Area of Use for Z100 (UNS S32760) Superduplex Stainless Steel Wireline.

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Abstract
Wirelines or slicklines are routinely used in the oil and gas industry for retrieving tools or for operating downhole valves etc. Usually the operation is relatively short, lasting a day or two, or less. If a wireline breaks during retrieval it can take a considerable time to retrieve the consequent "birds nest" that the broken wire forms. These failures often occur at sites of localised corrosion, where the stress is intensified. CRA's are frequently chosen to try and avoid this problem. However, alloys such as 316 still fail. The present paper presents both mechanical and corrosion data for Z100 superduplex stainless steel. A high strength is obtainable with this alloy while retaining ductility and giving a very high breaking load compared with 316L. The alloy is not as highly alloyed and so it is more cost effective than high nickel alloys, such as 6Mo stainless steel and nickel alloys such as 825 and 28, and also high cobalt containing alloys, such as MP35N. Z100 has been extensively tested in a wide range of sweet and sour environments and the data showing the limits of use is presented.

Keywords.
Stainless steel; oil and gas; wireline;

1.0 Introduction

Single strand wirelines (slicklines) are routinely used to lower instruments or tools into oil and gas wells, or they can be used to manipulate devices such as safety valves, sliding sleeves, side-pocket mandrels, etc.

With the increasing demand for oil and gas, wells are getting deeper and modern wells can be 20,000 to 25,000 feet (6000 to 7,600m) deep. Generally, the deeper the well, the higher are the temperature and pressure. With increasing depth, the weight of the wireline increases, decreasing the maximum payload. Hence there is a desire for stronger wirelines to increase payloads, without a significant loss of ductility. In addition, newer wells tend to contain higher quantities of carbon dioxide and hydrogen sulphide, which increases the risk of corrosion, particularly localised corrosion such as pitting or cracking. Localised corrosion creates a small notch that acts as a stress concentrator and can result in wire failure when the wire load is high. Hence, there is an increasing interest in corrosion resistant alloy (CRA) wirelines. This report presents the data for Zeron 100 superduplex stainless steel and demonstrates how it can be a cost effective alternative to other CRA's.

2.0 Physical and Mechanical Properties of Zeron 100

2.1 Composition

Zeron 100 is a superduplex stainless steel with a 50/50 austenite/ferrite microstructure. This combines the ductility of austenite with the strength of ferrite. It has the UNS designation S32760 and is known generically as Z100. The nominal composition of Zeron 100 is shown in Table 1, with some other common wireline alloys for comparison. It can been seen that Zeron 100 is more highly alloyed than

Alloy	**Nominal Composition (wt%)**								**PREN***
	Fe	**Cr**	**Ni**	**Mo**	**N**	**Cu**	**W**	**Ti**	
316	Bal	17	10	3	-	-	-	-	24
Alloy 825	Bal	21	40	3	-	2	-	1	31
Alloy 28	Bal	27	32	3.5	-	1	-	-	38
6Mo	Bal	20	18	6	0.2	0.7	-	-	43
Zeron 100	Bal	25	7	3.5	0.25	0.7	0.7	-	>40

Table 1: The nominal composition of some common wireline alloys.
Bal = balance
PREN = % Cr + 3.3 x % Mo + 16 x %N.

316L, and compares with some common nickel alloys, such as alloys 825 and 28. However, Zeron 100 contains much less nickel than these alloys and so is lower in cost. The 6% molybdenum stainless steels have also been used as wirelines. These are fully austenitic alloys, like 316L, and are not as strong as Zeron 100. In any given size they have a tensile strength and breaking load mid way between that of 316 and Zeron 100. As the 6Mo alloys also contain substantially more nickel than Zeron 100, they are also more expensive.

The pitting resistance equivalent number, or PREN, is an empirical number that indicates the resistance to localised corrosion in the presence of chlorides. Zeron 100 is made to a minimum PREN of 40, which is higher than 316L and the nickel alloys in Table 1. Francis et al[1] showed that the resistance to pitting and crevice corrosion in hot sour brines increased as the PREN of the alloy increased.

Table 1 shows that the 6% Mo alloys have a slightly higher PREN than Zeron 100. However, Kovach et al[2] showed that austenitic stainless steels need a PREN ~3 points higher than that of a duplex stainless steel to confer the same resistance to crevice corrosion.

2.2 Mechanical Properties

The mechanical conditions during service are considered to be severe in the case of a single wireline. A typical arrangement is shown in Figure 1. Under static conditions the load in the wire is that of the tool string plus the weight of the wireline below the sheave. The latter is a substantial fraction of the total. For a 6,500m wireline, the wire weight contributes a stress of ~500 MPa. Any minor nicks or changes in section along the wire can act as stress raisers, which mean that stresses close to yield are not uncommon. If the wire or tools stick at all during operation, then loads up to the breaking force may be produced. Zeron 100 is available in three standard wireline diameters, 0.092” (2.3mm), 0.108” (2.7mm) and 0.125” (3.2mm). Table 2 shows the measured breaking load for Zeron 100 wire with a minimum tensile strength of 1,600 MPa. These results show that Zeron 100 is 7 – 10% stronger than 316, with similarly higher breaking loads and safe working loads. As the cost of retrieving a broken wire can be very high, the higher strength of Zeron 100 wireline is a significant advantage.

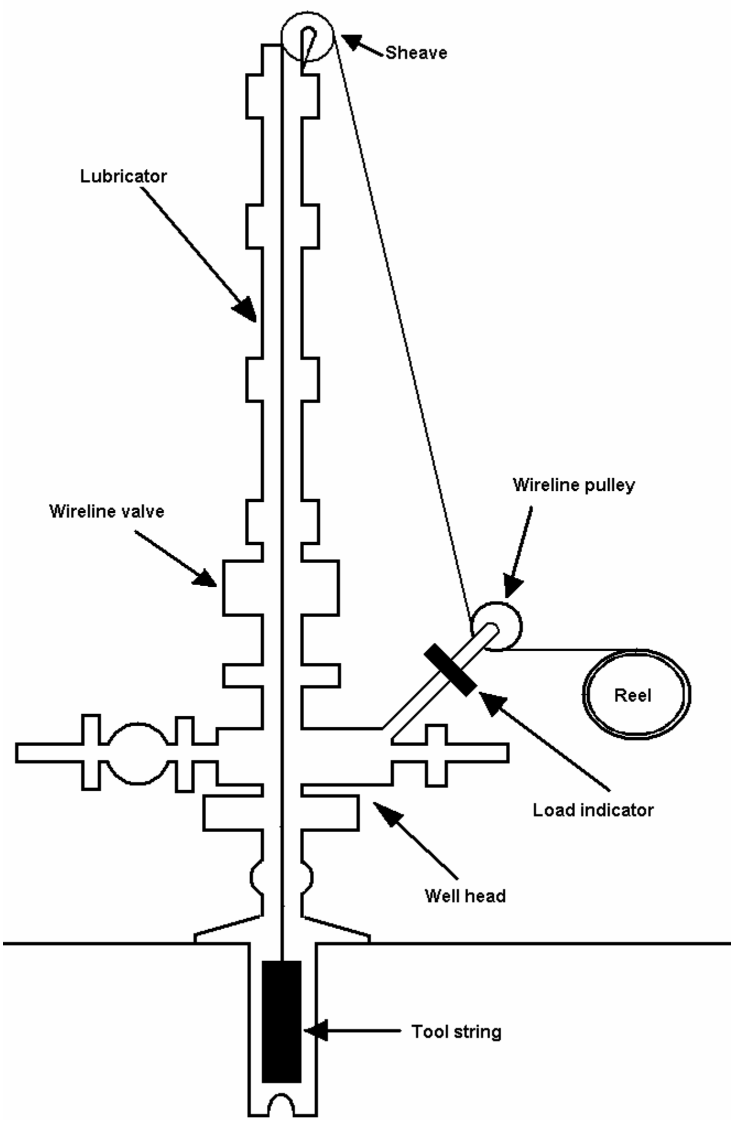

FIGURE 1 Schematic diagram of the arrangement during wireline operations.

Alloy	Min UTS (MPa)	Measured Breaking Load (lbf)			Safe Working Load (60%) (lb f)		
		0.092”	0.108”	0.125”	0.092”	0.108”	0.125”
316	1,500	1,455	1,870	2,500	873	1,122	1,500
Zeron 100	1,600	1,620	2,110	2,700	972	1,266	1,620

Table 2: Breaking loads for Zeron 100 wirelines.

3.0 Corrosion

All of the corrosion tests described below were conducted on cold worked wire tested as both U-bends and wrapped wire, as shown in Figure 2. The wire was 0.092” diameter and was bent around a 1” od bar for the u-bend samples. All testing was in accordance with EFC 17[3].

3.1 Sweet Wells

In sweet conditions, Zeron 100 showed no signs of corrosion, cracking or pitting after 7 days in a solution with 150,000 mg/l chloride and 25 bar CO_2 at 200°C. This is similar to the performance of 22% Cr duplex in sweet brines, as described by Craig[4] and it seems likely that Zeron 100 can tolerate higher CO_2 levels without any corrosion or cracking.

3.2 Sour Wells

When a sour well is shut in, the top of it will be around room temperature and there is a possibility of sulphide stress corrosion cracking (SSCC), either due to H_2S alone or stimulated by contact with carbon steel. Zeron 100 wireline was tested in the NACE TM0177 test (1 bar H_2S) for 90 days both alone and coupled to carbon steel. No corrosion or cracking occurred.

At downhole temperatures there is also a possibility of SCC, and EFC 17[3] points out that duplex stainless steels have their greatest susceptibility to stress corrosion cracking at 80° - 120°C. There are two conditions found in producing wells[3]. In the early life of gas wells, produced water may be dominated by condensed water. In this case chlorides are low and EFC 17 recommends testing with 1,000 mg/l chloride at a pH of 3.5 with H_2S. Zeron 100 was tested with 0.8 bar of H_2S with the pH at 3.5 due to the presence of 20 bar CO_2. The testing was conducted for seven days. This is a short duration compared with many tests, but wirelines are only downhole for short periods of a day or two so the test period was felt to be representative of service. No cracking or corrosion was observed on any of the test samples.

(A)

(B)

FIGURE 2 Appearance of corrosion test samples, A) U-bend, B) wire wrap

When formation water is produced, it often contains high levels of chloride, but also some bicarbonate, which increases the pH. EFC 17[3] recommends testing to simulate formation water at a pH of 4.5. Zeron 100 was tested at this pH with 120,000 mg/l chloride and 0.5 bar H_2S at 90°C. No corrosion or cracking occurred. More recently drilled, deep wells can operate at higher temperatures and the above test was repeated at 200°C. There was no corrosion or cracking of the Zeron 100.

The results of all the corrosion tests are summarised in Table 3, where it can be seen that Zeron 100 resisted corrosion and cracking in all the tests.

pH	**Temperature (°C)**	**Chloride (mg/l)**	**CO_2 (bar)**	**H_2S (bar)**	**Result**
~3.5	204	150,000	20	0	No corrosion
TM0177	24	30,000	0	1	No corrosion
TM0177 (coupled to Fe)	24	30,000	0	1	No corrosion
3.5	90	1,000	20	0.8	No corrosion
4.5	90	120,000	0.5	0.5	No corrosion
4.5	200	120,000	0.5	0.5	No corrosion

Table 3: Summary of corrosion test conditions and results for Zeron 100 wireline.

3.3 Corrosion in Storage

Some of the failures of wireline in service are attributable to corrosion that occurred in storage between uses. Although the wire passes through wipers as it is withdrawn, it is often not fully clean before it is spooled. Storage in climates where condensation may occur can result in corrosive solutions on the wire surface that may result in localised pitting or crevice corrosion. This is not too surprising with carbon steel wireline, but 316 can also suffer attack under such conditions, where the wound wire creates crevices. The corrosion sites act as stress raisers, which means that the breaking load is reduced when the wireline is next used. The greater the depth of attack, the bigger is the reduction in breaking load. The cost of retrieval of a broken wire can outweigh the cost of a more expensive material initially. Zeron 100 is much more highly alloyed than 316 and does not suffer pitting or crevice corrosion under such atmospheric storage.

4.0 Service Experience

Zeron 100 wireline has been used in some 15 to 20 wells in Asia since 2003. Table 4 shows some of the well conditions and it can be seen that these vary from sweet wells to sour wells with high H_2S contents over a range of temperatures. Zeron 100 was chosen as a replacement for 316 in some cases and as a first choice CRA in others. The performance to date has been excellent.

WELL	CO_2 (%)	H_2S (mg/l)	TEMPERATURE (°C)
1	50	100	160
2	20	500	150
3	5	0	85
4	0.56	0	99
5	0.2	500	60

Table 4: Some service conditions being experienced by Zeron 100 wirelines.

5.0 Conclusions

1. Zeron 100 wireline offers greater breaking loads than 316 and also higher corrosion resistance, both downhole and under storage.

2. Zeron 100 wireline offers a cost effective alternative to 6Mo austenitic stainless steels and nickel alloys.

3. Zeron 100 wireline has been successfully used in more than fifteen wells since 2004.

6.0 References

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