

New Materials

# Specialty Stainless For Solving Corrosion Problems in the Oil & Gas Industry

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Stainless steels cover a wide range of alloys, each with a particular combination of corrosion resistance and mechanical properties. In oil and gas applications many of these stainless steel grades are used, depending on the demands of the particular service environment. To achieve good corrosion resistance several damage mechanisms have to be considered, such as uniform corrosion, pitting corrosion and environmentally-induced cracking. Different strategies are used for developing specialty stainless steels which have properties far superior to those of the basic 304L and 316L grades. This paper will focus the attention on some duplex and superaustenitic grades and their corrosion properties and applicability to the oil and gas industry.

The resistance to localised corrosion of stainless steels can be estimated from the steel composition using the pitting resistance equivalent (PRE = percent Cr + 3.3x percent Mo + 16x percent N). In Table 1 PRE values for some stainless steels grades are listed. In order to increase the corrosion resistance of austenitic grades higher contents of chromium, molybdenum and nitrogen are added. Two examples of such superaustenitic stainless steels are 254 SMO (20 Cr 18 Ni 6 Mo 0.2 N) and 654 SMO (24 Cr 22 Ni 7.5 Mo 3 Mn 0.5 N), which have typical PRE-values of 43 and 56 respectively (see Table 1). The mechanical properties such as the yield strength also increase with increasing alloying content, this is especially noticeable in the case of 654 SMO that has around twice the yield strength compared to standard austenitic grades (Table 1). Another way to increase the yield strength is to decrease the nickel content so that the microstructure becomes duplex (ferritic-

austenitic). LDX 2101 (21.5 Cr 1.5 Ni 5 Mn 0.3 Mo 0.22 N) is a lean duplex grade with comparable corrosion properties of standard austenitic grades (PRE = 26), but with twice the yield strength as shown in Table 1.

Grade	Typical chemical composition [wt%]						PRE <sup>1)</sup>	Micro-structure	Rp0.2 [MPa]	Rm [MPa]	A <sub>3</sub> [%]
	Cr	Ni	Mo	C	N	Others					
304L	18.1	8.1	—	0.02	—	—	18	Austenitic	200	500	45
316L	17.2	10.1	2.1	0.02	—	—	24	Austenitic	220	260	45
LDX 2101 <sup>®</sup>	21.5	1.5	0.3	0.03	0.22	5Mn	26	Duplex	450	650	30
2205	22	5.7	3.1	0.02	0.17	—	35	Duplex	460	640	25
254 SMO <sup>®</sup>	20	18	6.1	0.01	0.20	Cu	43	Austenitic	300	650	40
654 SMO <sup>®</sup>	24	22	7.3	0.01	0.50	Mn, Cu	56	Austenitic	430	750	40

1)PRE = percent Cr + 3.3x percent Mo + 16x percent Mo

Table 1. Austenitic and duplex stainless steel grades & Mechanical properties (min values at 20°C according to EN 10088)

### Corrosion properties of LDX 2101\*

In seawater, chloride and temperature are two major factors within localized corrosion. The critical pitting temperature (CPT) using ASTM G 150 or ASTM G48 Method E (see Table 2) are both confirming LDX 2101 has a resistance to pitting intermediate between 304L and 316L. When Stresses are present in chloride containing environment, steels are prone to chloride-induced stress corrosion cracking (SCC) The results of a large number of tests (Table 3) demonstrate the superior resistance of LDX 2101 to SCC compared to standard austenitic grades in all these types of tests.

Materials intended for service in sour environments in the oil and gas industry also need sufficient resistance to

Grade	304L	316L	LDX 2101®	2205	254 SMO®	654 SMO®
CPT ASTM G150	< 10	20	17	52	87	> 90
CPT ASTM G48 F	10	20	15	40	65	> bp1)
CCTASTM G48 F	< 0	< 0	< 0	20	35	60

1)bp = 102.5°C

Table 2. Typical CPT and CCT values using test methods ASTM G150 and ASTM G48 Methods E and F [1]

Grade	304L	316L	LDX 2101®	2205	254 SMO®	654 SMO®
Wick test	SCC	SCC	No cracks	(No cracks)	No cracks	—
40% CaCl <sub>2</sub> , 100°C	SCC	SCC	No cracks	No cracks	—	—
25% NaCl, b.p.1)	—	SCC	No cracks	No cracks	—	—
DET2)	< 10%	< 10%	—	30%	80%	100%

1)b.p. = boiling point (107°C)

2)Drop evaporation test: results expressed as the threshold stress, percent of Rp0.2 at 200°C

Table 3. Summary of SCC testing of some stainless steel grades [2, 3]

Grade	pH <sub>2</sub> S	Cl <sup>-</sup>	CO <sub>2</sub>	Temp.	No. of specimens	
	[kPa]	[mg/l]			Tested	Cracked
13 Cr	1	100000	ba.	RT	6	6
LDX 2101®	10	100000	ba.	RT	6	0

Table 4. SSC testing of 13 Cr SMSS and LDX 2101®[1]

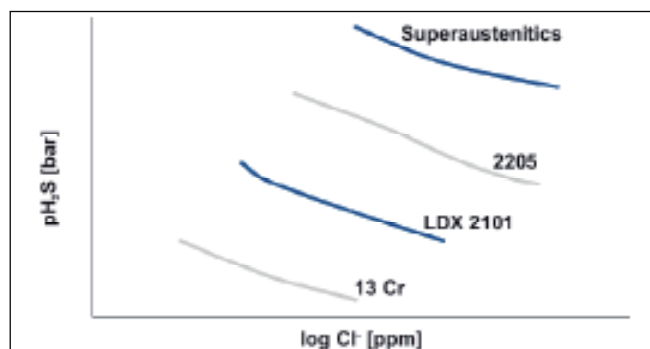


Figure 1: Schematic of limits of SSC resistance for some stainless steel grades.

sulphide stress cracking (SSC). SSC can be influenced by many factors such as the partial pressure of H<sub>2</sub>S, the pH, chloride concentration and temperature, making it complex to define limits for when SSC occurs. The results in table 4 show that all the 13 Cr specimens cracked while none of the LDX 2101 specimens exhibited any cracking, even though tested at ten times higher H<sub>2</sub>S partial pressure. Figure 1 shows a simple schematic illustration of limits of SSC resistance for LDX 2101® compared to some other stainless steels which is based on the results of this type of comparative investigations. Lean duplex stainless steels are suitable for subsea oil and gas applications, such as flowlines, and umbilicals in milder well conditions, as well as for topside applications. Lower cycling cost and possibility of weight reduction help to reduce the overall cost of O&G project. They can be an alternative to standard austenitic grades such as 304L, supermartensitic stainless steels, 2205 duplex stainless steel and also coated carbon steels.

### Corrosion Properties of 254 SMO and 654 SMO

Superaustenitic grades such as 254 SMO and 654 SMO have superior resistance to pitting corrosion compared to standard austenitic grades as shown in Table 2. The combination of high chloride content and the formation of biofilm or chlorination make natural seawater a very corrosive environment. Both 254 SMO and 654 SMO are candidates for sea water applications. 254 SMO can be susceptible to crevice corrosion at temperatures above 30°C in chlorinated seawater, while the extreme corrosion resistance of 654 SMO makes it an alternative to titanium and nickel-base alloys in many environments.

The superaustenitic grades also show excellent resistance to SCC and SSC as illustrated in Tables 3 and 5. NACE MR0175/ISO 15156-3 allows the use of both solution annealed and cold-worked 254 SMO and 654 SMO at any temperature up to 171°C in sour environments, if the partial pressure of hydrogen sulphide does not exceed 15 psi (1 bar), the chloride content does not exceed 5000 ppm and the hardness is not greater than HRB 95 for solution annealed material and HRC 35 for cold-worked material [7]. The superaustenitic stainless steels 254 SMO and 654 SMO are suitable for many oil and gas

Grade	Cold work	Stress	Temp.	Result
	[%]	[% of Y.S]	[°C]	
254 SMO®	0	100	90	No cracking
	40-80	90	25	No cracking
654 SMO®	0	100	90	No cracking
	0-80	100	25	No cracking

Table 5. SSC testing of 4-PB specimens in NACE solution (5% NaCl, pH 3, 1 bar pH<sub>2</sub>S) for 720 hours [4]

application where the very high corrosion resistance of these alloys is required. Successful applications include process piping, seawater piping, and condenser tubing.

**Conclusions**

The lean duplex grade LDX 2101 combines excellent mechanical properties, with pitting corrosion resistance on par with standard austenitic stainless steel grades and superior resistance to stress corrosion cracking. The SSC

resistance of LDX 2101 is significantly superior to that of 13 Cr supermartensitic stainless steel. It also can be an alternative to coated carbon steel. The superaustenitic grades 254 SMO and 654 SMO, show excellent corrosion resistance in a wide variety of media and find extensive use in seawater applications, demanding process fluids and sour service.

Both groups of stainless steels have an important place in the materials solutions for the oil and gas industry. ■

**References**

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## Safety Issues to be Looked Upon: EC

The European Commission has asked its member states to consider suspending oil and gas licensing until it has studied and assessed European offshore safety regimes. It also plans to introduce new European Union-prescribed safety standards so the offshore activities do not hamper. Malcolm Webb, CEO, Oil & Gas, said the measure was "wholly unjustified and inappropriate for the UK offshore oil and gas industry." "It is also deeply worrying that in addition, it [the Commission] now proposes to implement central-

ized and prescriptive safety regulation.

In our opinion, this would undermine the advanced and highly sophisticated regulatory regimes currently working so well, for example in the United Kingdom, Norway, and the Netherlands, each of these being global exemplars of which Europe should be proud," he added. This process is likely to be substantially completed before the Commission anticipates coming forward with its new legislative package.