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PERFORMANCE OF (UNS 8028) PRODUCTION TUBING MATERIAL IN SOUR SERVICE ENVIRONMENT OF KHUFF GAS FORMATION

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ABSTRACT

Khuff gas formation is one of the largest reservoirs of non-associated gas in the world. Recent developments in exploration and production from Khuff gas formation at the Qatar North Field required materials of construction with long periods of production without work over and chemical inhibition.

Gas produced contains corrosive constituents such as 1% H_2S, 4% CO_2 and brine at pressures exceeding 300 barg (CITHP).
For operational reasons, two of the 16 wells drilled were needed to work over after 2 years of service and showed evidence of crevice pitting corrosion and thread galling on the Corrosion Resistance Alloy (CRA) tubing material. Full inspection and analysis of the problem are addressed in this paper.

INTRODUCTION

The North Gas Field in Qatar is considered to be the largest single non-associated gas reservoir in the world; its proven reserves exceeds 300 trillion cubic feet (tcf) and its total reserves are put at 500 tcf. It covers an area of more than 6,000 square kilometers which is nearly half the size of the State of Qatar land area.
In view of the massive reserves of the North Field and the merits of natural gas as clean, safe and reliable source of energy, QGPC has initiated a programme for strategic development and utilization of the North Field. The first stage of this plan aims at the production of gas for local consumption and its onshore industry. QGPC completed the first stage of the North Field Development project in 1991. This stage produces 800 million cubic feet per day of gas for domestic and industrial use in addition to up to 40,000 bpd of condensates and natural gas liquids for export.

The design life of the offshore production complex is 50 years. 16 deviated wells were drilled. The wells were spudded in early 1988 and were fully completed by mid 1990. The wells are in Khuff K-4 Formation (Figure 1) with reservoir depth of up to 11,000 feet and pressure up to 5,200 psi (350 Barg). The produced fluid consists of gas and condensate (see Appendix 1).

DESIGN CRITERIA

The economics of using CRA production tubing material is easily demonstrated for deep sour gas wells where the conventional corrosion control methods are extremely expensive or not workable at all considering factors as the H_2S, CO_2 and PH levels, minimum workover and maintenance of the ultimate production rate all the time.

The traditional carbon steel tubing is protected either by coating or inhibitors which are not adequate. Since the early 1970's the high Ni austenitic stainless steel alloy OCTG are used (Table 1). They are usually strengthened by cold working and their high corrosion resistance against general corrosion, localized corrosion and SCC is due to the surface passivation film produced as corrosion products. Therefore, it is necessary to have stable austenitic single phase composed from high content of Cr, Ni Mo in sour service environment when using CRA Cr $\geq$ 18%, Ni $\geq$ 28% and Mo $\geq$ 3%. are required to prevent SCC at 150°C at least[1]. In 1987 the selection of material as the UNS 8028 for the North field were the ultimate technology. All tubulars and accessories connections featured high quality gas tight construction coupled with premium connection characteristics and they met the additional requirements which were:

- 100% minimum tensile strength efficiency.
- metal to metal seal on low angle taper mechanically energized by torque shoulder.
- anti galling surface treatment with pin threads blasted and box threads (coupling) copper plated.
- optimized stress distribution and jump out resistance design.

The design mechanical and chemical properties were to be in accordance to ASTM B 668 (Tables 2 and 3).

WORK OVER ACTIVITIES AND FIELD INSPECTION

Although the selection of CRA tubing material was supported by minimizing the workover to the completed wells, two gas wells were subjected to workover activity caused by leaking control lines of the sub surface control valve (SSCV). Retrieval of the existing completion was carefully carried out following the agreed drilling sequence procedure the tubing to be pulled out on a standard basis consisted of 3 joints of 37 feet each. Rig elevators and power tongs to 5 1/2" tubing were used and as recommended by the manufacturer stabbing guide, drift mandrel, thread protectors and the make-up monitoring systems were carefully utilised. Once the connection was broken, a brief inspection of the seal and threads of both pin and box (coupling) was conducted. Fresh solvent and clean rags were used to clean the connection and particular attention were paid to the seals for evidence of defects threads, galling or tearing. The outside surface of the tubing were inspected for damage caused by the power tong or back up tong dies and any foreign material in the threads. Any questionable connection or tube were laid down for through inspection. The manufacturer inspection guideline criteria for visual thread inspection and repair was adhered to (Figure 2).

INSPECTION ACTIVITIES

Good general appearance was evident on the CRA tubing. No sign of general corrosion was noticed on the tubing. All pin threads were broken within the manufacturer recommended torque. Torque - Turn graph (Figure 3A/B). The chemical cutting fluid (Bromine triflouride) was used, severe external attack by this chemical to the tubing were reported to the cut section and pinhole two feet above the cutting area were also observed.

The 1st well inspection data (Table 4). Generally the threads were even, clean and undisturbed. Two (2) galling and tearing cases on the 5 1/2" tubing were reported (Figure 4). The coupling connection generally had a sound copper plating with one (1) case of disbonding.
The power tongs used had created permanent marks on the outside surface of the tubing. This can be considered as stress raisers and initiator of surface corrosion. Wireline scouring or abrasion to the internal surface of the tubing were reported and measured 0.7 mm $\approx$ 10% wall thickness of the tubing.

The 2nd well inspection (Table 4) data, the threads' condition can be divided into two (2) parts; above the SSCV valve and below. Five (5) joints above the SSCV valve indicated severe localized attack by crevice pitting corrosion at the main seal and the internal shoulder seal (Figure 5).
All the joints inspected below the SSCV valve showed even, clean and undisturbed pin and coupling threads condition.

LABORATORY FAILURE INVESTIGATION

The tube joint attacked by the crevice pitting corrosion were removed and were subjected to detailed failure investigation analysis.

Visual Inspection:

Evidence of crevice pitting corrosion was observed at the tangent point main seal and the internal shoulder seal were found to have widely spread deep pitting (2 - 5 mm) to the ream of the tubing (Figure 2). No longitudinal or transverse cuts were noticed, threads have been found to be free from burns, tear, cuts or rust. On coupling side corresponding massive crevice corrosion attack was observed at same locations.
The copper plating on the threads was found to be free from any apparent damage except at the attacked area.

Tensile Testing:

Sub scale round tensile samples were machined from the joint, four samples from each of the tubing and the coupling.
The locations are shown schematically in (Figure 6A). All samples were taken in longitudinal direction and the results are shown (Table 2). The testing revealed that the mechanical properties of the joint material and coupling are meeting the specific requirement of corrosion resistance alloy CRA type (UNS 8028) in cold worked condition.

Hardness Testing:

Two samples from each tubing and coupling were evaluated (Figure 6B). Rockwell testers were used for the survey.
The average values are given (Table 2). The hardness values were within the specific requirement and did not exceed maximum level of 31 Rc.

Chemical Analysis:

Full chemical tests of the tubing material were done to confirm adherence to the manufacturing specification (Table 3).
The materials are within the required chemical analysis of the standard (ASTM B-668-84).

Metallographic Examination:

Different samples of the tubing and coupling were metallographically examined (Figure 6C). The microstructures revealed typical cold worked austenitic stainless steel with deformed grain structure (Figure 7). Thin and uniformed copper plating averaging $\approx$ 20 - 30 μm in thickness, however 10 μm were observed at the internal portion of the threads.

Pitting and Crevice Corrosion Laboratory Test:

The most common laboratory test for determination of crevice corrosion are probably the chemical method, 6% $FeCl_3$ test according to ASTM G-48[2]. As crevice corrosion is the most critical type of corrosion in sea water and brine, for piping system from austenitic stainless steel and duplex material[3]. The test revealed the tendency of the UNS 8028 tubing material to be affected by crevice pitting corrosion (Figure 8). A density of 0.05 pits/m^2, average pitting opening of 2.0 mm^2 and an average pit depth of 1.6 mm were measured as per ASTM G-46[4].

DISCUSSION

Investigations confirmed that the UNS 8028 tubing material adhered to the specified mechanical and chemical property. Although the general overall corrosion resistance were excellent, it shows poor resistance against crevice pitting corrosion. Wireline marks were evident in most of the CRA tubing along its length. This marks increased in severity with the increase in the drilling angle of the deviated wells. It's worth to mention that even the manufacturer make-up and break out of the connection threads were controlled by computerised monitoring system. The metal to metal seal area suffered the wedge effect (Figure 9) this can lower the seal integrity at very critical location of tube connection and represent very suitable location and environment for the crevice pitting corrosion attack. Improvement in this area can be beneficial for the future performance of the CRA tubing material.

CONCLUSIONS

1. The UNS 8028 revealed adequate general corrosion resistance under sour gas environment.

2. The UNS 8028 tubing material showed crevice corrosion under stagnant wet sour gas condition.

3. Chemical cutting method showed high efficiency. However excess chemical can harm the surrounding tubing and casing components.

4. Wireline operation can cause permanent and dangerous defects to the production tubing.

ACKNOWLEDGMENTS

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REFERENCES

1. A. Ikeda, T. Kudo, Y. Okada, S. Mukai and F. Terasaki; Corrosion 84 No. 206 NACE

2. ASTM-G-48-94 "Pitting and Crevice Corrosion Resistance of Stainless Steels and Related Alloys by Use of Ferric Chloride Solution".

3. M. Jasner Krupp VDM GMbH "Crevice Corrosion Behavior of High - Alloyed Austenitic Steels and Nickel - Base Alloys in Sea water".

4. ASTEM - G - 46-94 "Examination and Evaluation of Pitting Corrosion".

TABLE 1 CRA OCTG ALLOYS IN THE WORLD

	UNS	ALLOY	CHEMICAL COMPOSITION	MANUFACTURER
CW	N 08028	Sanicro 28	28 Cr - 32 Ni - 3 Mo - 1 Cu	Sandvik
	N 08825	Incoloy 825	21 Cr - 42 Ni - 3 Mo - Cu, Ti	INCO
	N 06625	Inconel 625	22Cr - 60 Ni - 9 Mo - 3.5 Nb	INCO
	N 06985	Hastelloy - G - 3	20 Cr - 45 Ni - 7 Mo - Cu, Nb	CABOT
	N 10276	Hastelloy - C - 276	16 Cr - 58 Ni - 16 Mo - 3.5 W	CABOT
	N 06975	SM 2550	24 Cr - 30 Ni - 6 Mo - Cu	SUMITOMO
PH	N 09925	Incoloy 925	21 Cr - 42 Ni - 3 Mo - Al, Ti	INCO
	N 07718	Inconel 718	18 Cr - 52 Ni - 3 Mo - 5 Nb, Ti	
		SM - PH 3	23 Cr - 52 Ni - 4 Mo - 5 Nb	SUMITOMO
		SM - PH 6	15 Cr - 58 Ni - 13 Mo - W	

CW: - Cold Worked PH - Precipitation Hardened

TABLE 2 MECHANICAL PROPERTIES OF THE CRA MATERIAL

	ULTIMATE TENSILE STRENGTH	YIELD STRENGTH	ELONGATION	HARDNESS Rc MAX
Design	115 ksi	110 ksi - 130 ksi	11 %	31
Laboratory Tubing	129 ksi	121 ksi	27 %	29
Coupling	128 ksi	121 ksi	25 %	28.5

TABLE 3 CHEMICAL ANALYSIS OF THE CRA MATERIAL

	Ni	Cr	Mo	C max.	S max.	P	Cu	Fe	Si max.	Mn max.
Design	30 - 34	26 - 28	3 - 4	0.03	0.03	0.03	0.6 - 1.4	36 bal.	1.0	2.5
Laboratory Chemical Analysis	30.2	26.1	4.0	0.02	0.005	0.02	1.25	37.5	0.48	0.34

TABLE 4 DATA LOG OF INSPECTION AND WORK OVER ACTIVITIES

TUBE SIZE	NO. OF STANDS	NO. OF JOINTS	NO. OF DEFECTIVE JOINTS	NO. OF COUPLING	NO. OF DEFECTIVE COUPLING
Well No. 1 5 1/2"	76	230	2	230	0
5"	16	49	1	50	1
Well No. 2 5 1/2"	77	233	5	235	6
5"	14	43	0	44	0

Appendix. 1

Typical Gas and Condensate Compostion of Produced Fluid.

Component	Mol %
H_2S	0.85
CO_2	2.5
N	3.5
C_1	85.0
C_2	5.0
C_3	2.0
C_4	0.50
C_5	0.60
C_6	0.25
C_7	0.20
C_8	0.20
C_9	0.10

Dissolved Solids on the Produced water, Mg/l:

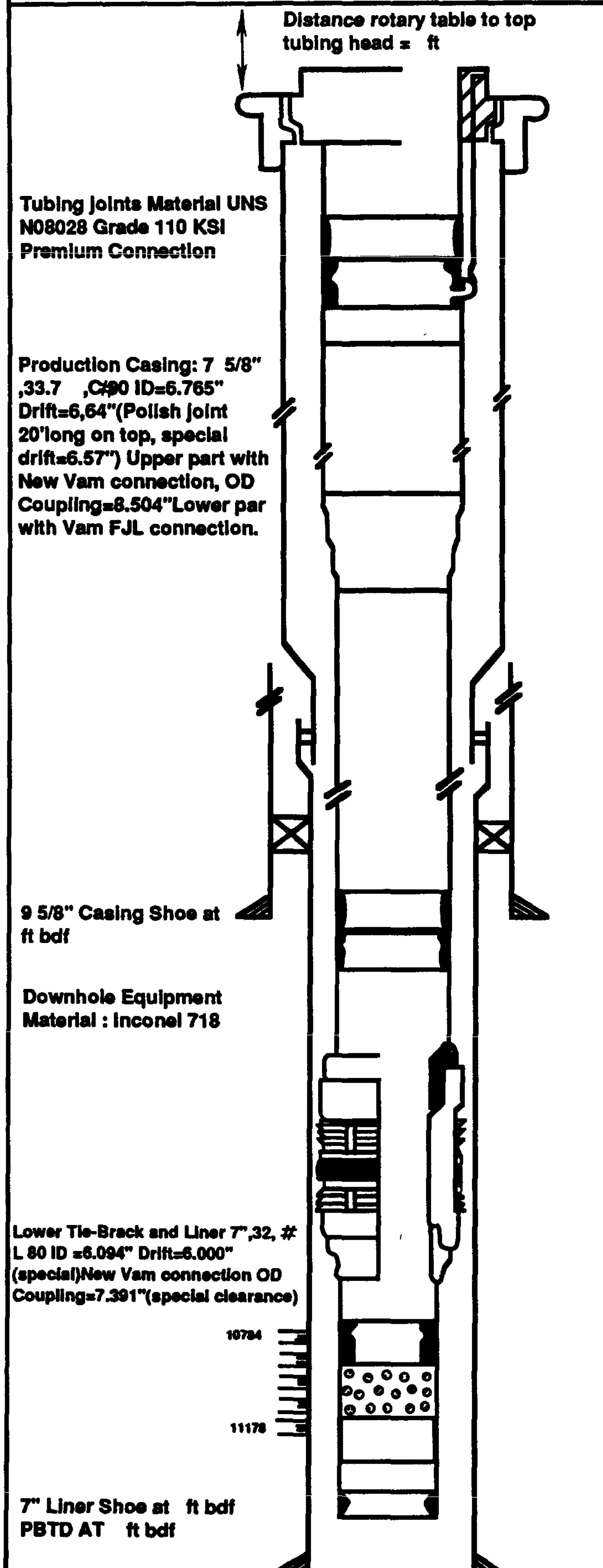
Na^+ : 73	Fe : 0.3
Ca^{2+} : 28	CL^- : 100
Mg^{2+} : 6	So_4^{2-} : 3

Physical Properties:

PH @ 23 °C :	3.5 - 4
Specific gravity:	Gas: 0.667

Fig.1

NORTH FIELD STANDARD COMPLETION



Item Description	ID"	OD"	DEPTHS (FT)
Tubing Hanger 5 1/2"	4.9	11	
Tubing 5 1/2"	4.892	5.500	
Flow Coupling 5 1/2"	4.892	6.050	
'BA' Nipple 5 1/2" x 4.56"	4.562	6.39	
Flow Coupling 5 1/2"	4.892	6.050	
Tubing 5 1/2", 17# Drift=4.767" OD Coupling =6.051	4.892	5.00	
X -Over 5 1/2" x 5"	4.408	5.500	
Tubing 5" , 15 # Drift = 4.283" OD Coupling = 5.563"	4.408	5.00	
Flow Coupling 5"	4.408	5.56	
'AOF Nipple 5" x 4.125"	4.125	5.62	
Tubing 5" + Pup joint (5ft)	4.408	5.00	
Anchor seal N22s w/met.seal 2 seal stacks,81FA48,OD: 5.5"	3.875	4.86	
Permanent Packer 7" Hydraulic Set Size 85 SABL-3 48 x 38 w/extended upper bore & 4 1/2" pin bottom guide	3.875	5.875	
Pup joint 4 1/2",13.5# (20 ft)	3.920	4.500	
'AOF' Nipple 4 1/2"x3.68"	3.688	5.25	
Perforated joint 4 1/2"(10ft) Drift:3.795", ODc:4.961	3.920	4.500	
'R' Nipple 4 1/2" x 3.688"	3.620	4.96	
Pump joint 4 1/2",x13.5# (20ft)	3.920	4.500	
WL Entry Guid 4 1/2"	3.750	4.96	
K4 perforations	TOP AT ft bdf Entry guide 80 ft Min. Bot. at ft bdf above top of perforations		

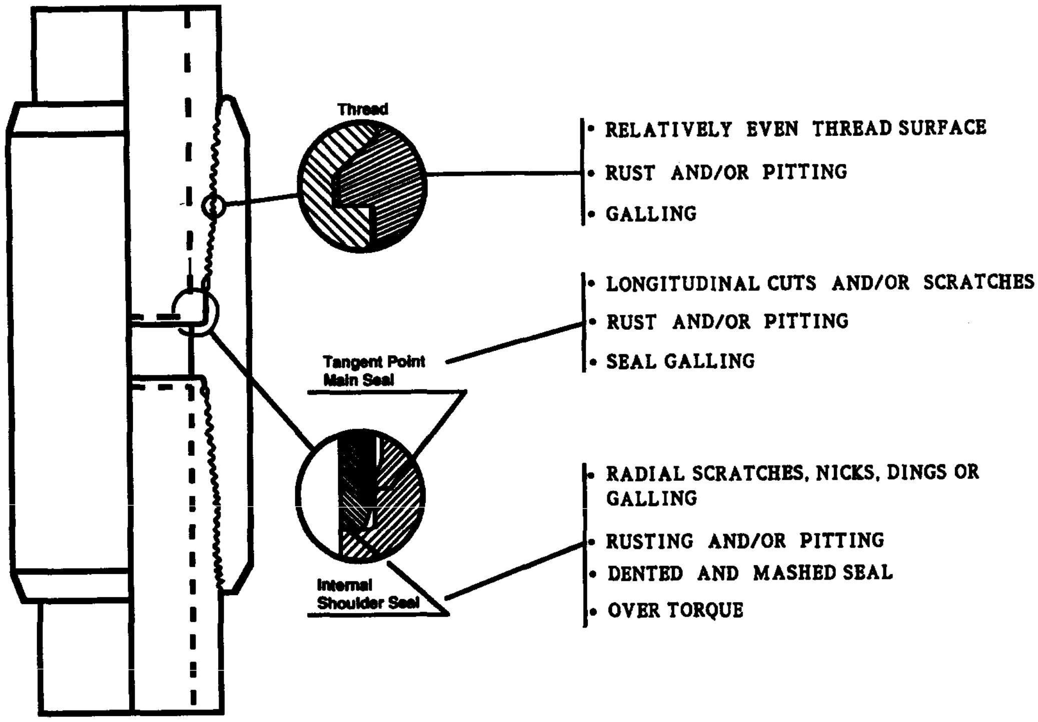


Fig.2 INSPECTION GUIDELINES

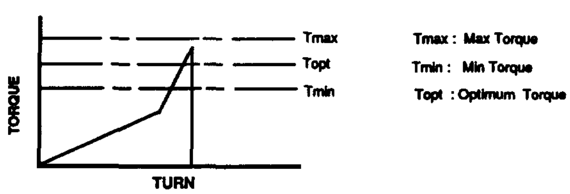


Fig.3A Typical acceptable Makeup Torque Curve

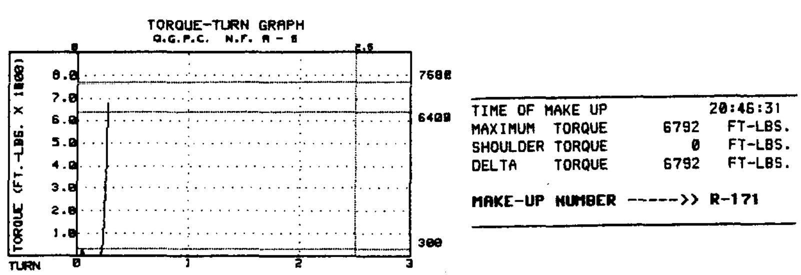


Fig.3B Field Make-up Monitoring System (Torque - Turn Graph).

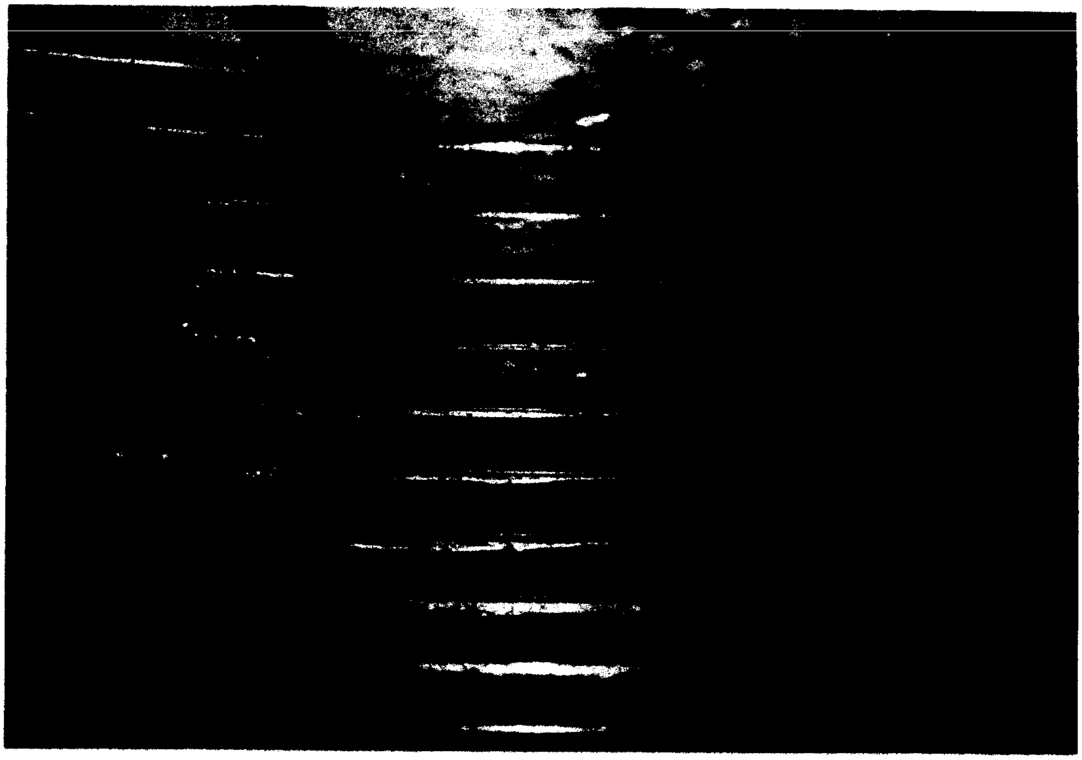


Figure 4 - Evidence of permanent galling to the thread connection of the tubing

Figure 5 - Severe attack by crevice pitting corrosion at the tubing seal area

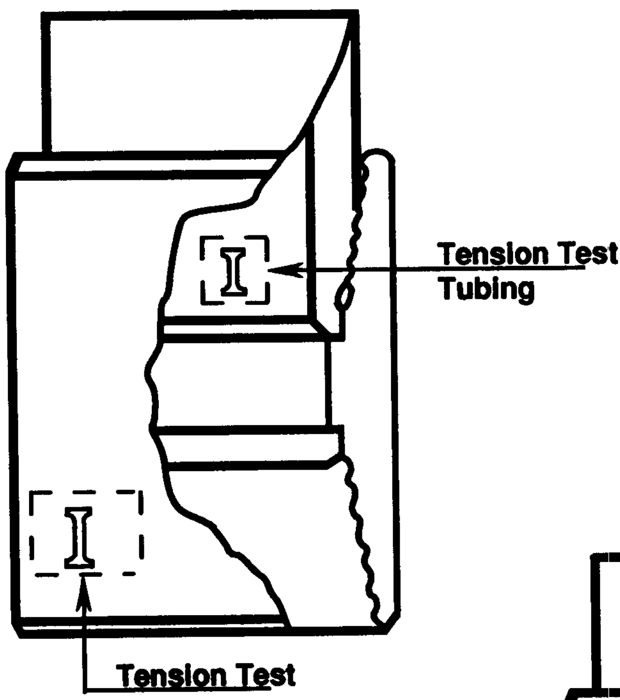


Fig. 6A Location fo tensile samples of the Tubing and Coupling

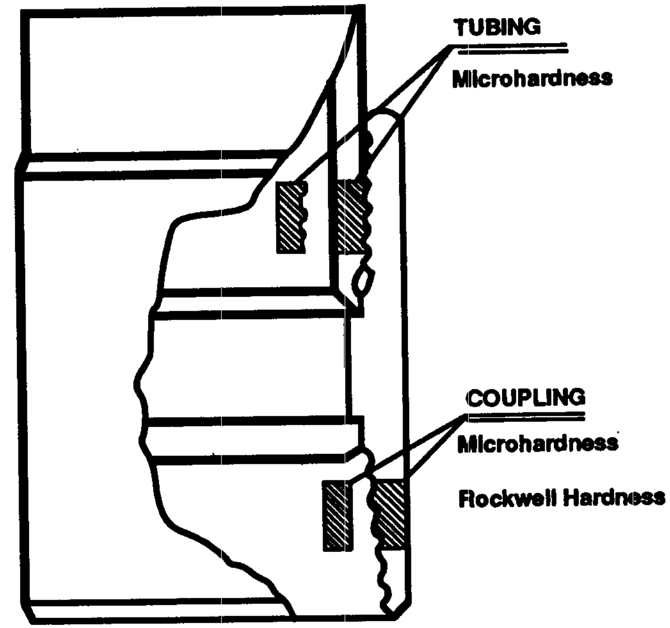


Fig.6B Location Of hardness samples

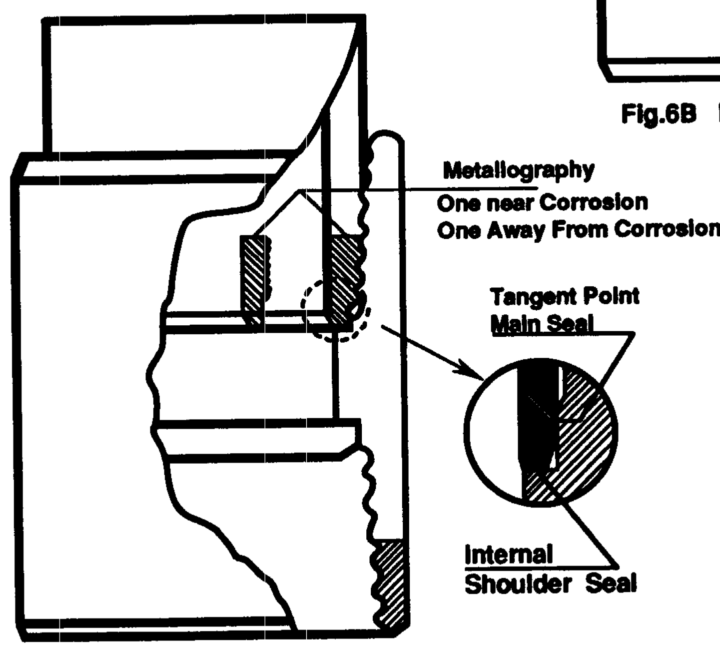


Fig.6C Location of metallographic samples

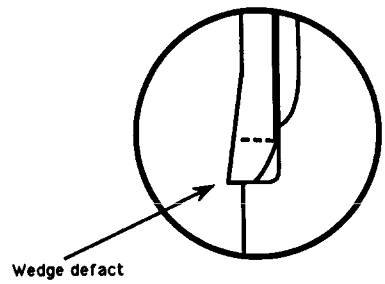


Fig.9 Schem of Wedge problem on Metal to Metal Seal System

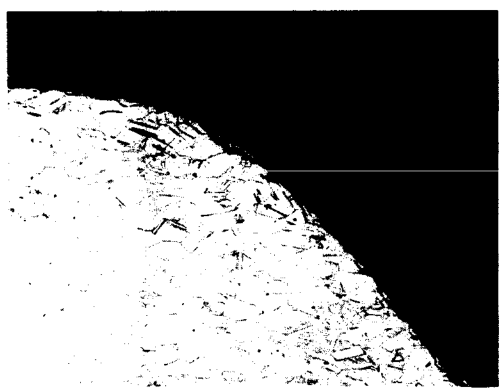


Figure 7 - Grains & micro structure of the alloy material & non-uniform copper plating spot at the thread area (100 x)

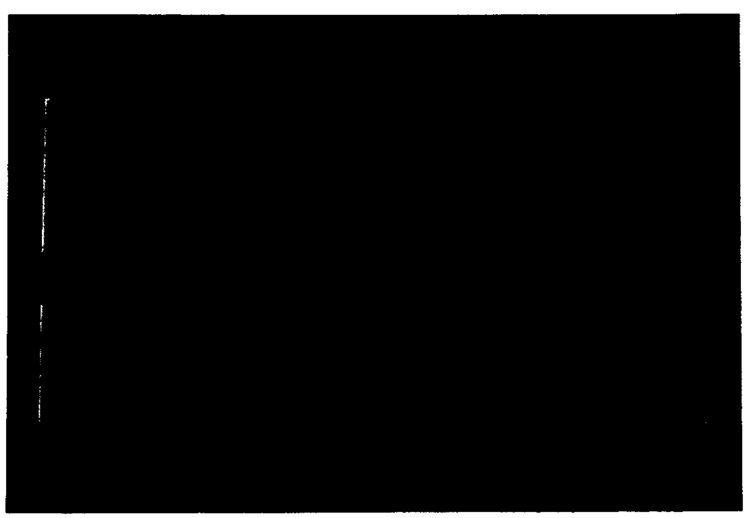


Figure 8 - Effect of crevice pitting corrosion on sample of UNS8028 alloy material under the laboratory test environment.