RODRELO LLC.

Consulting and Representation

Failure Analysis Report

<u>Addressed to</u>

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<u>Report Number</u>: 1-RR-618

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<u>Report Date</u>: XXXXXXXX

<u>Sample information</u>

- Well: 1-1-1
- Operator: Operador 1
- Date of failure: 11/2/2020
- Artificial Lift type: SUCKER ROD PUMPING
- Type of failure: SUCKER ROD PART
- Failure description: ¾" Norris 97 Guided 4x
- Depth of failure: 4400'

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Failure Analysis Report

Sample information:

- Type of failure: SUCKER ROD PART
- Depth of failure: 4400'
- Date of Failure: 11/2/2020
- First in operation: September 2019
- Estimated Run Time: 400-430 days (13-14 months)

- Sucker Rod Size: ¾"
- Manufacturer: Norris
- Grade: N97 (4330M High Strength type of sucker rod)
- Sold by: N/A
- Condition: REFURBISHED
- Wrench flat information:
  - Manufacturing Date: 2010 (Norris Sucker Rod) – 10/2018 (WFT Coupling)
  - Heat Code: BUZ (Norris Sucker Rod)

Observations

- The failure mechanism corresponds to a corrosion-fatigue process with an initiation section located on the periphery of the rod body on one of the multiple localized corrosion cracks examined.
- Multiaxial loads are observed on the final ductile section ("one lip up, one lip down" Characteristic bending morphology)
- A large slow propagation area was found (around 80%), this indicates low loading stress on the rod string section under analysis. The sample also shows two distinct slow propagation process indicating loading regime.
- The results from the ISDT (Iron Sulfide Detection Test) indicates a strong response of a superficial layer of $CaCO_3$ and a smaller film of FeS attached to the rod body. This indicates a risk of under deposit corrosion, especially on soft deposits like $CaCO_3$. These brittle deposits generate cracks where the production fluid could stay stagnant and accelerate localized corrosion due to a crevice process.
- The well analysis indicates probable sliding when drilling at the section from 4200 to 4600 ft deep creating an optimal environment for micro doglegs not perceived by the MWD or standard 1 every 100ft measurements of normal surveying techniques. The change in trajectory may be the contributing factor to the exaggerated friction on that section which could induce more buckling than simulated by RODSTAR.
- The spray metal coupling attached to the rod sample showed a heavy corrosion-erosion attack. It seems that the contact with the tubing due to buckling, the solids in solution and the flow around the couplings could delaminated the SM layer. Once delaminated the corrosion took place on the base material.

Conclusions

- The failure occurs by a corrosion-fatigue process initiated on localized corrosion cracking on the surface of the rod body close to its upset bed.
- The presence of superficial $CaCO_3$ deposits along with deep attached FeS could create a special environment for under deposit corrosion.
- The most predominant contributing factor to this failure process is the evidence of bending stress. This type of load increases the risk of potential stress risers (meaning a smaller stress riser was more critical because of the existence of bending), especially critical when using low toughness grade of sucker rods.

Recommendations

- Strongly recommend to re evaluate the need of a full guided string. The addition of friction (guide material has a higher friction coefficient than bare steel) could be potential be increasing the buckling tendency on the section from 4000-5000ft. Evaluate the use of **low friction couplings** instead of guiding for wear on tubing solutions.
- Strongly recommend the use a **tougher grade like KD (4320M) or KDP rods instead of high strength.** High strength rods like N97s have a significantly lower toughness and by it, more susceptible to reach critical size of stress risers quicker, resulting in premature failures.
- **Review the chemical treatment** in place addressing dosage and type of chemical utilized for a better efficiency especially avoiding $CaCO_3$ scale deposits.
- Evaluate previous history of wear on the section from 4000ft to 5000ft. if so, I would recommend running a micro surveying log (gyro) with shorter intervals, around 25 to 30 ft instead of 100ft.

Future work on sample for further analysis

- It'll be necessary to count with real downhole and surface dynamometric cards to make a better assessment of the buckling issue. It can also be perceived on estimated plunger travel velocity and sudden "stops and go".
- If there is further interest on the metallurgy and manufacturing parameters of the sucker rod under analysis, we can proceed to send the samples to a metallurgical lab to evaluate: Hardness, metallographic structure, and chemical composition. With these three parameters we can determine if the rod was manufactured complying with all operator manufacturing standard.
- A thorough failure and inspection historical data analysis will reveal more information about the facts that lead into having this failure with this run time.

Failure Assessment

Sample from the field and "As Received" condition

Figure 1: Field Condition

Figure 2: As received Condition

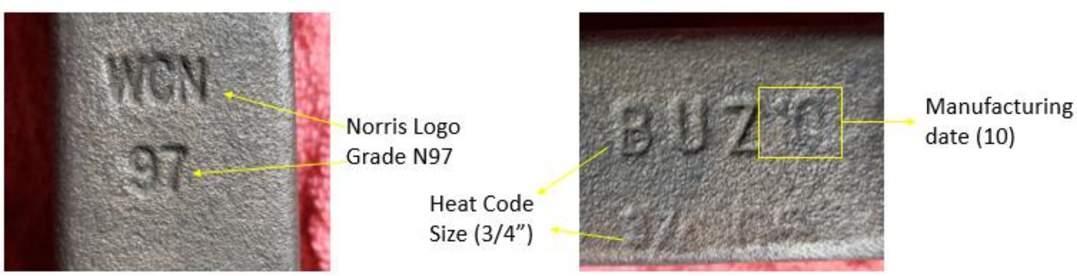


Figure 3: Wrench Flat information

Failure Morphology

The sample shows a large steady fatigue propagation area where friction was the predominant deformation method until the cross sectional are was small enough to complete the short cycle and ductile final break.

The large slow propagation area (more than 65% of the cross section) indicates low loading for this rod within the string.

The initiation area denotes a significant amount of stress risers and propagation planes until one predominant plane lead the plastic deformation that take place at the crack tip while propagating.

The final break lip also shows signs of multiaxial stress (normally bending or flexion) at the time of failure. This is characteristic of string sections with severe dog leg or compression especially close to the sinker bar or pump section. The proximity to the upset bed area indicates probable bending stress product of compression.

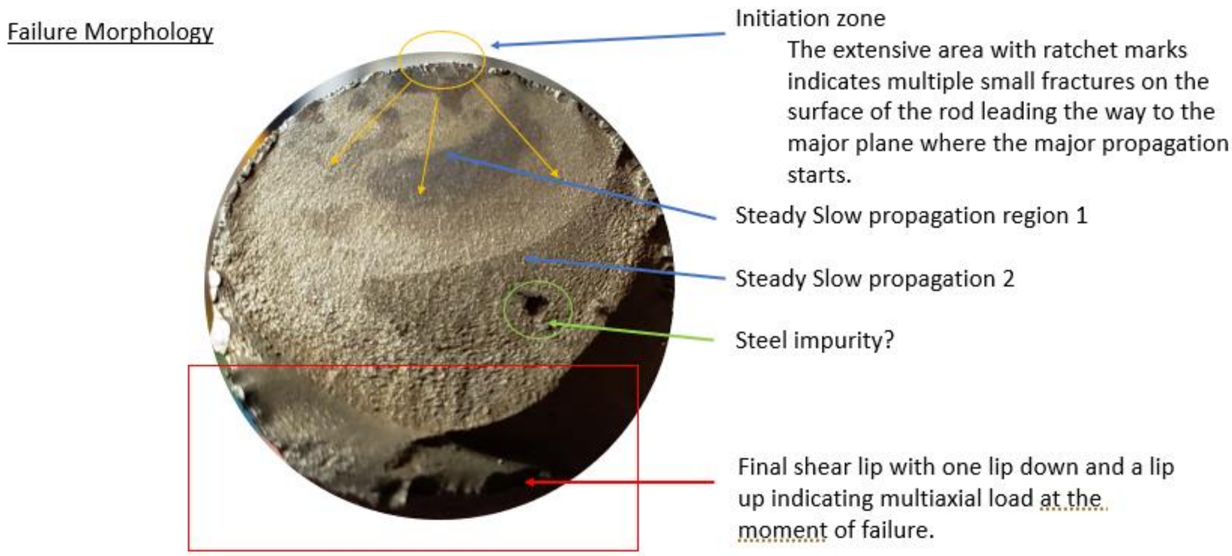
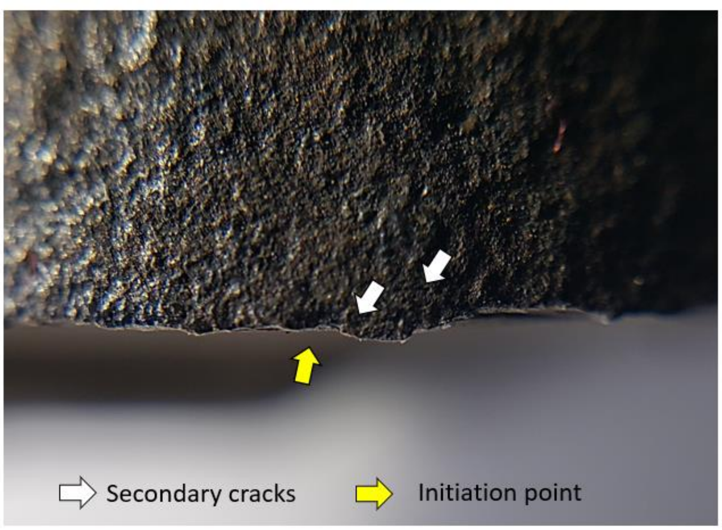


Figure 4: Failure Morphology Evaluation



The initiation point of the failure front shows secondary cracks. The crack pattern is irregular probably with initial assistance of sulfide stress cracking (SSC) or microcracking generating multiple ratchet marks.

Most high strength steels are susceptible exposed to SSC or other kind of embrittlement due to its energized microstructure and Nickel content. Nickel makes the lattice wider, allowing for atomic Hydrogen to allocate in between of their interstitial lattice space.

Figure 5: As received Condition

Coupling Assessment

The spray metal coupling showed a heavy corrosion-erosion attack. It seems that the contact with the tubing due to buckling, the solids in solution and the flow around the couplings could delaminated the SM layer. Once delaminated the corrosion took place on the base material.

Figure 6: delaminated SM coupling

ISDT (Iron Sulfide Test)

The evaluation with the ISDT solution of the deposits indicated the presence of $CaCO_3$ due to the effervescence (CO2 release) from the reaction with the HCl. The Yellow coloration and the mild rotten egg smell indicate the subjacent presence of FeS attached to the rod body. This combination normally is a result of under deposit localized corrosion.

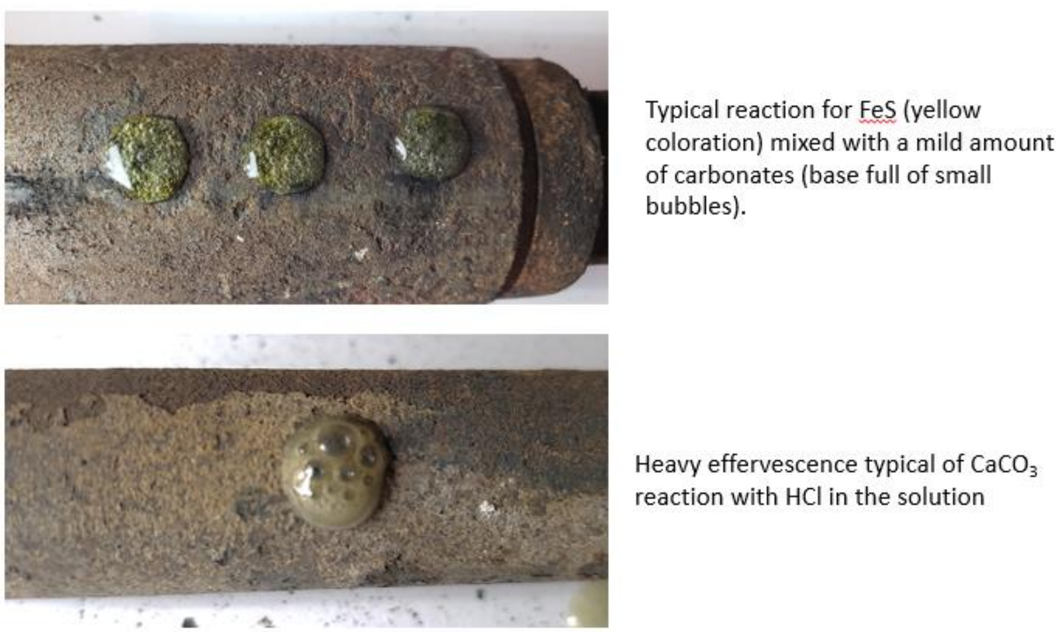


Figure 7: ISDT for CaCO3 and FeS

Well Analysis

- Supporting information received:
  - String Design
  - Pictures from the field
  - Failure depth and date of failure

- *Sliding area: inclination anomaly*

  Normally slight changes of inclination or orientation are seen in survey with measurement intervals of 1 every 100ft, but operators still see operational issues on these wells with no further explanation from a simulation point of view.

  When drilling deviates from the expected 2 degrees dog leg they try to re orientate the drill bit by adding weight. This sudden weight addition often generates sliding creating localized areas for abrupt changes in DLS not noticeable from standard measurement intervals. The only way to proper assess these issues is with a more define measurement with intervals o around 25 to 30 feet.

  The well geometry depicted on the string design simulation indicates that a change of inclination in the area of failure, and in combination with the excess of guides, a “hanging” area that multiplies the risk of bending due to compression of the string above the inclination anomaly.

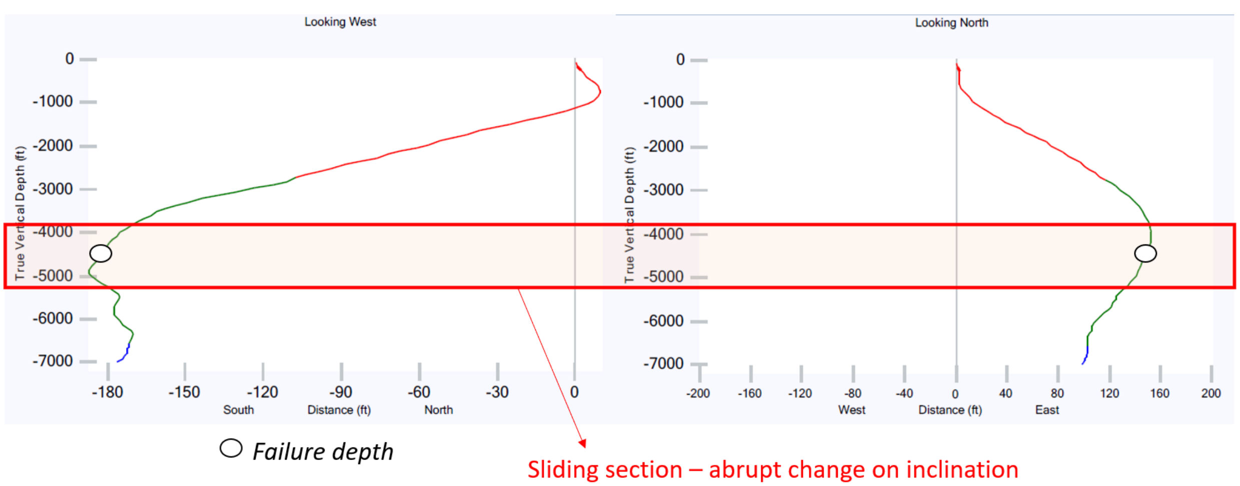
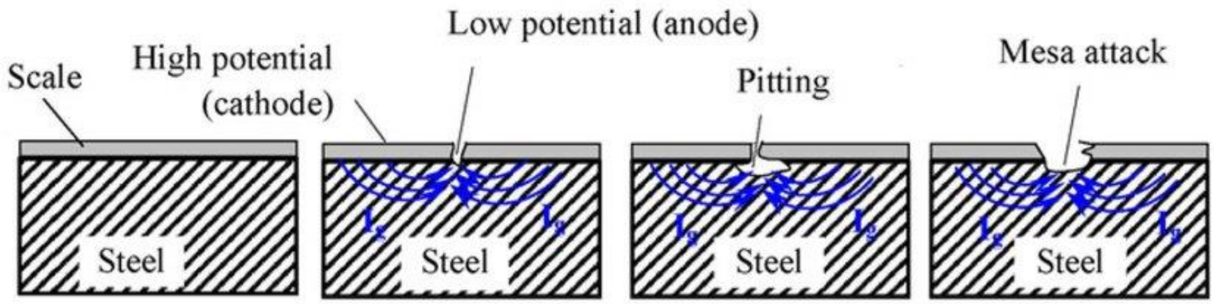


Figure 8: Inclination anomaly

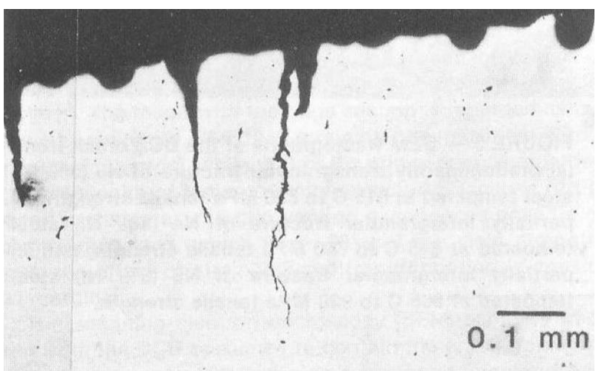
Annex: Supporting information

Under Deposit Corrosion



Above is the typical localize corrosion process associated to under deposit corrosion. This phenomenon varies depending on what type of deposit and what type of corrosive agent is present.

Typical H2S sharp pit morphology



H2S pitting morphology normally takes the shape of sharp edges, and it is hard sometimes to determine if they are pits or cracks. The embrittlement that happens on the tip of the crack, the highest loading section of the crack facilitates the entering of atomic Hydrogen that fragilize the surrounding area of steel making the propagation fasters on every loading cycle.

String Design