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The possibility of using the 2024 aluminum alloy drill pipe that was Processed Superficially to reduce failure During dynamic loading

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1. Introduction

This paper outlines practically critical loads which affecting steel drill pipe while drilling deep wells as a result of frequent practices of drilling operations and down hole conditions . For this reason a practical ways of eliminating this trouble are explained in this paper, or at least reducing this problems. Since a better understanding of the stress distribution along the steel drill string will certainly lead to more optimized drill string designs.In this spect, one solution is the use of drill pipes made of alternative lighter materials instead of the conventional steel drill pipes. This study is therefore aimed to check whether by using a new material selection which is superficially treated 2024 aluminum alloy this problems can be faced.

2. Approach

The present study is structured as follows; Firstly general outcomes are given about manufacturing process of superficially treated 2024 aluminum alloy by plasma electrolytic oxidation (PEO) technology, followed by a summary about 0.2159 m hole diameter section. Tracked by a bottom hole string dynamic analysis for identifying the uniform stress loads distributions in steel drill string during drilling operation, by using Decision Space Well Engineering Software. This will be compared to stress loads by integrating aluminum drill pipe with steel drill string under operating conditions of this section and identifying the resulting stresses. This will be completed by evaluation of real data sets to explore the validity of the hypothesis of integrating superficially treated 2024 aluminum alloy in giving an optimum solution to the problem. Finally, a close examination of the results is done to produce coherent conclusion

2.1 Superficially treated 2024 aluminum alloy Technology

Test Tube Sections	Ultimate tensile strength σr [MPa]	Proof stress σ0,2 in [MPa]	Elasticity limit σpr [MPa]	Relative extension to rupture δ en %	elastic range slope α [°]	Young's modulus E [MPa]
2X30	Before superficial treatment (OMA)					
	491	381.6	359.8	12.2	80.5	71805
	After superficial treatment (OMA)					
	467.5	359.5	337.0	13.4	80.8	88763

The micro arc oxidation method is an electrochemical surface treatment as an anodisation method where a very high voltage is used which permitted to produce electric discharges. The component is immersed in an electrolytic acid and an electric potential of 200V is applied which lead to form an oxide coating. Therefore sparks produce agglomerates, and make the oxide dense and partially convert it to an amorphous alumina in crystal form such as corindon. Consequently, the mechanical properties such as the toughness increase.

Table 1: Results of tests to traction (micro-tests) of test-tubes in 2024, carried out on the machine "ALA-TOO". [2]

2.2 Well Design and integrity

The pay zone formations will be covered with 0.1778 m production Liner from 2942m to 4785m, the top of liner will be approximately 50m above Horizon B formation at 2370 in the Silurian F6 unit B. Potential reservoirs could be pressured above existing mud weight resulting in well control kicks. The drilling parameters are provided in tables 2 below.

Table 2: Hydraulics data Summary.

Hole Size (m)	Depth (m)	Bottom hole assembly Type	Recommended Flow rate (m3 /h)	Minimum Flow Clean (m3 /h)	Mud Weight (kg/m3)	Average Rate Of Penetration (m/hr)
0.2159	4785	Packed	84-108 m3 /h	39.18	1297-1347	7

2.3. Drill string dynamic analysis method

2.3.1. Steel drill string

The String analysis summary results indicate the mechanical integrity and stretch data of steel drilling string thus; any failures due to stress, buckling and torque are indicated. The total stretch in the string is computed as the sum of stretch components due to axial, buckling and ballooning which is caused by differential pressure inside and outside of the string(eq.1) Therefore Table 3 depicts load summary throughout rotating operations (on/off) and tripping out of the hole. An overall fatigue failure of drilling string is observed.

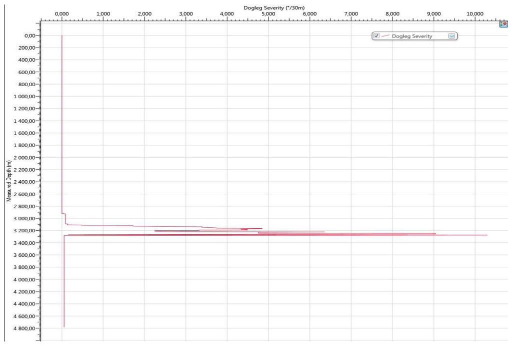
$$\Delta L\ \text{stretch} = \Delta L\ (\text{Hooke's Law}) + \Delta L\ (\text{Buckling}) + \Delta L\ (\text{balloon}) + \Delta L\ (\text{thermal}) \ \ldots\ldots \text{eq. (1)}$$

Table 3: String Analysis Summary for steel drill pipe

Load Condition	Stress Failure	Buckling Limits	Stretch(m)		
			Mechanical	Ballooning	Thermal
Tripping out	FATIGUE	No buckling	4.99	0.36	1.60
Rotating on bottom	FATIGUE	No buckling	3.94	0.36	1.60

As a quick snippet of the result from figure 1, it may be suggested, that the well path was exposed to variation in wall trajectory via tortuosity.

Figure 1: Dog legs severity curve and related fatigue stress



To identify the maximum stress at any given point on the string for instance, use is of table 4 which illustrates the maximum relative value for the cited stresses.

Tables 4:Rotating on bottom stress analysis for steel Drill

Measured Depth (m)	Component Type	Contact Force stress (lbf/length)	Hoop Stress (psi)	Radial Stress (psi)	Torsional Stress (psi)	Shear Stress (psi)	Axial Stress (psi)	Bending Stress (psi)	Bending Stress Magnification Factor	Von Mises Stress (psi)	Von Mises Ratio	Fatigue Ratio
3 243,03	Drill Pipe	3 950	-4 692,6	-4 692,6	11 376,0	1 836,0	17 583,7	27 373,3	2,726	53 511,1	0,51	1,782
3 252,15	Drill Pipe	2 115	-4 704,7	-4 704,7	11 002,7	983	17 435,3	16 506,9	2,715	43 123,7	0,411	1,073
3 261,27	Drill Pipe	2 753	-4 717,2	-4 717,2	10 802,8	1 279,3	17 283,8	18 547,2	2,703	44 712,1	0,426	1,204
3 270,39	Drill Pipe	2 193	-4 729,7	-4 729,7	10 542,8	1 019,1	17 141,9	19 491,6	2,692	45 249,1	0,431	1,263

2.3.2 Load data in aluminum drill pipe

Additionally, full-scale tests were carried out with replacing joints of steel drill pipes by lighter aluminum drill pipes in the drilling string while keeping the same bottom hole assembly and the tool-joints which are manufactured from steel .Table5 presents details of each drilling string specification, followed by stress analysis table 6 for AL 2024 rill pipe .

Table5: Details in each specific drilling string

Section	Steel / Steel drill pipe	Aluminium /Steel drill pipe		
Grade	5 in,19.5 ppf G105	5 in,19.5 ppf G105	5 in, 21,92 ppf AL2024	5 in,19.5 ppf S135
Depth (m)	4400	850	250	3060
Yield strength (Mpa)	724	723949.516	359	931
Tensile strength (Mpa)	931	792897.089	466.5	1138
Young module(Mpa)	206896.55	227526,9906.69	88763	206896.55
Fatigue Endurance limit (Mpa)	137.89	137.89	160	137.89

Table6: String Analysis Summary for AL2024 drill pipe

Load Condition	Stress Failure	Buckling Limits	Stretch(m)			
			Mechanical	Ballooning	thermal	Total
Tripping out	No fatigue	-	533	0.87	1.36	7.95
Rotating on bottom	No fatigue	No buckling	7.37	0.87	1.36	9.60
Rotating off bottom	No fatigue	No buckling	5.84	0.87	1.36	8.07

summary during selected operation in Table 7. the maximum relative value for the cited stresses axial, bending, torsional, and shear stress in table 9 is given after that.

Tables7: Rotating on bottom stress analysis for AL2024 drill pipe

Measured Depth (m)	Component Type	Contact Force (lbf/length)	Hoop Stress (psi)	Radial Stress (psi)	Torsional Stress (psi)	Shear Stress (psi)	Axial Stress (psi)	Bending Stress (psi)	Bending Stress Magnification Factor	Von Mises Ratio	Fatigue Ratio
3 167,90	Drill Pipe	2 136	-4 587,8	-4 587,8	8 080,2	971,7	15 755,4	6 721,1	12,458	0,585	0,508
3 176,83	Drill Pipe	2 033	-4 599,5	-4 599,5	7 882,7	925,2	15 602,0	7 132,2	12,398	0,587	0,537
3 185,76	Drill Pipe	1 463	-4 611,1	-4 611,1	7 694,6	665,5	15 449,1	6 132,1	12,337	0,564	0,459
3 194,69	Drill Pipe	1 105	-4 623,7	-4 623,7	7 559,3	502,7	15 296,3	4 740,9	12,276	0,536	0,353
3 203,62	Drill Pipe	1 649	-4 636,5	-4 636,5	7 457,1	750,2	15 144,1	5 449,6	12,214	0,544	0,404
3 212,55	Drill Pipe	2 829	-4 650,3	-4 650,3	7 304,6	1 287,2	14 992,7	8 679,0	12,153	0,597	0,641
3 221,47	Drill Pipe	2 173	-4 663,9	-4 663,9	7 042,9	988,6	14 842,4	6 897,3	12,092	0,559	0,508
3 230,40	Drill Pipe	2 645	-4 674,7	-4 674,7	6 841,9	1 203,6	14 692,1	6 825,1	12,031	0,553	0,5
3 239,33	Drill Pipe	3 192	-4 687,4	-4 687,4	6 597,2	1 452,3	14 542,9	11 423,8	11,969	0,629	0,833
3 248,26	Drill Pipe	984	-4 699,9	-4 699,9	6 302,0	447,7	14 396,4	2 162,8	11,909	0,459	0,157
3 257,19	Drill Pipe	3 361	-4 712,7	-4 712,7	6 211,0	1 529,3	14 247,9	12 944,7	11,847	0,648	0,936

Another area of this topic that is worth looking at is the dynamic, caused by unsteady, hard to report loads, especially the critical speed analysis, which is used to identify critical rotary speeds and areas of high stress concentration in the entire drill string. The practice is to find a corresponding critical rotary speed above which the system is unstable. Results obtained can be used to avoid critical rotary speeds that accelerate pipe fatigue resulting in catastrophic drill string failure as provided in table 8

Tables8: Critical speed analysis for Aluminum 2024 drill sting

G105/ S135 Steel drill sting					Steel -Aluminium drill string				
Rotational Speed	Axial Stress	Bending Stress	Torsional Stress	Shear Stress	Rotational Speed	Axial Stress	Bending Stress	Torsional Stress	Shear Stress
(rpm)	(psi)	(psi)	(psi)	(psi)	(rpm)	(psi)	(psi)	(psi)	(psi)
86	718,8	71,8	96,9	30	86	714,2	473,9	98,4	141,4
88	736,2	100,7	97,8	36,3	88	731,8	263,2	99,3	79,4
90	753,5	167,1	98,6	48,5	90	749,5	176	100,2	53,5
92	770,9	293,9	99,4	76,2	92	767,3	142,1	101	43
94	788,3	237,8	100,2	59,2	94	785,2	124,1	101,8	35,2
96	805,5	142,8	100,9	34	96	803,1	111,9	102,6	30,1
98	822,4	98,9	101,7	24,7	98	820,9	103,7	103,4	26,9
100	839,2	87,7	102,5	20,5	100	838,6	102,7	104,1	26,8

3. Results interpretation

After having gone through all string analysis summaries, we can settle that all operations were below tensile limits. No buckling or yielding was an issue during the drilling process

Accordingly Results can be explained as follows:

Initially, The G105 steel drill-string was experienced to fatigue failure during rotating on/off bottom operations., in extremely harsh environment, which may be the result of unintentional deviations and loading conditions For instance, rotation in a dangerous dogleg region where the severity exceeds 10°/9.14 m [6] makes the drill pipe subjected to large alternating stresses with friction coefficients increasing in these ranges during operating modes. Consequently risky results were obtained by increasing the severity of the moment bending curvature on the fore mentioned zones, where the pipe goes through cyclic bending stresses, which lead to stretch of the pipe outer wall in this dogleg region and creates a greater tension load change to the other side of the pipe. Thereby , the following high stress concentration led to fatigue ratio increases from 1.26 up to 1.78 , which is higher than the minimum fatigue ratio (based on Lubinski [4] torque and drag mode ,the minimum fatigue ratio is equal to 1 as safety limit). As a consequence, drill pipe fatigue failure is enhanced since axial-force transfer efficiency is weakened. which led to Von Misses ratio up to 1.78 (minimum Von Misses ratio is 1) as shown in table 4 ,thus the component is likely to faille .

Contrariwise, the treated 2024 aluminum drill pipes show significantly good results concerning fatigue resistance, despite exposed to extremely harsh loading conditions. These results are confirmed in tables 6 and7 in which it can be seen that this later has significantly a good fatigue resistance even in the simultaneous presence of high torque and axial load in addition to severe doglegs. These were confirmed by the fatigue ratio value which is 0.936 less than 1for all selected operations ,thus the component is unlikely to fail. Therefore the aluminum drill pipe (ALDP) reduces both string weight and side forces acting on the string.

Additionally, The bending stress level falls down in aluminum drill pipe in comparison with steel drill pipe in the dog leg region, which lead to enhanced transfer efficiency in dog leg region thus drill pipe fatigue failure is improved on one hand, and a reduction in weight can considerably decreases stress on the drill string and prevent buckling in many cases on the other.

As a final point, the uniform rotation is unstable if the drill- string is longer than the critical length or if it rotates below the critical rotational speed. Accordingly, it is clearly seen from the table 8, that when the drill string rotates at a speed of 100 rpm, the axial stress along the longitudinal axis of the string is significantly substantial compared to other stresses for both mixed and not mixed drilling string.

Conclusions

To sum up, this analysis has provided significant added values in pre-engineering stage, in order to sidestep fatigue drilling failures, when the drill string is exposed to extremely harsh environmental and loading conditions, which lead the pipe to be subjected to large alternating stresses in a curved segment (dog- leg) which may be the result of unintentional deviations or which are necessary for directional wells. In addition, to bit bounce on the cutting surface may occur and damage the bit. This may cause severe bending moments to develop in the BHA leading to fatigue failures. Accordingly, it was established that the 2024 aluminum alloy drill pipe exert significant influence on the degree of stress distribution but to a larger extent affects the amount of critical loads at which the loss of stability of drilling string doses not occur, besides good resistance to wear and corrosion even at high temperature

References

[1] Abdel Salam M., Mahmood A., 2016. Handbook of Materials Failure Analysis with Case Studies from the Oil and Gas Industry, Applied thermal engineering journal, Elsevier, ISBN: 9780081001172.

[2] Abdelbaki N., Atmani D., 2002. Test of an aluminium alloy treated superficially using oxidation by electrical micro- arc to the fissures formation under tension. 15th International Congress of Chemical and Process Engineering, Prague, 25–29.

[3] K.A. Macdonald, J.V. Bjune. Failure analysis of drillstrings. Eng. Fail. Anal. Volume 1

[4] Lubinski A. Maximum permissible dog-leg in rotary boreholes. J. Pet. Technol. Volume 13. Issue 2. February 1961. 175 –194. 4. Issue 8. 2007. 1641–1666.