

## QUALITY TESTING AND FRACTURE MODE ESTIMATION FOR WELDED PIPES OF GRADE 321 STAINLESS STEEL

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**Abstract:** The enormous existing and promising technology have tailored the structural and fractural analysis with measuring means. Stainless steel pipes are welded using tungsten inert gas welding technique. In its very primary stage of preparation only weld bead is removed with bead fitted mills. Welded segments and pipes are also subjected to different heat treatment and mechanical operations. These pipes are used in precise applications in refineries and petrochemical plants where they bear ambient pressure/temperature conditions. Because of heat treatable condition requirement the steel is worked with austenitic phase condition. Stainless steels with  $\gamma$  phase has relatively high ductility, low yielding strength, high tensile strength with ease in fabrication and Ti makes the alloy good corrosion resistant. This may lead to corrosion of welded segments in ambient temperature conditions.

Present work deals with the effect of weld gases, alloying element added (Titanium) on the strength and microstructure of the 321 type Stainless Steel. Apart from the benefits of TIG, hot-cracking susceptibility can be industrially exploited and HAZ is satisfactorily would be analyzed using ultrasonic testing. For the present work, we have limited our work up to the spectroscopic chemical analysis of the parent metal and weldment.

**Key words:** Stainless steel grade 321, Titanium, TIG, spectroscopic analysis

### 1. INTRODUCTION

Austenitic stainless steels have high ductility, low yield stress and relatively high ultimate tensile strength, when compare to typical carbon steel. Carbon steel on cooling transforms from Austenite to a mixture of ferrite and cementite. With austenitic stainless steel, the high chrome and nickel content suppress this transformation keeping the material fully austenite on cooling as the Nickel maintains the austenite phase on cooling and the chrome allows the transformation down so that a fully austenitic structure can be achieved with only approx 8% Nickel.

Austenitic steels are not susceptible to hydrogen cracking, therefore pre-heating is seldom required, except to reduce the risk of shrinkage stresses in thick sections. Post weld heat treatment is required as this material as a high resistance to brittle fracture, occasionally stress relief is carried out to reduce the risk of stress corrosion cracking, however this is likely to cause sensitisation unless a stabilised grade is used. If any part of stainless steel is heated in the range 500° to 800° for any reasonable time there is a risk that the chrome will form chrome carbide—a compound formed with carbon with any carbon present in the steel. This reduces the chrome available to provide the passive film and leads to preferential corrosion, which can be severe. This is often referred to as sensitisation. Therefore it is advisable when welding stainless steel to use low heat input and restrict the maximum interpass temperature to around 175°C, although sensitisation of modern low carbon grades is

unlikely heated for prolonged periods. Small quantity of Titanium (321) added to stabilise the material will inhibit the formation of chrome carbides. Most 300 series alloys are designed to solidify initially as delta ferrite, which has a high solubility for sulphur, transforming to austenite upon further cooling. This creates an austenitic material containing tiny patch of residual delta ferrite, therefore not a true austenite in the strict sense of the word. Filler metal often contains further additions of delta ferrite to ensure crack free welds.

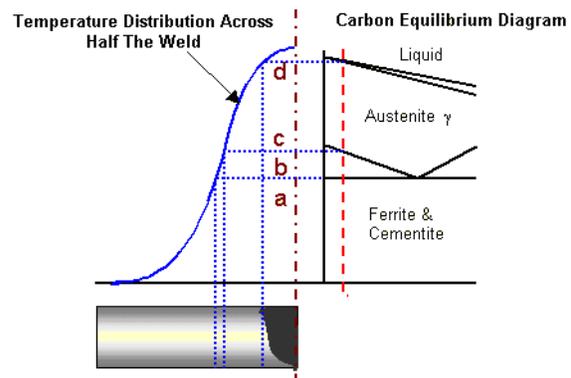


Fig.1 Temperature distribution with carbon equilibrium diagram and heavy distortion because of rapid heating and cooling rate involved in the welding process.

Welds, the metallurgy of a weld is very different from the parent materials. Welding filler metals are designed to create strong and tough welds, they contain fine oxide solidifies, its grains grow from the coarse HAZ grain

structure, further refinement takes place within these course grains creating the typical acicular ferrite formation shown in figure 2.



Fig 2. Acicular Ferrite

A.I.S.I. grade 321 is an austenitic stainless steel stabilised by the addition of upto 4.00 % Titanium. It is predominantly used in applications within the carbide precipitation temperature range of 425-850°C, due to its improved resistance to inter-granular corrosion at these temperatures. Within these temperatures grade 321 exhibits high strength, resistance to scaling and good resistance to subsequent aqueous corrosion. A modified version of Grade 321, Grade 321H, is available. This grade features higher carbon content, to provide improved high temperature strength. Like other austenitic grades, grade 321 has excellent to outstanding forming characteristics. The grade is not generally recommended for applications requiring welding due to poor arc transference. Grade 321 does not polish well, so is not recommended for applications requiring a decorative or refined surface finish such as diaphragm mould tooling. Grade 321 is less readily available in most product forms than grade 304L. Therefore grade 304L is generally used in preference to grade 321. A consideration in using 304L is that it has lower hot strength than 321 and so is not the best choice if the requirement is resistance to an operating environment over 450°C.

## 2. ALL ABOUT 321 FAMILY OF STAINLESS STEEL (Atlas steels Australia. 2000-2007)

### 2.1 Chemical Composition

Table1. Typical chemical compositional ranges for grade 321 stainless steels.

Grade	C	Mn	Si	P	S	Cr	Mo	Ni	N	Other
321	Min.	2.00	0.75	0.045	0.030	17.0	---	9.0	0.10	Ti=5(C+N)
	Max.	0.08	---	---	---	19.0	---	12.0	---	0.70
321H	min.	2.00	0.75	0.045	0.030	17.0	---	9.0	---	Ti=4(C+N)
	max.	0.10	---	---	---	19.0	---	12.0	---	0.70

### 2.2 Mechanical Properties

Table 2. Typical mechanical properties for grade 321 stainless steels

Grade	Tensile Strength	Yield Strength 0.2% Proof	Elongation	Hardness Rockwell B	Hardness Brinell
Unit	MPa	MPa	% per 50mm	HR(B)	(HB)
321	515	205	40	95	217
321H	515	205	40	95	217

### 2.3 Physical Properties

Table 3. Typical physical properties for grade 321 stainless steels

Grade	Density	Elastic Modulus	Poissons Ratio	Co-efficient of Thermal Expansion	Thermal Conductivity	Specific Heat Capacity	Elec Resistivity
Unit	kG/M <sup>3</sup>	Gpa		µm/m <sup>3</sup> °C	W/m.K	J/kg.K	nΩ.m
321	8027	193	0.3	16.6	16.1	500	720

### 2.4 Alternative Material Specifications

The alternative material specifications below are pre-approved for use only where SDL retains design authority. For all other purposes they are provided for comparative purposes only, not as a schedule of contractual equivalents. If exact equivalents are needed application of the use of the material must be considered in conjunction with the original specifications.

Table 4. Possible alternative grades to 321 grade stainless steel

A.I.S.I. Grade	B.S. 970		EuroNorm (E.N.)		Swedish SS	Japanese JIS
	1955	1983	No	Name		
321	EN 58 B EN 58 C	321S31	1.4541	X6CrNiTi18-10	2337	SUS 321
321H	-	321S51	1.4878	X10CrNiTi18-10	-	SUS 321H

### 2.5 Corrosion Resistance

Equivalent to Grade 304 in the annealed condition and superior if a weldment in these grades has not been post-weld annealed or if the application involves service in the 425-900°C range. Subject to pitting and crevice corrosion in warm chloride environments, and to stress corrosion cracking above about 60°C. Considered resistant to potable water with up to about 200mg/L chlorides at ambient temperatures, reducing to about 150mg/L at 60°C.

### 2.6 Heat Resistance

Good oxidation resistance in intermittent service to 900°C and in continuous service to 925°C. These grades perform well in the 425-900°C range, and particularly where subsequent aqueous corrosive conditions are present. 321H has higher hot strength, and is particularly suitable for high temperature structural applications.

### 2.7 Welding (Shimada et al., 2002)

Excellent weldability by all standard fusion methods, both with and without filler metals. AS 1554.6 pre-qualify welding of 321 and 347 with Grade 347 rods or electrodes; high silicon version of 347 is also pre-qualified for welding of 321. In the present a single run of weld on a plate is considered. The parent metal directly under the weld has suffered grain coarsening shown in figure 3 by red. The grain refinement, shown by blue.

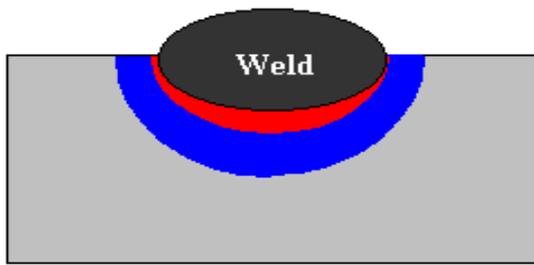


Fig 3. Illustration of HAZ for the weldment

Sensitisation is one of the corrosion mechanisms which cause widespread problems in austenitic stainless steel, particularly in welded assemblies. This problem can be so severe as to cause grain decohesion as shown in figure4.

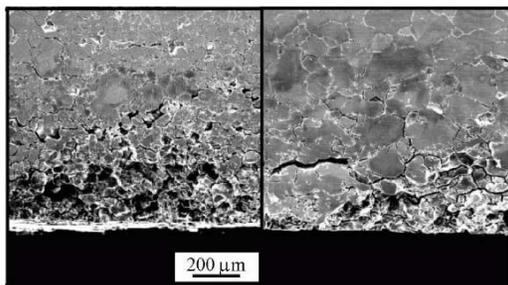


Fig 4. Grain decohesion due to intergranular corrosion (M. Shimada 2002)

In normal conditions, austenitic stainless steels are given a high temperature heat-treatment, often called a solution-treatment, which gives a fully austenitic solid solution. However, at temperatures below about 800° C, there is a tendency to precipitate chromium- rich carbides as the alloy enters the carbide plus austenite phase field. An alternative is use solute such as Nb, Ti, V or Ta which have a greater affinity for carbon than chromium. These are called stabilised stainless steels. In the present work we have selected types 321 (Titanium stabilised austenitic steels. Titanium cannot be used to make alloys deposited by arc welding because it readily oxidises, type 347 is used instead as a filler metal. Stabilisation involves more than just an addition of Ti or Nb. Figure 5 shows how carbon accelerates sensitisation

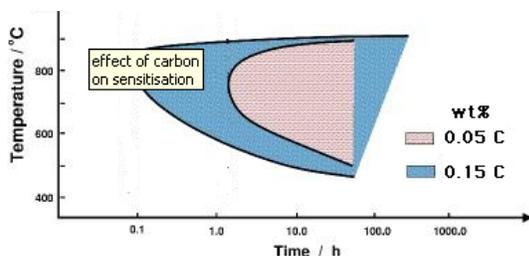


Fig 5. Effect of carbon on sensitisation (Gooch 1975)

### 3. EXPERIMENTAL SETUP AND ANALYSIS

In the present work the results are shown for the parent material tested under spectrometer for its compositional analysis with the same metal under weld.



Fig 6. Spectroscope with data printing device

#### 3.1 Material selection

Initially three materials were selected like 304, 316 and 316L for the basic comparison with 321 grade stainless steel. Figure 7



Fig 7. Grades of stainless steel 316, 304 and 316L

**3.1.1 Grade 316:** C-0.0713%, Si-0.428%, Mn-1.44%, P-0.0244%, S-0.0179%, Cr-16.26%, Ni-10.18%, Mo-1.95%, Cu-0.388%, Ti-0.0240%, Nb-0.0627%, Al-0.0011%, Co-0.118%, V-0.0644%, N-0.0531%, Fe-68.8%

**3.1.2 Grade 304:** C-0.0558%, Si-0.534%, Mn-1.89%, P-0.0186%, S-0.04005%, Cr-17.84%, Ni-9.12%, Mo-0.463%, Cu-0.403%, Ti-0.00810%, Nb-0.0475%, Al-0.00308%, Co-0.243%, V-0.101%, N-0.0605%, Fe-69.1%

**3.1.3 Grade 316L:** C-0.0284%, Si-0.399%, Mn-1.20%, P- 0.0162%, S-0.00485%, Cr-16.67%, Ni-11.19%, Mo-0.03%, Cu-0.311%, Ti-0.436%, Nb-0.030%, Al-0.0270%, Co-0.149%, V-0.0806%, N-0.0541%, Fe-66.8%

After analysing the various factors considering availability, applications and suitability final material under examination is grade 321.

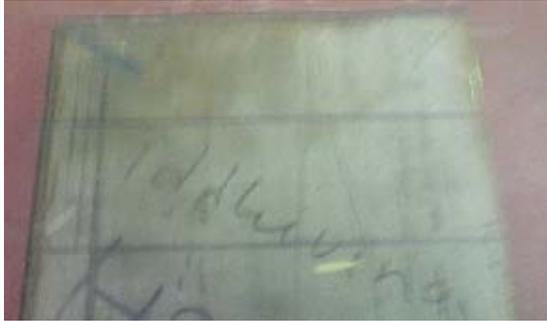


Fig 8. Grade 321 stainless steel

We have selected 6 mm thick plate for the welding and Tungsten inert gas welding is done using rectifier welding in conjunction with Argon gas. The standard set for plasma cutting of the alloy and welding is shown in figure 9 and 10 respectively.



Fig 9. Plasma cutting set up

The plasma cutting unit consists of plasma torch having hair thick diameter with temperature as high as 3700°C.



Fig 10. Tungsten Inert Gas Welding set up

## 4. RESULTS AND DISCUSSION

**4.1 Grade 321:** C-0.029%, Si-0.465%, Mn-1.356%, P-0.026%, S-0.004%, Cr-17.196%, Ni-9.230%, Mo-0.416%, Cu-0.150%, Ti-0.102%, Nb-0.020%, Al-0.007%, Co-0.160%, V-0.099%, N-0.084%, Fe-70.525%

This result vary from the parent alloy if the standards are referred and this proves that if 321 is used as filler metal than titanium does not transfer well across a high temperature arc, so is not recommended as a welding consumable. In this case grade 347 is preferred-the Niobium performs the same carbide stabilisation task can be across a welding arc. Grade 347 is therefore the standard consumable for welding 321 grade stainless steel. Additionally grade 347 is only occasionally used as parent plate material. It is best suited to an operating environment over about 500° C because of its high hot strength.

## 5. CONCLUSION

As reported our work deals with the way to improve welding susceptibility and success. Excellent weldability by all standard fusion methods, both with and without filler metals is obtained. AS 1554.6 pre-qualify welding of 321 and 347 with Grade 347 rods or electrodes is pre-qualified.

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