresses and strains and ultimately premature failure. This phenomenon seems to be misunderstood but does need to be addressed. Basically there are two causes of thermal shock, either changing the cooling or heating media too fast, typically more than 14°C {25°F} in one minute, or changing the vessel media too fast, typically more than 28°C {50°F} in one

minute. These rapid temperature changes cause an unequal rate of heating or cooling between the thin dimple jacket material and the thick vessel wall, resulting in high thermal stresses and strains. Specific examples of this are:

1. Steam cleaning of the inside of a vessel at 93-150°C {200-300°F} and then sending chilled water, such as 5°C {40°F}, through the dimple jacket, without tempering, to cool the vessel down so it can be re-used in a faster time.
2. Switching dimple jacket media instantaneously from steam to cold water or vice versa.
3. Cleaning a vessel at high temperatures, 77°C {170°F}, and rinsing immediately with cold water, such as 16°C {60°F}) without tempering.

In all these cases, the thermal expansion of the thin dimple jacket and generally much thicker vessel wall do not change at the same rate, resulting in extreme stresses. If this situation cannot be adjusted by tempering the process, then the jacket must be designed to accommodate repeated application of thermal shock.

Most dimple jacket failures, when investigated fully, are not the result of manufacturing defects but are more related to factors such as the misapplication of either an incorrect design, incorrect material of construction, incorrect weld process, or improper installation. The majority of failures do not necessarily occur from just one factor but a combination of factors such as inappropriate dimple jacket material combined with an operating procedure that routinely exposes the dimple jacket to thermal shock.

Past and Current Design/Fabrication Practices

Many fabricators over the years have produced embossed dimple jackets for tanks and vessels from 1.5 mm {16 ga} 304 and 316L stainless steel. Failures occurred due to SCC, crevice corrosion, pitting and repeated thermal shock. The immediate 'fix' was to use a thicker material for the dimple jacket such as 1.9 mm {14 ga} 304 and 316L stainless steel. This might buy some time but really does not improve or address the real problem. Over the past 10–20 years designers and fabricators realized the advantages of using nickel alloys such as alloy 600 (N06600) and alloy 625 (N06625) for the dimple jackets. These alloys seemed to solve many of the corrosion problems and thermal shock issues. These nickel alloys are very resistant to chloride stress corrosion cracking and have a lower coefficient of thermal expansion compared to austenitic stainless steels, which minimizes the level of thermal stress and strain. Also, since nickel alloys like N06625 have higher strength, see Table 1, they can withstand more stress and strain. The use of N06625 has been field proven as a solution, especially for applications involving thermal shock. In cases where a 316L dimple jacket failed in less than two years, the N06625 replacement alloy has been in service exposed to the same conditions for over 10 years. This material appears to solve what is believed to be low-cycle fatigue (LCF) failures due to repeated thermal shock. Currently the standard for some fabricators is to use 1.5 mm {16 ga} or 1.9 mm {14 ga} N06625 for thermal shock conditions while others use 1.9 mm 316L as a cost savings measure in an attempt to solve the problem.

ASME Section VIII, Division 1, allowable design values in MPa {ksi}. Note: dual certified values for SA-240, 316/316LSS, values of S32101 for t<6.5 mm {1/4"} per Code Case 2418 [6, 7]

Table 1

Alloy	Design Stress 38°C {100°F}	Design Stress 93°C {200°F}	Design Stress 149°C {300°F}	Design Stress 204°C {400°F}	0.2% Yield Strength	Ultimate Tensile Strength
S31600/S31603 (A/SA-240)	138 {20.0}	138 {20.0}	138 {20.0}	134 {19.3}	205 {30}	575 {75}
S32101 (A/SA-240)	200 {28.9}	200 {28.9}	190 {27.5}	184 {26.5}	530 {77}	700 {101}
N06625 (B/SB-443, Gr1)	216 {34.3}	216 {34.3}	215 {34.3}	213 {33.6}	380 {60}	760 {120}

Composition of S32101 1.5 mm {16ga} dimple jacket material used in this investigation [6, 8]

Table 2

Element	Mill Certificate (%)	ASTM/ASME Range (%)
Cr	21.5	21.0–22.0
Ni	1.60	1.35–1.70
Mn	5.01	4.00–6.00
Mo	0.30	0.10–0.80
N	0.237	0.20–0.25
C	0.025	0.040 Max.
Si	0.61	1.00 Max.
Cu	0.34	0.10–0.80
P	0.019	0.040 Max.
S	0.001	0.030 Max.
Fe	Balance	Balance

The goal of this investigation is to look at the properties of the S32101 lean duplex stainless steel to determine if it is a viable candidate for dimple jacket applications that involve thermal shock conditions. Properties of the S32101 alloy, see Tables 1, 2, are compared with the 316L stainless steel and N06625 alloy to rank its relative performance.

Experimental Results and Procedures

Corrosion Testing

Data on the stress corrosion cracking, crevice, and pitting resistance (including PREN comparisons) for the three alloys are readily available in the literature and producers data sheets, however no corrosion testing of actual dimple jacket plug welded assemblies has been performed. Because of this, corrosion tests were performed on single plug-welded coupons (See Figure 4) using a 5% ferric chloride -1% sodium nitrate test solution. This solution was chosen so that the critical pitting temperatures of the 316L and S32101 stainless steels would be well above room temperature allowing the use of a standard temperature bath for the test exposures. Samples with different plug weld fillers and shielding gases were tested. Included in this testing is a sample made with a 316L dimple jacket welded to a 316L back-up plate. This sample was included to compare the corrosion performance of S32101 and 316L dimple jackets. Welded coupons were exposed to the test solution for 72 hours at a test temperature of 40°C and the weight loss and a description of the attack were recorded. These exposures resulted in attack primarily on the 316L back-up plate. Because of this the weight loss is reported as grams per area of the 316L back-up plate. The results of this testing are summarized in Table 3. Figures 5 (A) and 5 (B) show the typical attack found on the mill surfaces and edges of the 316L back-up plate and Figure 6 shows the typical attack found on the 316L dimple jacket and back-up plate edges.

Fig. 4 Typical plug welded corrosion specimens used to evaluate the pitting resistance of the S32101 dimple jacket assemblies.



Low-Cycle Fatigue Testing

To determine if S32101 has improved resistance over type 316L to repeated thermal shock, low-cycle fatigue (LCF) testing was performed. Solution annealed strip coupons (see Table 4 for tensile properties), of 1.5mm {16 ga} thickness,

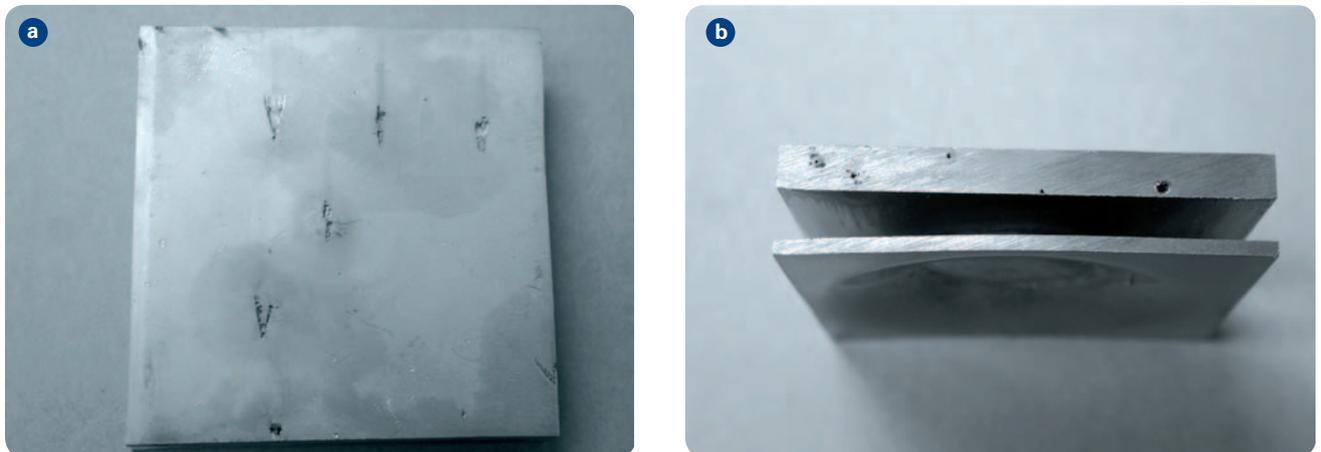
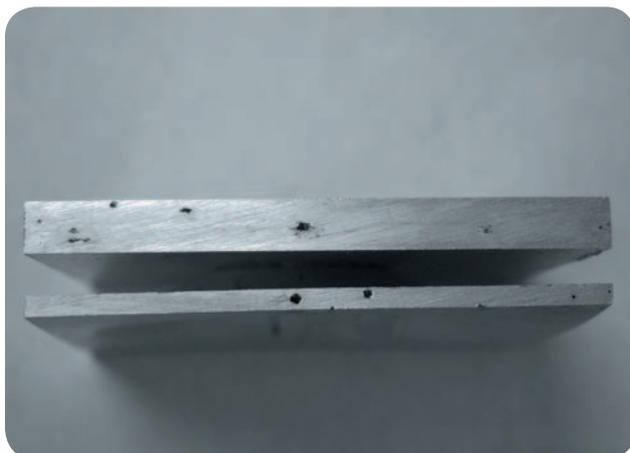
Corrosion results of dimple jacket nugget samples 5% Ferric Chloride + 1% Sodium Nitrate at room temperature Table 3

DJ Sample #	DJ Material	Back-up Material	Weld Filler	Weld Gas	Weight Loss g-cm ⁻²	Observations
1	S31603	S31603	ER316L	75He/25Ar	0.0172	Severe pitting on the 316L dimple jacket and back-up plate
2	S32101	S31603	ER316L	75Ar/25He	0.0187	Severe attack on the 316L back-up plate
3	S32101	S31603	ER2209	75Ar/25He	0.0167	Severe attack on the 316L back-up plate
7	S32101	S31603	ER2209	69Ar/30He/1N ₂	0.0176	Severe attack on the 316L back-up plate

Actual mill certificate values of strips used in LCF Testing

Table 4

Alloy	0.2% Yield Strength, MPa	Ultimate Tensile Strength, MPa
S31600/S31603	331	641
S32101	600	820
N06625	490	917

Fig. 5 Typical corrosive attack found on the 316L back-up plate. (A, left) shows pitting on the mill surface of the 316L Plate. (B, right) shows severe pitting on the edges of the 316L back-up plate.**Fig. 6** Severe pitting on edges of the 316L back-up plate and 316L dimple jacket

of each alloy were tested by straining coupons from zero to a predetermined tensile strain at a frequency of 0.5 Hz. Unless otherwise indicated, all specimens were cut so the axis of the specimen was parallel to the rolling direction.

The maximum strain used for testing the 316L specimens was approximately 0.495%, which was chosen so that the 316L specimens would fail in the low-cycle fatigue regime, see Table 5. The thermal stresses that occur during rapid heating and cooling processes are the result of the temperature difference between the thin dimple jacket sheet and the thicker 316L vessel and the magnitude of the thermal strain is proportional to the coefficient of thermal expansion of the dimple jacket material. Because of this, the strains used to test the S32101 and N06625 specimens were reduced in direct proportion to each material's coefficient of thermal expansion.

Comparison of alloy strain

Table 5

Alloy	Thermal Conductivity W·m ⁻¹ ·K ⁻¹ @ 21°C	Thermal Expansion Coefficient K ⁻¹ @ 21°C *	0.2% Yield Strength MPa	Modulus of Elasticity @ 94°C MPa	Strain, at Yield Point** %	Test Strain (proportional to 316L value)
S31600/ S31603 (SA-240)	15	16·10 ⁻⁶	205	190	0.00109	0.00494
S32101 (SA-240)	15	13·10 ⁻⁶	530	194	0.00273	0.00407
N06625 (SB-443, Gr1)	9.8	13·10 ⁻⁶	380	203	0.00204	0.00396

* Obtained from producer's data sheets

** Calculated from yield strength/elastic modulus

Low-Cycle Fatigue (LCF) testing of 1.5 mm material samples [9]

Table 6

Sample #	Alloy	Sample Description	Applied (%)	Total Strain Cycles	Observations
316L-3	S31603	Roll direction parallel to applied strain	0.493	15 450	Low Cycle Fatigue Failure
316L	S31603	Roll direction parallel to applied strain	0.493	41 663	Low Cycle Fatigue Failure
316L-4	S31603	Roll direction parallel to applied strain	0.487	43 200	Test Discontinued
316L-5	S31603	Roll direction parallel to applied strain	0.494	43 200	Test Discontinued
2101-1*	S32101	Roll direction parallel to applied strain	0.405	534 462	Test Discontinued
2101-1	S32101	Roll direction parallel to applied strain	0.404	43 200	Test Discontinued
2101-2	S32101	Roll direction parallel to applied strain	0.402	43 200	Test Discontinued
2101T	S32101	Roll direction transverse to applied strain	0.403	43 200	Test Discontinued
2101W	S32101	Roll direction parallel to applied strain–GTAW butt welded	0.404	43,200	Test Discontinued
2101HS	S32101	Roll direction parallel to applied strain – same strain applied as S31603	0.494	43 200	Test Discontinued
2101-2*	S32101	Roll direction parallel to applied strain – same strain applied as 31603	0.491	25 457	Low Cycle Fatigue Failure
625-1	N06625	Roll direction parallel to applied strain	0.395	43 200	Test Discontinued
625-2	N06625	Roll direction parallel to applied strain	0.394	42 753	Test Discontinued

* samples planned to be tested until failure

The maximum strains used in the testing the S32101 and N06625 specimens were approximately 0.405% and 0.395%, respectively. Each sample was tested until it either fractured or achieved over 42,500 cycles. An additional sample of S32101 was tested past 42,500 cycles.

In order to obtain a reliable measurement of each material's relative resistance, tests were performed on base metal samples. Also included in the testing was a welded S32101 specimen. This specimen was welded using ER2209 filler with 100% Argon shielding gas. In order to evaluate the LCF properties of the S32101 sheet material in the transverse direction, a specimen was tested with the rolling direction perpendicular to the axis of the specimen. The welded and transverse specimens were both tested with a maximum applied strain of approximately 0.405%.

In addition to the above tests a S32101 coupon was also tested using the same strain applied to the 316L specimen. The results of this testing are summarized in Table 6.

Microstructural Evaluation

The microstructures of the plug welds used to fabricate the S32101 dimple jackets were evaluated by examining cross sections cut through the center of the plug welds. Metallographic specimens were prepared using standard polishing techniques and specimens were etched using an electrolytic sodium hydroxide etch as outlined in ASTM A 923 Test Method A. Figure 7 shows a typical cross section of a ER2209 plug weld. The microstructure of the S32101 base metal is presented in Figure 8 and the Heat Affected Zones (HAZs) for

Fig. 7 Typical cross section of a S32101 dimple jacket welded to a S31603 plate utilizing ER 2209 weld filler.

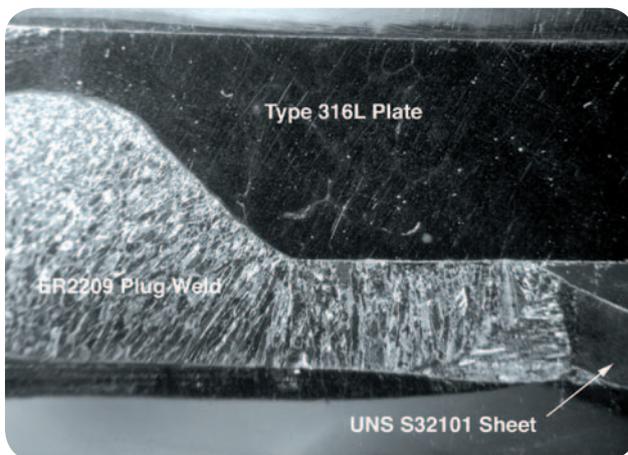


Fig. 8 Typical microstructure of the S32101 sheet (mag. = 400X)

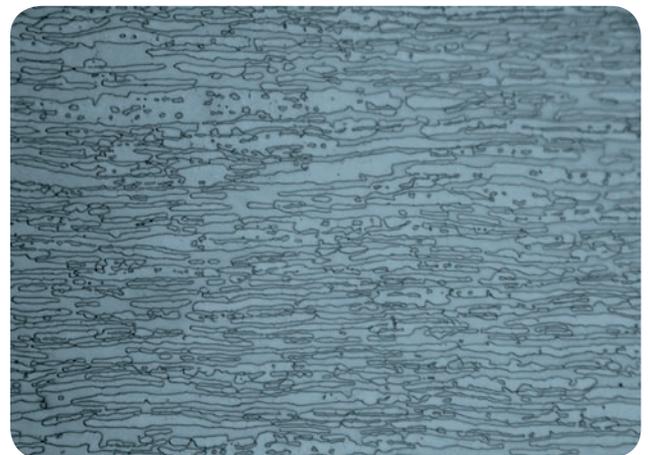


Fig. 9 Microstructure of weld and S32101 HAZ for a ER2209 plug weld using a shielding gas of 75% Argon / 25% Helium (mag. = 200X)



Fig. 10 Microstructure of weld and S32101 HAZ for a ER2209 plug weld using a shielding gas of 69% Argon / 30% Helium / 1% Nitrogen (mag. = 200X)

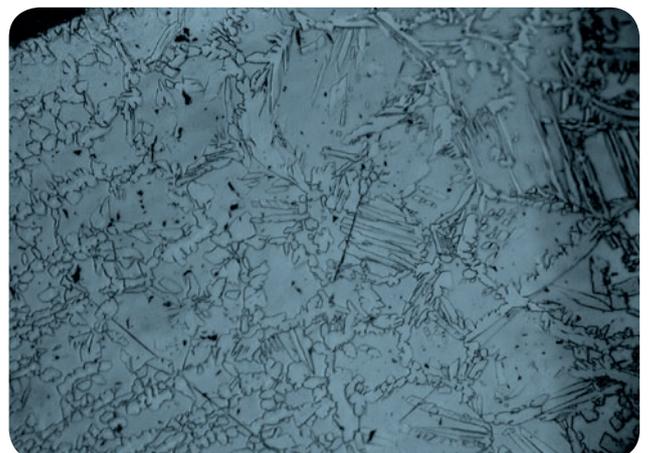


Fig. 11 Typical cross section of a S32101 dimple jacket welded to a 316L plate utilizing a ER316L weld filler.

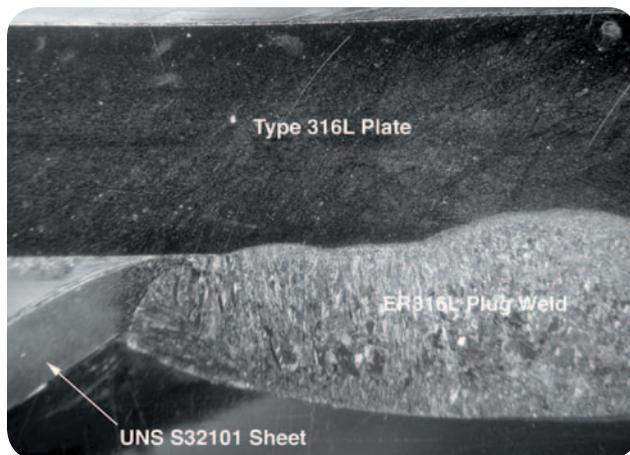
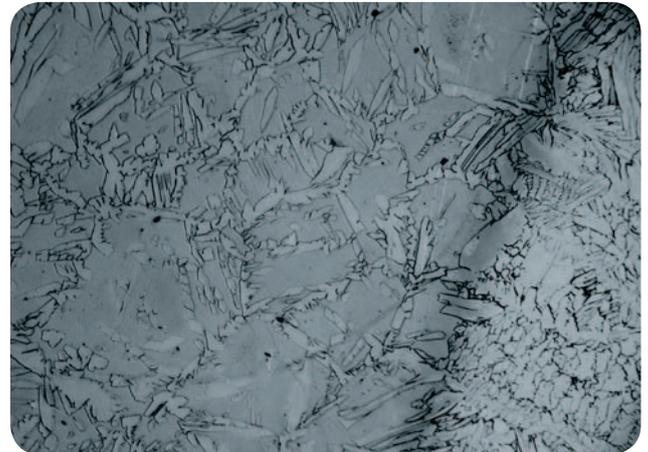


Fig. 12 Microstructure of weld and S32101 HAZ of a ER316L plug weld using a shielding gas of 75% Helium / 25% Argon (mag. = 200X)



ER2209 plug welds using a shielding gas of 75% Argon / 25% Helium and 69% Argon / 30% Helium / 1% Nitrogen mixtures are presented in Figures 9 and 10, respectively. The use of an ER316L filler to attach the S32101 dimple jacket to a type 316L plate was also evaluated and a typical cross section of the S32101 and HAZ zone microstructure are shown in Figures 11 and 12.

The percent ferrite in the S32101 base metal, the plug weld material and the HAZ were measured by using a Fischer Feritscope MP30 and the results are tabulated in Table 7.

Ferrite percentage measurements in S32101 Duplex plug weld samples on 316L back-up plate (average of 10 readings minimum)

Table 7

Area	DJ Sample # 2	DJ Sample # 3	DJ Sample # 7
Filler Wire of Plug Weld	ER316L	ER2209	ER2209
Weld Gas	75He/25Ar	75Ar/25He	69Ar/30He/1N
S32101 Base DJ Material	40%	40%	40%
HAZ	32%	37%	36%
Plug Weld	14%	65%	56%

Discussion

Properties

The mechanical and physical properties of the S32101 grade (see Tables 1 and 2) do offer some advantages for the fabrication and service performance of dimple jackets over type 316L stainless steel. As with other duplex stainless steels the S32101 grade has a higher thermal conductivity and lower coefficient of thermal expansion, which will promote lower thermal stresses during welding operations than what typically occur with austenitic stainless steels [3]. These lower thermal stresses are an advantage in avoiding hot cracking during welding and will also result in lower residual stresses associated with the welds.

The relatively high yield strength of the S32101 results in higher allowable design stresses (see Table 1) and the possibility of reduced wall thickness requirements. This can result in reduced weight and lower costs. The higher yield strength and lower coefficient

of thermal expansion provides better resistance to buckling compared to standard austenitic grades such as 304 and 316L grades. For example, the S32101 grade has a much higher strain at the yield point than 316L and N06625 (see Table 5). This is advantageous to the dimple jacket application as the same amount of applied strain will be a smaller proportion of the yield strength for the S32101 grade.

Corrosion Properties

The important corrosion properties for dimple jacket applications are the resistance to chloride SCC and the pitting and crevice corrosion resistance. Both the 304/304L and 316/316L grades have similar, but very poor resistance to chloride SCC, while duplex stainless steels tend to have much improved resistance. Ericsson [4] measured the SCC resistance of S32101 and type 304L (S30403) stainless using stressed specimens exposed to a $MgCl_2$ test solution and found the SCC resistance of S32101 to be superior to that of type 304L. A summary of their results is given in Table 8. Because of this improved

SCC results measured in 4M $MgCl_2$ at 100°C {212°F} for 500 hours [4]

Table 8

Alloy	4-Point Load	U-Bend
S32101	No SCC	No SCC
304L (S30403)	SCC and pitting	SCC

resistance, chloride SCC failures should not be a concern with S32101 dimple jackets under the typical heating and cooling conditions encountered in high purity systems.

Based on the composition of the S32101 grade and the corrosion results reported in Reference [4], it is expected that the pitting and crevice corrosion resistance of the S32101 grade will be similar to type 316L. However, this does not guarantee that after dimple jacket fabrication the pitting resistance will be maintained. The ferric chloride tests summarized in Table 3 show that all specimens were attacked primarily on the 316L back-up plate. The only exception to this is the sample with a dimple jacket made of 316L sheet. The 316L sheet material showed light pitting on the mill surface and severe pitting on the edges of the 316L sheet (see Figure 6). The 316L back-up plates on all tested coupons suffered severe attack on the edges and mill surfaces (see Figures 5, 6). This observation indicates the 316L back-up plate is more susceptible to localized chloride attack than the S32101 dimple jacket and plug weld. Hence, the S32101 grade and plug welding procedures used in this investigation did not reduce the pitting resistance of the fabricated dimple jacket. The weight loss reported in Table 3 is similar for all samples. This is the result of the attack being located primarily on the 316L back-up plate which is similar for all coupons. The performance of the different welding parameters used in this testing could not be evaluated because all of the attack tended to occur on the 316L plate. This observation indicates that all of the weld filler metal and shielding gas combinations that were tested produced weldments that are at least as resistant as the type 316L back-up plate.

Fatigue Testing

Failure will occur if and when the fatigue life at the induced stress level is exceeded. If the thermal shock situation can't be avoided by slowing down the rapid heating and cooling rates, then the components must be designed to tolerate these repeated thermal stresses. Using a material that has higher strength and better fatigue life is one solution.

Previous published data has shown that S32101 has higher strength and better high-cycle fatigue than 316L [5]. This experiment addressed the possible low-cycle fatigue failure mode of dimple jackets. In evaluating the relative performance of candidate materials for their resistance to thermal shock it is important to remember that grades with lower

coefficients of thermal expansion will produce lower levels of thermal stress during rapid temperature changes. Hence, in evaluating the S32101 grade's resistance to thermal shock it is important to consider both the LCF properties as well as the reduced thermal strains due to its lower coefficient of thermal expansion. Because of this, the candidate materials were compared by applying a maximum cyclic strain that is proportional to the alloy's thermal expansion coefficient.

Out of four tests of 316L at an applied strain of 0.494, 50% failures were encountered. Even the S32101 specimens that were strained at the same maximum strain (0.495%) as the 316L sample, had equivalent failures of 50% and shows evidence that it performs at least equally at this higher strain. Out of five tests on S32101, at a proportional strain (by coefficient of thermal expansion) of 0.405%, 0% failed in the LCF regime. In fact, one test sample achieved over 500,000 cycles and still did not fail. The testing also reveals that the LCF properties of the S32101 material are not substantially reduced in the transverse direction or in the as welded condition. The two N06625 specimens were not tested to failure and presumed equivalent or better than S32101. The LCF tests summarized in Table 6 do reveal that the S32101 grade is more resistant to low cycle fatigue at an applied maximum strain of 0.405% than the 316L grade tested with a maximum strain of 0.495%.

These results certainly suggest that S32101 dimple jackets should provide better resistance to thermal shock than the 316L grade.

Weld Cross Sections

The weld cross sections show very good weld penetration and no welding or fabrication defects were observed on any of the samples. The cross sections show that there is a 'notch' or crevice created in the vicinity of the plug weld where the dimple jacket sheet is joined to back-up plate. This is inherent in the design of embossed dimple jackets and may be a factor in promoting SCC and crevice corrosion failures. This notch can also concentrate stress and be a possible factor in fatigue failures.

With duplex stainless steel welds it is important to maintain a desirable austenite/ferrite ratio in the weld and HAZ. It is also important to avoid any undesirable secondary phases such as sigma. With the lean composition of the S32101 grade the kinetics of sigma formation is very slow and sigma phase precipitation is very unlikely during normal welding operations. As expected, no undesirable phases were found in any of the microstructures. The microstructures in Figures 8, 9, and 10, and the ferrite measurements in Table 7 show that the dimple jacket fabrication procedures used in this investigation maintained the ferrite in the desired 25% to 70% range in the weld and HAZ of the ER2209 welds. Similarly, the ferrite range in the S32101 HAZ of the sample welded with ER316L was also within the desired range. From the ferrite measurements presented in Table 7 it can be seen that shielding with 1% Nitrogen in the gas did result in a slightly lower level of ferrite in the weld and HAZ. Based on this examination no deficiencies in the microstructures were detected.

Conclusion

Based on the findings of this study the S32101, a lean duplex stainless steel, is an acceptable material of construction for embossed dimple jacket using the design and fabrication methods examined in this investigation. Specific conclusions that can be drawn from the results of this investigation are:

1. Sample plug welds made with either ER2209 or ER316L filler showed acceptable microstructures with no precipitation of intermetallic phases and ferrite levels using the ER2209 filler were between 25 – 70% in the weld and HAZ.
2. Ferric chloride corrosion tests showed that the S32101 dimple jacket material is more corrosion resistant than the 316L back-up plate and 316L dimple jacket sheet material. This combined with the improved chloride SCC of the S32101 grade suggest it will provide corrosion resistance that is equal to or better than 316L dimple jackets.
3. The S32101 grade's low coefficient of thermal expansion and its good performance in low cycle fatigue tests suggest that the alloy will show a marked improvement over the 316L grade for applications that expose the dimple jacket to repetitive thermal stresses.
4. The higher strength level of the S32101 over the 316L grade will allow higher design stress and improved resistance to buckling.

References

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