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PDC Corrosion Resistant Cutter Testing and Validation in the Permian

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Abstract

Corrosion has been a challenge in the Permian Basin since drilling became popular in the area. Initially, the challenge was with Roller Cone leg breakage, and has evolved with drill bit technology to manifest itself on PDC cutter substrates.

Over the years, the Product Engineering group has identified this corrosion issue from thousands of dulls observed in the field. Evaluation of the cutters revealed corrosion was attacking the cobalt depleted area at the interface between the diamond table and carbide substrate. This resulted in compromised structural integrity of the cutters, loss of WC behind the diamond table, ultimately leading to premature breakage. This information was relayed to Schlumberger's cutter manufacturer and a corrosion resistant cutter was developed to address the issue.

The newly designed corrosion resistant cutter was strategically placed on a 9.875" 6 blade, 16mm cutter PDC design along with traditional cutters, for a paired comparison test. The bit was run in the Delaware Basin where the highest likelihood of encountering corrosion would occur. The first tests returned promising results, with the corrosion resistant cutters displaying no corrosion, while the traditional cutters displayed extensive corrosion. After the initial test, the volume of test units in the fleet was expanded. Much like the first trial, the results were positive. The dull condition of the corrosion resistant cutters was improved and allowed for 15% improvement in overall footage drilled. The trials confirmed the changes made to the substrate eliminated the corrosion attack to the substrate, improving the overall post-run condition of the bit as well as performance.

Introduction – The Permian's Corrosive Environment

The drilling environment in the Permian Basin poses many difficult challenges. One of these challenges is utilizing steel-based tools to drill in the brine-enriched formation across the Basin. (Stueber 1998). The brine-enriched formations result in corrosive attacks on many high strength steels (should we say metals?) commonly utilized. In addition, the frequent use of water-based drilling fluids introduces additional electrolytes in the drilling environment, leading to a greater risk of Galvanic corrosion.

Corrosion poses a detrimental effect on tool reliability. In terms of drill bits, damage from corrosion was first noticed in Roller Cones, where corrosion would attack the steel components of the bit, leading to premature bit failure.

Even as companies have transitioned to the more efficient Polycrystalline Diamond Compact (PDC) type bits, corrosion from the brine-enriched environment remains a problem. The corrosive environment attacks the interface between the tungsten carbide substrate and the diamond table. *See* Figure 1. The corrosion removes a thin band in the tungsten carbide behind the cutter resulting in the diamond table being unsupported and leading to premature cutter breakage. This substrate damage from corrosion has been observed on all the cutter types and shapes run in the Permian.

Figure 1 PCD cutters with corrosion damages after drilling service

This corrosion damage was observed in the thousands of dull bits that were studied and examined over the years. Once the damage was understood, the local engineering team worked with their PCD cutter team to develop a solution.

Cutter Development

Polycrystalline Diamond (PCD) cutter typically has two components - an ultra-hard PCD table and a substrate of tungsten carbide (WC) cemented in cobalt (Co) matrix. The schematics showing the general structures of drill bit, PCD cutter and associated materials, as presented in Figure 2. PCD cutters are sintered under pressure greater than 4.5 GPa and at temperature approximately 1,500 degrees Celsius. The cutter sintering involves sweeping molten Cobalt (Co) from substrate into diamond powder compaction and facilitating the formation of the bonded grain structure of diamonds. High-pressure and high-temperature (HPHT) presses are employed to sinter PCD cutters.

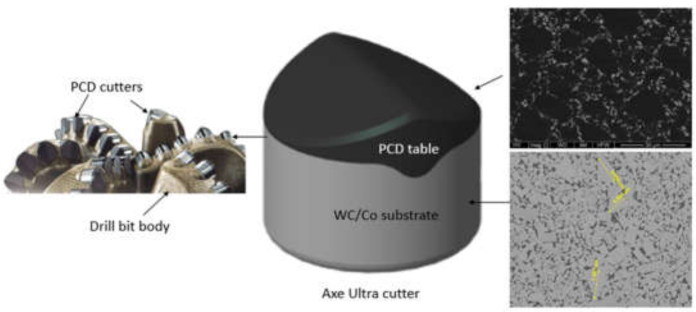

Figure 2 Schematics showing a drill bit with PDC cutters (R) and an AXE Ultra cutter (M). SEM images of microstructures of UR) PCD and LR) WC cemented in Co matrix were also included

Corrosion Cutter Analysis

The local product engineering team in the Permian worked with various cutter development stakeholders to analyze cutters with various modes of failure for cutter improvement. Multiple cutters were identified to have corrosive damage and were sent to the cutter group for further analysis. The cutters were at various stages of failure and provided an excellent illustration of their failure progression.

In one cutter sample, separation between the PCD table and the carbide substrate was evident (Figure 3). Internal cracks initiated from the tip of separation (Figure 4), resulting in PCD fracture in the bottom of PCD table. The damaged carbide substrate was studied by the scanning electron microscopy (SEM). The microstructural observation indicated cobalt was leached out of the carbide material in the work area of the cutter, resulting in a loosely bonded skeleton of tungsten carbide grains (Figure 5). The cobalt leaching was attributed to corrosion. Understanding the impact corrosion had on the cobalt layer and the detrimental effect it caused to the cutter's strength and integrity allowed for an enhancement of the chemical composition of the substrate.

The electrode potential of cobalt in the current substrate material was -0.28 volts. As a result, the team chose to create a proprietary new binder solution for the WC substrate which is more passive than cobalt and was introduced to replace the original cobalt-based binder. The cutters built on modified substrate material showed much improved corrosion resistance in the paired cutter tests, as shown in Figure 9.

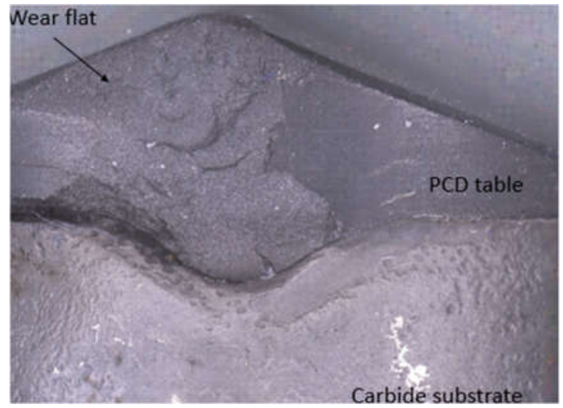

Figure 3 Side-view of a dull cutter

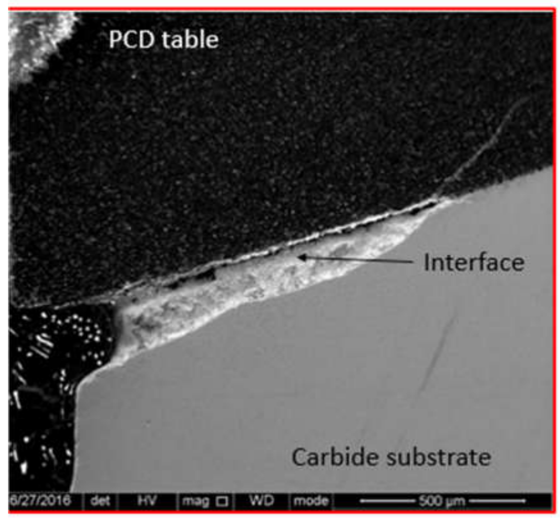

Figure 4 Cross-sectioned view of a cutter with damage along the cutter interface

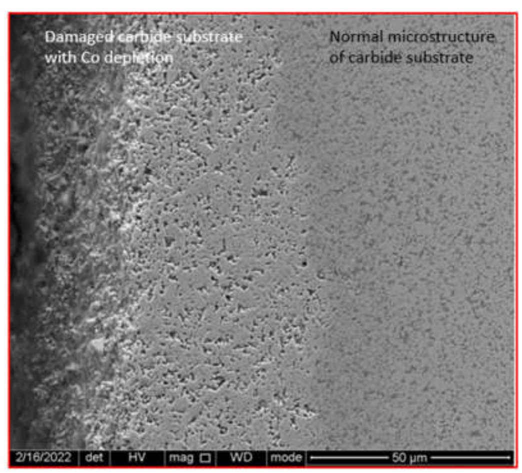

Figure 5 SEM image showing the microstructure of damaged carbide

substrate

Field Testing and Evaluation

Once the new corrosion resistant cutters had been developed, they were ready to be tested in the field. Partnering with a local operator who had extensive experience drilling in corrosive environments, A test well was identified. The chosen cutters were brazed into a 9.875" 6 blade – 16mm cutter design. Both standard cutters and the new corrosion resistant cutters were strategically positioned on the primary blades 1, 3 and 5, at the 4th cutter position. They were placed between two non-corrosion resistant cutters which allowed for a comparison of cutters facing similar forces and work rates and the impact of corrosion on their dull conditions. The test cutter quantity was limited to three in order to minimize the risk of failure (Figure 6).

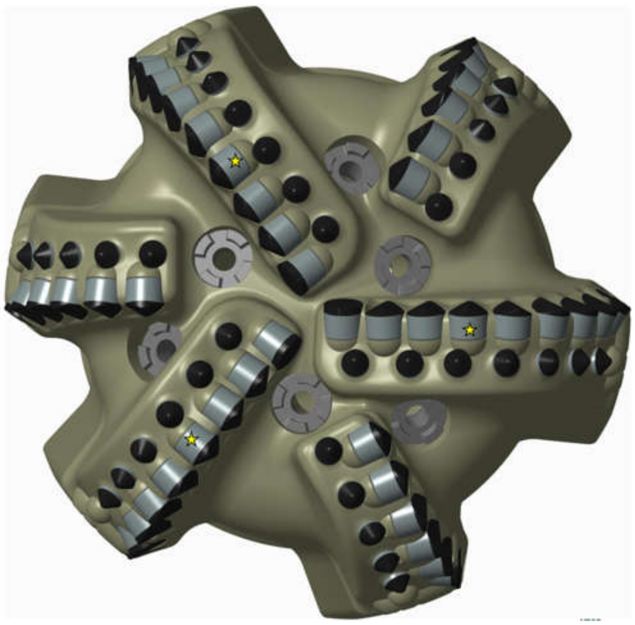

Figure 6 Cutting Structure Layout with Corrosion resistant cutter positioned at the location identified with yellow stars

The initial test run started at a depth of 1,080 ft and was able to drill to a total depth of 8,587 ft, achieving 7,507 ft drilled in 60.5 hours for an overall Rate of Penetration (ROP) of 124.1 ft/hr.

The condition of the corrosion resistant cutters compared to standard cutters was telling. The corrosion resistant cutters displayed little to no damage as compared to non-corrosion cutters on either side. Figure 7 and 8 show the overall condition of the bit.

Figure 7 Condition of Dull after run. Yellow stars designated corrosion resistant cutters

Figure 8 Close up view of cutters

These cutters were sent back to the cutter vendor for further analysis. Their analysis confirmed that the corrosion resistant version did not show any signs of corrosion (Figure 7 & Figure

8). Figure 9 below shows a side-by-side comparison of the cutters from the test. The modified substrate provided resistance to corrosion as compared to other non-corrosion version on the same bit.

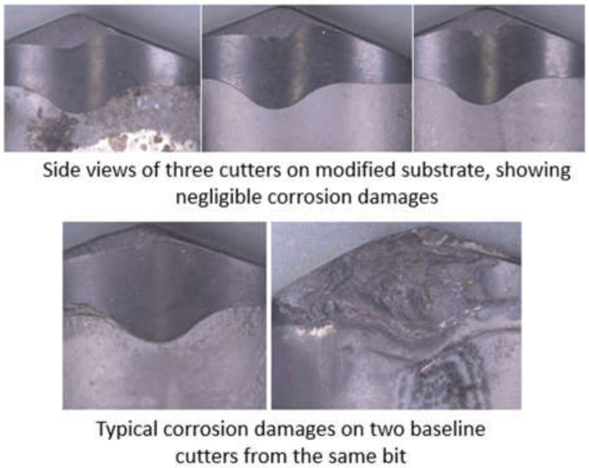

Figure 9 The paired cutter test exhibited improved corrosion resistance when Axe Ultra cutters were built on modified substrate materials

Following the initial positive result, another test was planned to verify the capabilities of corrosion resistant cutters on other areas of the bit. The cutter quantities increased from three (3) cutters positioned on each primary blade to three (3) per blade totaling nine (9) cutters. The goal of increasing the quantities was to further evaluate the cutters in higher work rate areas of the cutting structure. Figure 10.

Figure 10 Second Cutter Test with increase corrosion cutters, positions designated by yellow stars

The second test followed a similar trend. The bit was able to drill 6,745 ft, an improvement of 21% over the offsets. The run also finished in 60 hours for an overall ROP of 113 ft/hr, a 20% improvement over the offsets. The corrosion resistance cutters showed again to be great shape as compared to their non-corrosion resistance counterparts. Placement further out on the shoulder improved overall durability, resulting in the bit drilling more footage with an improvement in ROP and a better dull condition as shown in 11 Figure 11 Dull condition of 2nd corrosion resistant cutter test. This further confirmed and validated the development of the corrosion resistant cutter.

Figure 11 Dull condition of 2nd corrosion resistant cutter test

Once the initial testing was completed with positive results, testing was expanded to other applications across the Permian. Similar results were observed with each additional run.

Case Study 1

A test was completed in the 8.5" lateral section in the Delaware Basin. This application provided a great test candidate to isolate the cutters by replacing standard cutters with the corrosion resistant version on the same PDC cutting structure, allowing a head-to-head comparison.

The test results were staggering. When comparing only drill-out runs with depths-in ranging between 9,500-10,500 ft, the average footage drilled with the corrosion resistant cutters was 4,649 ft compared to only 1,875 ft with the non-corrosion resistant cutters. An exceptional 1.5x improvement in average footage drilled Figure 12.

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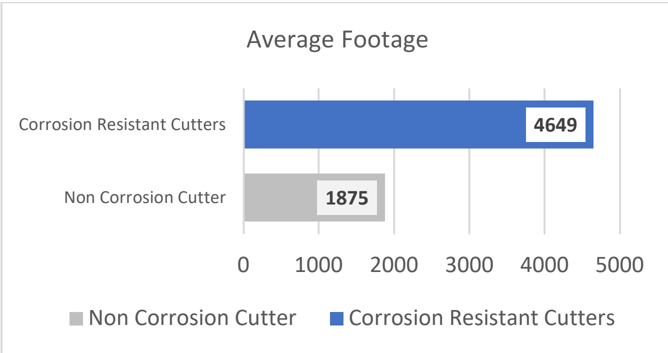

Figure 12 Footage Improvements for 8.5" Section

Case Study 2

The local product engineering team noticed that one of the dulls from an operator in the Delaware basin showed signs of damage sustained from corrosion. The dull had both broken and chipped cutters, along with evidence of corrosion "banding" at the diamond table and WC bond line. The local team reacted quickly and recommended running a corrosion resistant cutter on the next pad on the well.

The design with the corrosion resistance cutters was able to drill 6,604 ft in 24 hours – a 25% improvement and record for the operator.Figure 13 The overall run was able to drill 8,470 feet with an overall ROP of 206 ft/hr. This was a 13% improvement in terms of overall footage drilled and 17% improvement compared to the offset well.

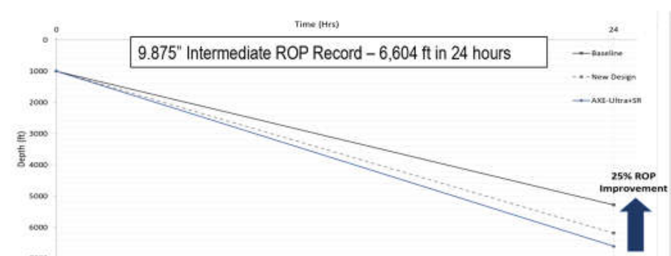

Figure 13 24 Hour Footage Record with Corrosion Resistant Cutters

Conclusions

The brine-enriched environment in the Permian Basin poses many unique drilling challenges. Cutter corrosion on PDC bits have historically led to premature cutter damage and declines in overall performance. The identification of corrosive attacks led to the development of a corrosion resistant cutter. To date, there have been a total of 1,734 runs and over 4.7 million feet drilled with corrosion resistant cutters in the Permian Basin. Based on the successful introduction and evaluation of the cutter, other areas around the world have adopted the new cutter technology to address corrosion.

Acknowledgments

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Nomenclature

PDC = *Polycrystalline Diamond Compact*
PCD = *Polycrystalline Diamond*
HPHT = *High-pressure and high temperature*
SEM = *Scanning Electron Microscopy*
ROP = *Rate of Penetration (ft/hr)*

References

1. Alan M. Stueber,2 Arthur H. Saller,3 and Hisashi Ishida "Origin, Migration, and Mixing of Brines in the Permian Basin: Geochemical Evidence from the Eastern Central Basin Platform, Texas" AAPG Bulletin, V. 82 (1998), No. 9 (September 1998), P. 1652-1672