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Representing In Asia:

WEBSTER & HORSFALL LIMITED
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Wire Specialists

WIRELINES and WELL-SERVICE STRANDS

High quality wire and stand for the oil and gas industry

A range of well-servicing products in high carbon and stainless steels

Wirelines

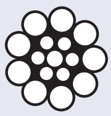
Minimum Breaking Loads

Diameter inches	Diameter mm	HT Carbon lbf	EHT Carbon lbf	316 Stainless lbf	Zeron 100® lbf
0.092	2.34	1740	1980	1350	1620
0.105	2.67	2270	2580	1760	2010
0.108	2.74	2400	2730	1900	2125
0.125	3.18	3220	3660	2500	2700

Weight per Unit

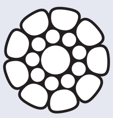
Nominal Diameter inches	Nominal Diameter mm	HT Carbon/EHT Carbon lbs per 1,000ft	316 Stainless Steel lbs per 1,000ft	Zeron 100® lbs per 1,000ft
0.092	2.34	22.71	23.08	23.1
0.105	2.67	29.56	30.05	30.0
0.108	2.74	31.11	31.62	31.8
0.125	3.18	41.93	42.62	42.6

Well Service Strands



1 x 16 (9/6/1) CONSTRUCTION

Nominal Diameter	Weight	Minimum breaking Load	
		Carbon Steel	316 Stainless
ins	lbs/1000'	lbs	lbs/1000'
3/16	71	4960	3990
7/32	96	6610	5400
1/4	126	8640	7030
5/16	196	13490	11000



1 x 19 (9/9/1) COMPACTED STRAND

Nominal Diameter	Weight	Minimum breaking Load	
		Carbon Steel	316 Stainless
ins	lbs/1000'	lbs	lbs/1000'
3/16	85	6170	4940
7/32	110	8370	6500
1/4	148	11200	8640
5/16	230	17550	13560

WEBSTER & HORSFALL LTD ***ARE THE ORIGINATOR OF LEAD PATENTED WIRE.***

INSTITUTE of SPRING TECHNOLOGY MEMBER

LLOYD'S REGISTER QUALITY ASSURANCE ISO9002

ZERON 100®

www.weirclearliquid.com

WH ZERON® 100 SDSS(UNS32760) SLICKLINE DATA SHEET

High quality wire and strand for the oil and gas industry

Zeron 100 is a Super Duplex stainless steel available in all wire diameters that has high mechanical properties whilst retaining good ductility. The alloy has excellent resistance to stress corrosion cracking, pitting corrosion and crevice corrosion, making it suitable for use in sulphide, chloride and acid environments. Due to its high strength and microstructure, Zeron 100 also exhibits excellent resistance to abrasion and high resistance to fatigue and corrosion fatigue. Zeron 100 has a low coefficient of thermal expansion.

Further information on any of these properties, or advice on the use of Zeron 100 is available on request.

Chemical Analysis

	C	Si	Mn	S	P	Cr	Ni	Mo	Cu	N	W	Fe
Min						24	6.0	3.0	0.5	0.2	0.5	Bal
Max	0.03	1.0	1.0	0.03	0.03	26	8.0	4.0	1.0	0.3	1.0	

PREN = Cr% + 3.3 Mo% + 16 N% = 40 min

PRENW = Cr% + 3.3 (Mo% + 0.5 x %W) + 16 x %N = 42.15 min

Mechanical Properties

Wirelines Diameter	0.092"	0.108"	0.125"
Breaking Load (lbf)	1620 (min)	2125 (min)	2700 (min)
UTS (MPa)	1675 (min)	1595 (min)	1510 (min)
0.2% PS (% of TS)	82-90	75-90	75-90
Elastic Limit (% of TS)	40-50	40-50	30-60
Elongation on 100mm GL (%)	2-3	2-4	2-4
Torsion on 8"GL (typical)	6	5	4
Minimum Bend Diameter	120 x d	120 x d	120 x d

Physical Properties

Density (g/cm^3)		7.84
Mean Coefficient of Thermal Expansion (10^{-6} K^{-1})	20 - 200°C	12.8
	20 - 300°C	13.3
	20 - 300°C	13.8
Modulus of Elasticity (GPa) (+/- 10%)	20°C	155
Thermal Conductivity (Wm^{-1} K^{-1})	20°C	12.9
	100°C	14.4
	150°C	15.4
	200°C	16.3
	250°C	17.3
	300°C	18.2

Magnetic Permeability		29
Specific Heat (J kg^{-1} K^{-1})	20°C	482
	100°C	500
	150°C	513
	200°C	523
	250°C	535
	300°C	547
Resistivity (10^{-6} ohm.m)	20°C	0.851
	100°C	0.897
	150°C	0.927
	200°C	0.956
	250°C	0.985
	300°C	1.014
Poisson's Ratio		0.32

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Wire Specialists

- High quality wirelines for the oil & gas industry
- Manufactured to API 9A. Supplied weld free in continuous length on reels
- Good ductility
- Other diameters and wire grades can be supplied upon request
- Diameter tolerance: +/– 0.001 inch (0.0254mm)

Standards

* HT Carbon Steel
* EHT Carbon Steel
* 316 Stainless Steel
* Zeron 100® Super Duplex Stainless Steel

Minimum Breaking Loads

Diameter inches	Diameter mm	HT Carbon lbf	EHT Carbon lbf	316 Stainless lbf	Zeron 100® lbf
0.092	2.34	1740	1980	1350	1620
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A COMPARISON OF ZERON 100® AND 6% Mo TYPE AUSTENITIC STAINLESS STEEL WIRELINES.

Zeron 100 is a superduplex stainless steel with a 50/50 austenite/ferrite microstructure, while 6%Mo alloys are fully austenitic. The nominal compositions of the alloys are shown below.

ALLOY	NOMINAL COMPOSITION (WT%)							PREN*	PRENW+
	Fe	Cr	Ni	Mo	N	Cu	W		
6% Mo	Bal	20	18-25	6	0.2	0.7	-	43	43
Zeron 100®	Bal	25	7	3.5	0.25	0.7	0.7	>40	>42

Bal = balance, *PREN = % Cr + 3.3 x % Mo + 16 x % N, +PRENW = % Cr + 3.3 x (W+Mo) + 16 x %N

- The Pitting Resistance Equivalent number, or PREN, is an empirical relationship that has been shown to be related to the resistance to localised corrosion in chloride-containing solutions. The higher the PREN the greater the resistance to localised attack.

- The PRENW equation includes tungsten, which plays a similar role to molybdenum in preventing localised attack by chlorides, increasing the performance of Zeron 100.

- Microstructure is as important as PREN. In aerated seawater a duplex alloy needs a PREN >40 to resist crevice corrosion while a 6% Mo alloy needs a PREN >43. (Kovach and Redmond, Paper 267, Corrosion '93, NACE International).

- Zeron 100 wireline will resist sulphide SCC up to at least 0.5bar H_2S under normal conditions, at all chloride concentrations.

- 6% Mo alloys will resist high levels of H_2S ONLY if the chloride <5,000mg/l.

- At normal chloride levels (50,000 to 150,000mg/l) 6% Mo is, at best, only equal in corrosion resistance to Zeron 100 in sour brines.

- 6% Mo alloys contain more nickel and molybdenum than Zeron 100 and, hence, will be more expensive.

- Zeron 100 has a higher breaking strain than 6% Mo alloys because of its duplex microstructure.

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TECH4823.doc, July 2006.

ZERON

Weir Materials & Foundries
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Number 33381
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Date 18 August 2005 **From** ROGER FRANCIS

Attention of VINCENT LOY **Copies to** G WARBURTON, C FARR

Subject: COMPARISON OF 6Mo AND ZERON® 100 WIRELINES

There are a number of 6% molybdenum alloys that are currently used for wirelines by the Oil and Gas industry. Over the last year or two companies have been changing to Zeron 100 superduplex stainless steel for number of reasons. The nominal composition of the alloys is shown below:

ALLOY	Nominal Composition (wt%)							PREN*
	Fe	Cr	Ni	Mo	N	Cu	W	
Supa 75®	Bal	20	18	6	0.2	0.7	-	43
Sanicro 26Mo®	Bal	20	25	6	0.2	-	-	43
GD31Mo®	Bal	20	25	6	0.2	-	-	43
ZERON 100®	Bal	25	7	3.5	0.25	0.7	0.7	>41

Bal = balance **PRENW = %Cr + 3.3 (%Mo + 0.5 x %W) + 16 x %N*

The Pitting Resistance Equivalent Number, or PREN, is an empirical relationship that has been shown to be related to the resistance to localised corrosion in chloride-containing solutions. The higher the PREN the greater the resistance to localised attack. The 6%Mo alloys have a PREN of 43, while that of Zeron 100 is > 41. This does not mean that the 6%Mo allolys are more resistant to corrosion. It has been demonstrated by several workers that the resistance to localised corrosion of stainless steels depends on the microstructure as well as the composition. Thus, you need a higher PREN in an austenitic alloy to get the same corrosion resistance as a duplex alloy. For instance, in seawater you need a minimum PREN of 40 in a duplex stainless steel to resist crevice corrosion, but with an austenitic stainless steel you need a minimum PREN of 43.

Because the 6%Mo alloys contain 18% or 25% nickel (compared with 7% for Zeron 100) it will be more expensive than Zeron 100, as there is a big surcharge on nickel at the moment. The austenitic alloys also contain more molybdenum than Zeron 100, which also has a high metal surcharge, further increasing the price differential.

The 6%Mo alloys are all austenitic in structure, while Zeron 100 is a superduplex with a norminal 50/50 austenite/ferrite ration. The superduplex microstructure is inherently stronger than the austentenitic one. This means that the austenitic alloys require more cold work to reach the same strength as Zeron 100. This effectively means that Zeron 100 has a higher breaking strain than the austenitic alloys.

In sour service, downhole, the corrosion performance of Zeron 100 and 6%Mo alloys are similar. The 6%Mo alloys are slightly better at temperatures below 100°C, while Zeron 100 is better at temperatures above 100°C. Test data currently available shows resistance of Zeron 100 to sulphide stress corrosion cracking at temperatures up to 200°C with 0.5bar H_2S.

Overall, the advantages with Zeron 100 are lower cost, higher breaking strain and similar or better corrosion resistance, compared with the 6%Mo alloys.

ROGER FRANCIS
Corrosion Services Manager

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Date	10 May 2005	**From**	ROGER FRANCIS
Attention of	GEOFF WARBURTON	**Copies to**	VINCENT LOY

Requires ☐ Immediate attention ☐ 1-3 day turnaround ☐ Information only ☐ Follow up by:

Subject: THE LIMITS OF USE OF ZERON® 100 WIRELINES.

GEOFF WARBURTON

Based upon the data available to date, we can recommend the following limits of use for Zeron 100 wireline (Tensile strength up to 1,750 MPa).

a) Sweet Wells

With wells containing only CO_2, Zeron 100 will resist both general and localised corrosion at CO_2 pressures up to 100 bar and at tempereature up to 200°C. Corrosion is unaffected by chloride concentration.

a) Sour Wells

There are two main conditions found in sour oil wells. The first is where there is no produced water. Conditions are then, a pH of ~3.5 and chlorides up to 1,000mg/l. Under these conditions Zeron 100 will resist sulphide stress corrosion cracking (SSCC) up to 1 bar of H_2S. Where there is produced water, the pH is usually 4.5 or greater and the cracking susceptibility depends on the chloride content. Currently, Zeron 100 will resist SSCC up to 0.5 bar H_2S with 120,000mg/l chloride.

Further tests are under way and these limits of use may be increased in the next few months.

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REPORT

The use of Zeron® 100 Superduplex Stainless Steel for Oilfield Wirelines

Prepared by: Roger Francis
Corrosion Services Manager

Approved by: Stan Hebdon
Technical Manager

CIRCULATION

Division	Engineering
Job No.	
Reference No.	OC 14992 to 14997
Report No:	TN1482
Iss No.	0
Date:	Dec 2005

THE USE OF ZERON® 100 SUPERDUPLEX STAINLESS STEEL FOR OILFIELD WIRELINES.

TABLE OF CONTENTS

FIGURES

SUMMARY

The report describes the use of cold-drawn Zeron 100 wire for oilfield wirelines. The mechanical properties of Zeron 100 are superior to those of austenitic alloys such as 316, giving a higher breaking load. Corrosion tests in both sweet and sour conditions over a range of temperatures and pH values show the high resistance of Zeron 100 to corrosion, pitting and cracking in aggressive oilfield environments. Zeron 100 offers a cost effective alternative to 6Mo austenitic stainless steels and nickel-base alloys.

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 the temperature and pressure. 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. 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 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.

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.

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.

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. 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.

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.

REFERENCES

1. R. Francis and G. Byrne, Paper 64, Corrosion ’94.
Baltimore, MD, USA, March 1994, NACE International.

2. C. W. Kovach and J. D. Redmond, Paper 267, Corrosion ’93. New Orleans, LA, USA. March 1993, NACE International.

3. EFC Publication No. 17, “Corrosion Resistant Alloys for Oil and Gas Production: Guidance on General Requirements and Test Methods for H_2S Service”, Institute of Metals, 2nd Edition, 2002.

4. B. D. Craig, " Selection Guidelines for Corrosion Resistant Alloys in the Oil and Gas Industry", NiDI publication No. 10073, 2nd Edition, 2000.

Table 1: The nominal composition of some common wireline alloys.

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

Bal = balance
PREN = % Cr + 3.3 x % Mo + 16 x %N.

Table 2: Breaking loads for Zeron 100 wirelines.

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

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

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

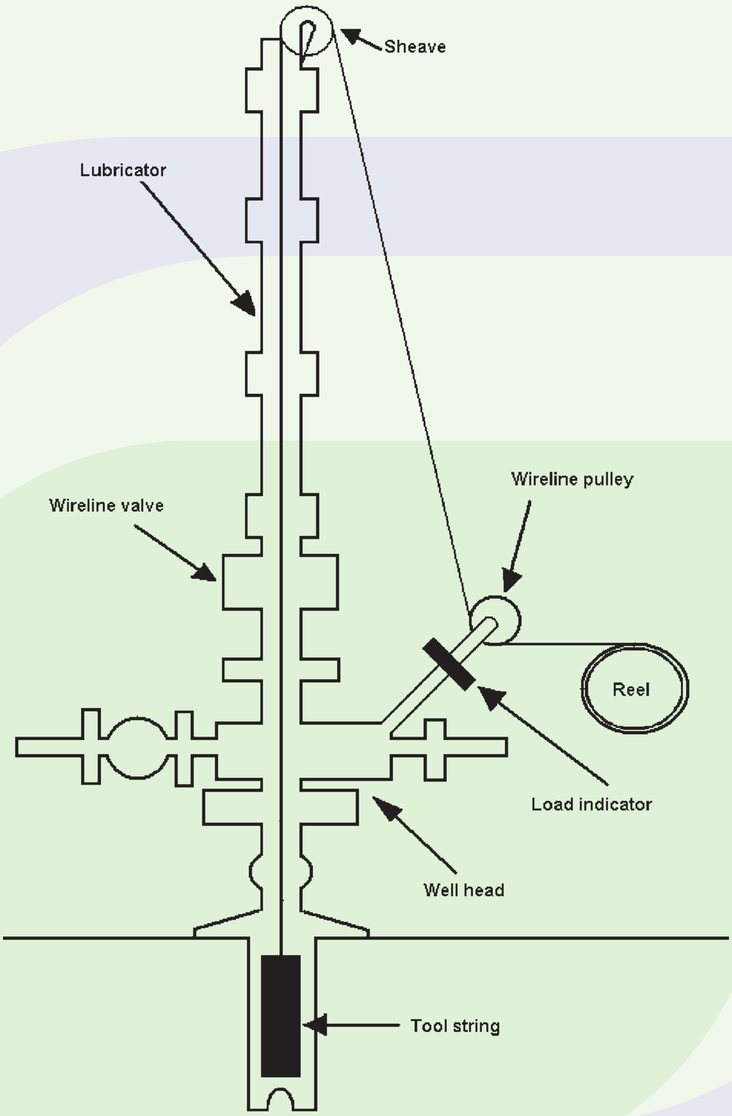
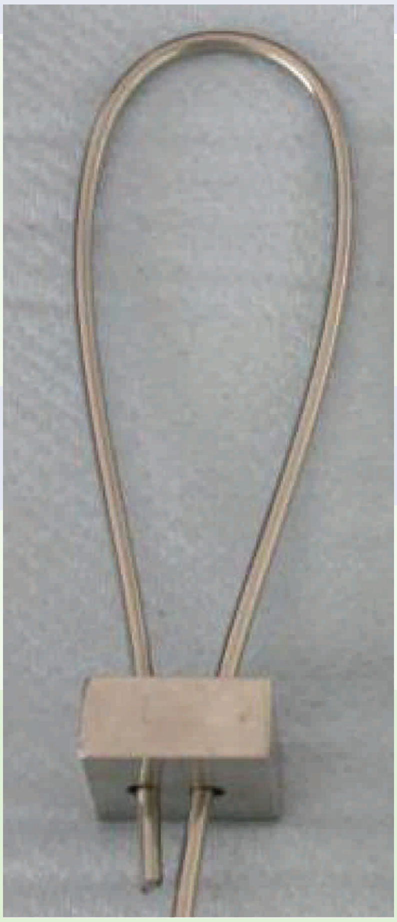


FIGURE 1 Schematic diagram of the arrangement during wireline operations.



(A)

(B)

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