

**Welding of CRA with Insufficient Purging Gas
Impact on Mechanical Properties and Corrosion Resistance**

Kristian Eriksen
Aker BP
Jåttåvågveien 10
NO-4020 Stavanger, Norway

Roy Johnsen
Norwegian University of Science and Technology (NTNU)
Richard Birkelandsvei 2b,
7491 Trondheim, Norway

Stian Hauger
Kværner
Hamnevegen 7
NO-7652 Verdal, Norway

ABSTRACT

During fabrication of piping systems discoloration (heat tint) in excess of that accepted by welding standards such as Norsok M-601 is sometimes experienced.¹ This is normally a result of insufficient purging gas. The effect on mechanical properties and corrosion resistance were investigated. Pipe spools made from 22Cr duplex stainless steel, 25Cr duplex stainless steel and titanium Gr. 2 were welded using argon purging gas with mixed-in oxygen at various concentrations to simulate insufficient purging. The mechanical testing included tensile testing, impact testing and hardness measurements while the corrosion testing included ASTM G48² – Method A pitting tests, critical pitting temperature measurements in simulated seawater and critical pitting potential measurements in simulated well fluids according to ASTM G61.¹⁴

The results from tensile testing, impact testing and hardness measurements showed that the tested materials were virtually unaffected by the purging gas conditions, except when welded with no purging gas at all. The corrosion testing also showed that the materials were more or less unaffected by the purging gas conditions, both in seawater service and in hydrocarbon service. The main conclusion of the work is that the integrity of piping systems in 22Cr duplex stainless steel, 25Cr duplex stainless steel and titanium Gr. 2 does not seem to be compromised by insufficient purging, as long as some level of purging gas is used for butt welds.

Keywords: Welding, Purging gas, Heat tint, Duplex Stainless Steel, Titanium, Pitting Corrosion, Seawater systems, Hydrocarbon systems

INTRODUCTION

The term Corrosion Resistant Alloys (CRAs) covers a wide range of metallic materials that is protected against corrosion by an oxide layer also called a passive film. The passive film is only a few nanometers thick and is formed on stainless steels when chromium reacts with oxygen to form chromium oxide. Other alloying elements like nickel, molybdenum and nitrogen also provides increased corrosion resistance. Other corrosion resistant metals like aluminum and titanium form passive films of aluminum oxide and titanium oxide respectively without the need for alloying elements to provide corrosion resistance.³

The passive film is formed almost instantly when the metal is exposed to an oxygen rich environment like air or water. When these metals are exposed to elevated temperatures during hot-forming, welding, heat treatment, etc. the protective passive film is damaged. The degree of damage is depending on the temperature, where higher temperatures gives more damage. On stainless steels the degradation process can be explained by thickening of the chromium rich oxide layer that results in a fragile layer more like scaling. This leads to a chromium depleted layer beneath the oxide layer. Another effect of the high temperature is additional loss of chromium from the oxide layer leaving an iron rich and brittle oxide layer.⁴

CRAs are used in the oil and gas industry to provide long term resistance against internal corrosion in process and utility systems containing e.g. hydrocarbons, formation water, raw seawater, chemicals.⁵ CRAs are also used to provide external corrosion protection against marine atmosphere for process and utility systems, blast walls, pipe supports, outfitting steel, etc. without the need for external coating.

Purging gas is used to suppress oxygen from root area where the high temperatures during welding cause oxygen to react with the metal with discoloration (heat tint) as main result. While the main concern with CRAs like duplex stainless steels welded with insufficient purging gas is loss of corrosion resistance, the concern with titanium is predominantly embrittlement. Oxygen and nitrogen diffuse into the matrix at temperatures above 400 °C and cause an increase in yield and tensile strength, but a reduction in toughness.

Limited information is available in published literature regarding the effect of increasing levels of discoloration on mechanical properties and corrosion resistance of duplex stainless steel grades and titanium. Especially corrosion resistance in hydrocarbon systems is lacking. However, the influence of oxygen content in shielding gas on corrosion resistance has been investigated by some researchers.⁶⁻¹¹

During fabrication of piping systems, discoloration in excess of that accepted by welding standards such as Norsok M-601 is sometimes experienced.¹ Weld discoloration is normally a result of insufficient purging gas, and to investigate the effect on mechanical properties and corrosion resistance, a test program was initiated. Pipe spools made from 22Cr duplex stainless steel, 25Cr duplex stainless steel and titanium Gr. 2 were welded using argon purging gas with mixed in oxygen at various concentrations to simulate insufficient purging. This caused various degree of discoloration of the welds and the heat affected zone (HAZ). Welding with proper purging gas and without purging gas were also performed and included in the test program.

The mechanical testing included tensile testing, impact testing and hardness measurements while the corrosion testing included ASTM G48 pitting tests, critical pitting temperature measurements in

simulated seawater and critical pitting potential measurements in simulated well fluids according to ASTM G61.

EXPERIMENTAL

Welding of test spools

Six test spools were welded as shown in Figure 1 and Table 1. The two 22Cr duplex stainless steel spools and the two 25Cr duplex stainless steel spools were made from pipes with 3.8 mm w.t. (wall thickness) and 10.3 mm w.t. The titanium spool was made from a 3.8 mm w.t. pipe. Chemical composition can be found in Table 2. Each spool was made from 4 pipe sections, cut from the same mother pipe, and three patch plates as shown in Figure 1. The thickness of the patch plates was 6 mm. The sixth spool was a short 3.8 mm w.t. 25Cr duplex stainless steel spool with two butt welds. Each spool was identified by numbers from 1-6 as shown in Table 1.

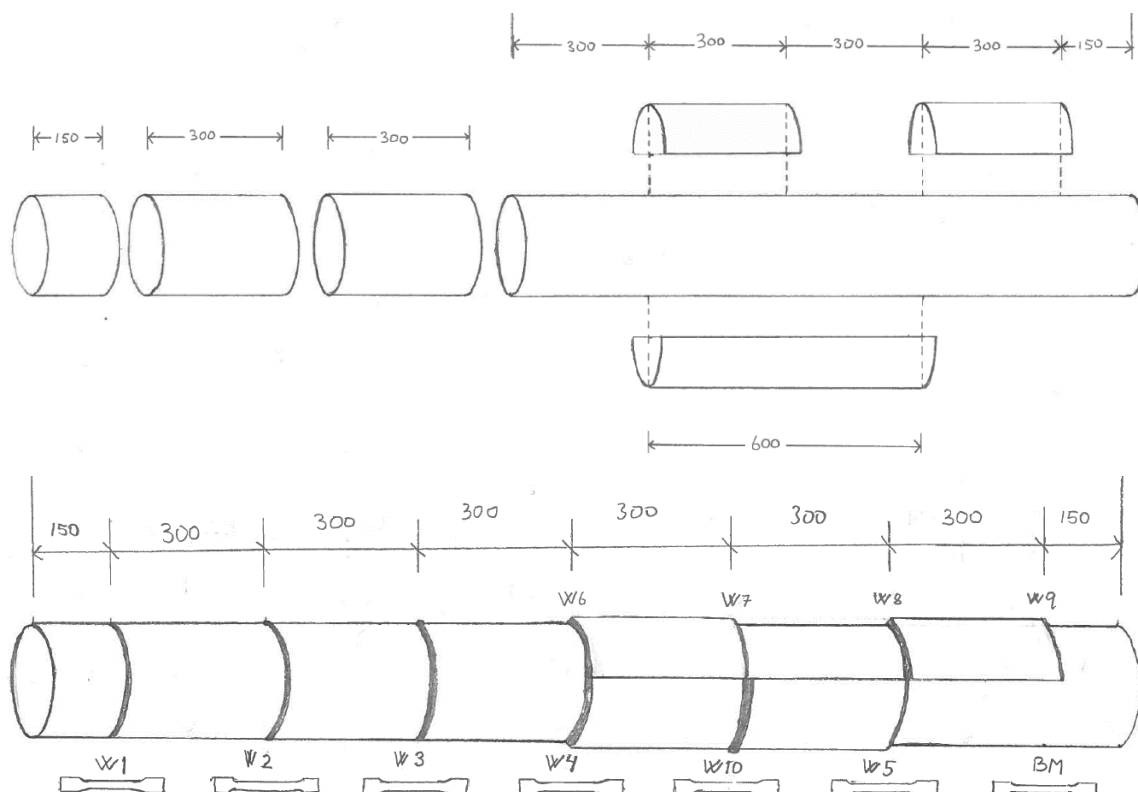


Figure 1: Test spool schematic before and after welding (in mm).

The setup shown on Figure 1 gave a total of three 360° butt welds, six 180° fillet welds and a bead weld on top of the longest patch plate.

Table 1
Spool identification.

Spool	Material	OD [mm]	W.t. [mm]	Length [mm]	Butt welds	Fillet welds
1	22Cr DSS ¹⁾	219.1	3.8	2100	3	6
2	22Cr DSS ¹⁾	219.1	10.3	2100	3	6
3	25Cr SDSS ²⁾	219.1	3.8	2100	3	6
4	25Cr SDSS ²⁾	219.1	10.3	2100	3	6
5	Titanium Gr. 2	219.1	3.8	2100	3	6
6	25Cr SDSS ²⁾	219.1	3.8	600	2	0

Table 2
Chemical composition of pipe material

ALLOY	W.t [mm]	UNS	C	Si	Mn	P	S	Cr	Ni	Mo	N	Cu	W	Co
22Cr DSS	3.8	S31803	0.016	0.40	1.35	0.025	0.001	22.38	5.73	3.15	0.165	0.23		0.12
22Cr DSS	10.3	S31803	0.023	0.450	1.42	0.024	0.001	22.44	5.66	3.16	0.180	0.07		0.10
25Cr DSS	3.8	S32750	0.016	0.35	0.75	0.022	0.001	24.86	6.88	3.79	0.287	0.25		
25Cr DSS	10.3	S32760	0.019	0.33	0.47	0.024	0.0003	25.49	7.14	3.67	0.250	0.55	0.55	
		Grade	Fe	C	N	O	H							
Ti gr. 2	3.8	Gr.2	0.04	0.02	0.01	0.12	0.001							

Each weld was given a number from 1 to 10 as shown on Figure 1. A 180° section was left unwelded for testing of base material (BM). Spool id and weld id were then combined to create unique weld numbers (spool 1 and weld 5 gave weld number W-105).

All welds were TIG-welded by experienced welders using pre-qualified procedure. Common welding parameters for each material are shown in Table 3. The DC current and welding speed were adjusted to achieve a relatively high heat input, but still within the qualified range. The only exception was the bead weld on top of the patch plate (weld 10) that was welded as hot as possible. The intention of the fillet welds and the bead weld was not to test the weld itself but to test the effect on the pipe below the welds. None of the welds or the heat effected zones were pickled or grinded to remove heat tint after welding since the purpose of the test program was to investigate the effect of the heat tint.

Table 3
Common welding parameters.

Material	Weld process	Consumable	Preheat	Max inter pass temp. (°C)	Groove angel	Root gap	Position
22Cr DSS	141	OK Tigrod 2209	No	150	60°	4 mm	PF
25Cr DSS	141	OK Tigrod 2509	No	100	60°	4 mm	PF
Ti gr. 2	141	UTP ERTi 2-IG	No	250	60°	4 mm	PF

Purging gas quality was the main parameter that was changed from weld to weld. The different purging gas qualities used, are listed below.

Purging gas quality:

- BG 1: Ar4.6 (Argon purging gas with 99.996% purity)
- BG 2: Ar4.6 + 500 ppm by weight (later called ppm) oxygen
- BG 3: Ar4.6 + 1000 ppm oxygen
- BG 4: No purging gas
- BG 5: Ar4.6 + 2500 ppm oxygen
- BG 6: Ar4.6 + 5000 ppm oxygen

Purging gas quality BG 1-4 was used on test spools 1-5 while BG 5-6 was only used on the additional 25Cr duplex stainless steel test spool (spool 6). Before the test spools were dispatched, all butt welds were examined by radiography (RT) to detect any weld defects that could compromise the test results from mechanical testing and corrosion testing.



Figure 2: Test spool 3 after completion of all welds. Each weld identified by weld numbers.

Cutting and machining

After completion of welding and RT, each spool was cut into smaller sections with a band saw. The sections to be used for corrosion testing were cut into smaller samples and the patch plates and fillet welds were removed. The samples for mechanical testing were extracted by water cutting (Figure 3). All weld numbers were transferred from each test spool to each cut section and to each test sample to maintain traceability through all stages.



Figure 3: Test samples ready for corrosion testing and mechanical testing.

Mechanical testing

Tensile testing, impact testing, hardness measurements and visual examination were performed for each weld and base material for each spool. Testing was performed in accordance with Norsok M-601¹ and the applicable data sheets in Norsok M-630.¹⁵