

ENHANCING DURABILITY IN ROD LIFT PUMPING SOLUTIONS: A COMPREHENSIVE ANALYSIS OF DIAMOND COATING

Riyadh Saloom and Jay Taylor
SLB

Abstract

Mechanical components used in artificial lift systems are continuously exposed to harsh downhole environments characterized by corrosion, abrasion, erosion, and cyclic mechanical loading. These conditions significantly limit the operational life of rod lift equipment, particularly in sand-producing and corrosive wells. To mitigate these challenges, surface engineering techniques including coatings, diffusion treatments, and advanced metallurgical solutions have been widely adopted across the oil and gas industry. This study provides an overview of conventional and advanced surface treatments used in rod lift systems. The paper also introduces Harbison-Fischer's Deka (EN-Diamond) coating as an emerging solution designed to enhance wear resistance and extend component life. Through metallurgical characterization and controlled wear testing, the performance of these surface technologies is assessed to quantify their effectiveness under simulated downhole conditions. The objective is to provide operators with a comparative understanding of available technologies and support optimized material selection to maximize run-life and minimize failure frequency.

1. Introduction

Surface protection through coatings is not a modern innovation. Early civilizations, including ancient Egypt, applied gold leaf and gilding techniques to protect and preserve materials from environmental degradation. This fundamental concept evolved significantly with the advent of electrochemical processes in the early 19th century, when Luigi Brugnatelli introduced electroplating using electrical current to deposit thin metallic layers.

As industrial demands increased, coatings transitioned from decorative applications to functional engineering solutions. By the early 20th century, technologies such as hard chrome plating and thermal spray coatings were developed to address wear and corrosion challenges in mechanical systems.

In the oil and gas industry, the need for durable materials became critical with the expansion of drilling and production operations into increasingly aggressive environments. Surface treatments such as nickel plating, hard chrome, and boronizing were adopted to protect equipment exposed to:

- Corrosive fluids (CO_2 , H_2S , brines)
- Abrasive solids (sand production)
- Mechanical wear and cyclic loading

Over time, these technologies evolved into more advanced solutions, including composite coatings (e.g., Ni-SiC) and thermal spray carbides, enabling improved performance in extreme conditions. Artificial lift systems, particularly rod lift systems, operate under some of

the most demanding conditions in production environments. Key degradation mechanisms include:

- Abrasive wear due to sand-laden fluids
- Corrosion and tribocorrosion
- Adhesive wear and galling between plunger and barrel
- Stress corrosion cracking (SCC) in aggressive chemistries

The plunger-barrel interface is especially critical, as it directly impacts sealing efficiency, pump performance, and overall system reliability.

2. Surface Treatments in Rod Lift Systems

To address these challenges, a range of coatings and surface treatments have been implemented in rod lift equipment. For plunger applications the following coatings have been developed and some of them are used today:

- Flame Spray
- HVOF (High Velocity Oxy-Fuel)
- Hard Chrome
- Boronizing
- Carburizing
- Laser Cladding
- Plasma Spray
- CVD and PVD (Chemical & Physical Vapor Deposition)

For barrels the following coatings and surface treatment have been developed and some of them are used today:

- Hard Chrome
- EN-Carbide (Ni-SiC / Ni-Carbide composites)
- Carburizing
- Boronizing
- EN-Diamond

These technologies vary in terms of hardness, corrosion resistance, adhesion, and cost, and are selected based on well conditions and performance requirements. For a coating to function properly it has to offer the following characteristics:

- High hardness - Assuming high hardness reflect high abrasion & wear resistance.
- Low friction - Assuming low friction reflects good tribological behavior.
- High corrosion resistance in downhole environment.
- Strong adhesion to prevent delamination.
- Compatibility with the counter part, i.e., the barrel surface is compatible with the plunger surface and vice versa.
- Predictable and repeatable performance.

3. Transition to Advanced Composite Coatings

Despite the wide range of available technologies, challenges remain in balancing wear resistance, corrosion protection, coating integrity, and cost-effectiveness. Environments with simultaneous sand abrasion and corrosive fluids continue to drive the need for improved surface solutions. This has led to the development of next-generation composite coatings that combine a corrosion-resistant metallic matrix and embedded ultra-hard particles.

4. Introduction to EN-Diamond Coating

To address the limitations of conventional coatings, Harbison-Fischer has developed an advanced composite coating system, referred to as Deka (EN-Diamond), for rod lift barrel applications. This coating builds upon the principles of electroless nickel deposition while incorporating diamond particles, one of the hardest known materials, into the coating matrix. The objective is to achieve a unique combination of exceptional abrasion resistance, improved corrosion protection, and enhanced surface durability under harsh downhole conditions. Unlike traditional coatings, which may optimize either wear or corrosion, Deka is designed to provide a balanced performance profile suitable for demanding rod lift environments.

4.1 Abrasion Resistance Evaluation (ASTM G174 Loop Test)

To quantitatively evaluate the abrasion resistance of various coating systems, testing was conducted in accordance with ASTM G174, which utilizes a loop abrasion configuration designed to simulate sliding wear under abrasive conditions. This test method is particularly relevant for rod lift applications, where continuous contact between the plunger and barrel occurs in the presence of entrained sand particles. In the ASTM G174 loop test, a specimen is subjected to controlled sliding contact against an abrasive medium under a defined load, speed, and duration. The primary performance metric obtained from this test is wear volume loss (mm^3), which provides a direct measure of material degradation due to abrasion. The testing apparatus schematic is shown on Figure 1.

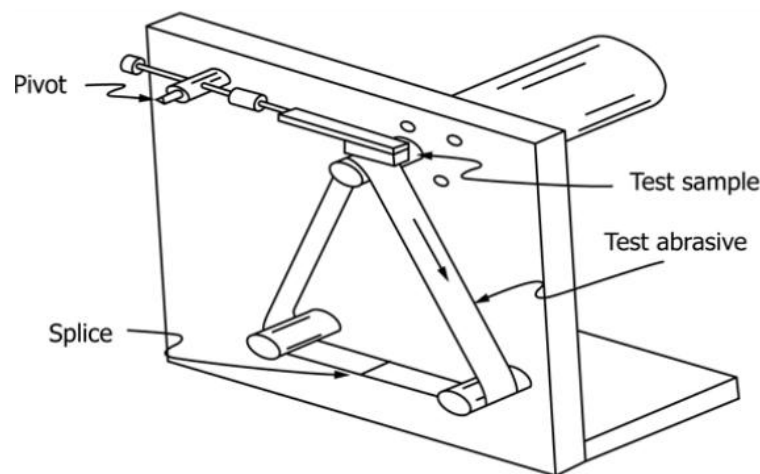


Figure 1. ASTM G174 Test Setup

Figure 2 presents the comparative wear performance of several coating systems, including hard chrome, EN-SiC on brass, hard EN-SiC, and EN-Diamond coatings.

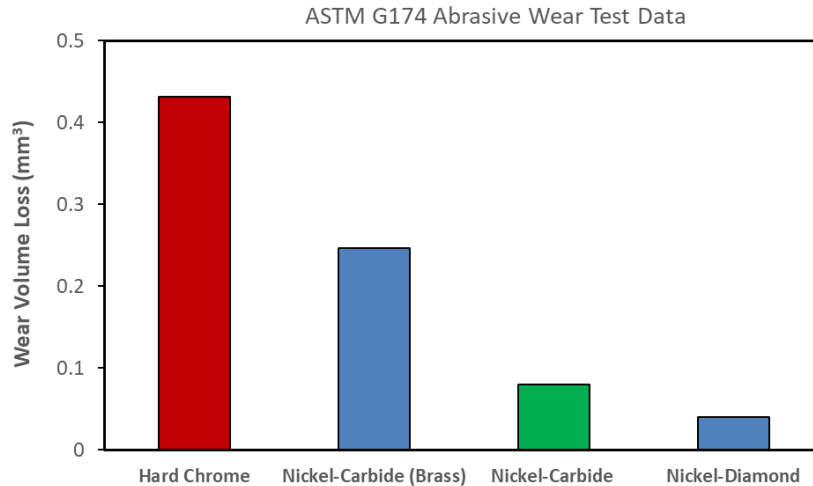


Figure 2. Abrasion resistance results for different barrels coatings using ASTM G174 abrasion test.

The results demonstrate a clear trend in abrasion resistance among the evaluated materials. Hard Chrome exhibited the highest wear volume loss ($\sim 0.43 \text{ mm}^3$), indicating limited resistance under abrasive conditions. EN-SiC on brass showed improved performance ($\sim 0.25 \text{ mm}^3$), attributed to the presence of hard carbide particles, though still susceptible to matrix wear. Hard EN-SiC on steel further reduced wear ($\sim 0.08 \text{ mm}^3$), reflecting enhanced abrasion resistance due to aging heat treatment. EN-Diamond exhibited the lowest wear volume loss ($\sim 0.04 \text{ mm}^3$), representing a significant improvement over all other evaluated coatings.

The EN-Diamond coating reduced wear volume by approximately $\sim 90\%$ compared to hard chrome, and $\sim 50\%$ compared to standard EN-SiC coatings. This superior performance is primarily attributed to the incorporation of diamond particles, which possess hardness values exceeding $8000\text{--}10,000 \text{ HV}$, significantly higher than conventional carbides ($\sim 1500\text{--}2500 \text{ HV}$). The presence of these ultra-hard particles within the nickel matrix effectively resists micro-cutting and plowing mechanisms caused by abrasive particles. Additionally, the uniform dispersion of diamond particles within the electroless nickel matrix provides a consistent barrier against localized wear, minimizing material removal even under severe conditions. From a wear mechanism perspective, the EN-Diamond coating transitions the dominant wear mode from severe abrasive wear (in chrome) to mild abrasive interaction with minimal material removal. This behavior is critical in rod lift systems, where continuous exposure to sand can rapidly degrade conventional coatings.

4.2 Friction and Wear Behavior of Diamond-Based Coatings

Beyond abrasion resistance, diamond-based coatings exhibit unique tribological properties that further enhance their performance in rod lift applications. Diamond is characterized by:

- Extremely low coefficient of friction ($\sim 0.05\text{--}0.1$)
- High Hardness
- Chemical inertness

When incorporated into an electroless nickel matrix, these properties contribute to improved sliding behavior at the plunger-barrel interface. The low friction characteristic of diamond reduces contact stress between mating surfaces, heat generation during operation, and adhesive wear and galling. This is particularly important in rod lift systems, where boundary lubrication conditions are often present, and metal-to-metal contact cannot be completely avoided. Furthermore, the combination of hard diamond particles (load-bearing phase) ductile nickel matrix (support phase) creates a synergistic effect that enhances both wear resistance and coating integrity. The nickel matrix provides corrosion protection and mechanical support, while the diamond particles act as primary wear-resistant elements. As a result, EN-Diamond coatings are expected to maintain surface finish over longer operational periods, reduce degradation of sealing interfaces, and improve overall pump efficiency and run-life

To further evaluate the tribological performance of the coating systems, friction and wear testing was conducted in accordance with ASTM G133, which utilizes a reciprocating sliding configuration to simulate boundary and mixed lubrication conditions typical of rod lift systems. This test method is particularly representative of the plunger–barrel interface, where repeated sliding contact occurs under load in the presence of limited lubrication and abrasive particles.

4.2.1 Coefficient of Friction Behavior

Figure 3. presents the coefficient of friction (COF) as a function of time for both EN-Diamond and EN-SiC coatings under dry sliding conditions, revealing a clear distinction in their tribological behavior. The EN-Diamond coating exhibits a higher COF in the range of approximately 0.65–0.80, along with noticeable fluctuations and periodic spikes throughout the test duration. In contrast, the EN-SiC coating demonstrates a lower and more stable COF, typically between 0.45–0.60, with reduced variability over time. The EN-Diamond curve is characterized by greater instability and transient increases in friction, indicating more dynamic surface interactions during sliding. Meanwhile, EN-SiC maintains a smoother and more consistent friction response, reflecting more stable sliding conditions.

Despite the higher friction observed in EN-Diamond, its superior wear performance can be attributed to the extreme hardness of diamond particles and their ability to resist deformation and material removal under load. The elevated COF is likely associated with increased asperity interaction and load-bearing contribution of diamond particles at the interface. However, this does not translate to increased wear; rather, it results in a more robust surface capable of sustaining abrasive conditions. From an operational perspective, while EN-SiC offers lower friction behavior, EN-Diamond provides significantly improved wear resistance and durability, which are critical factors in extending component run-life in rod lift applications.

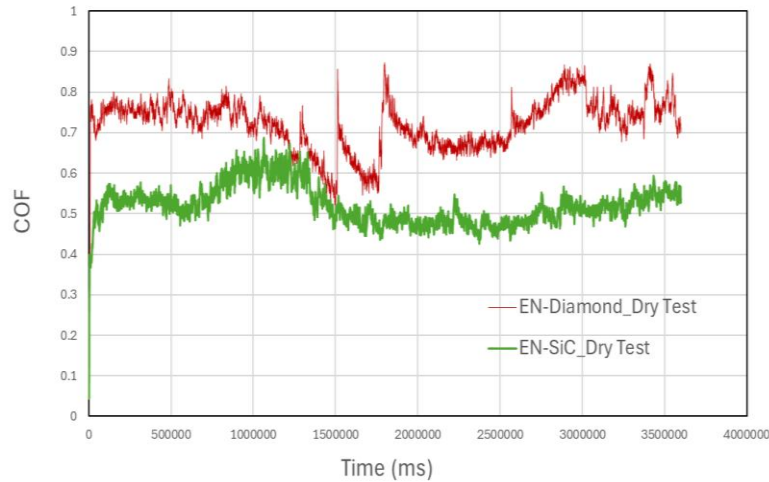
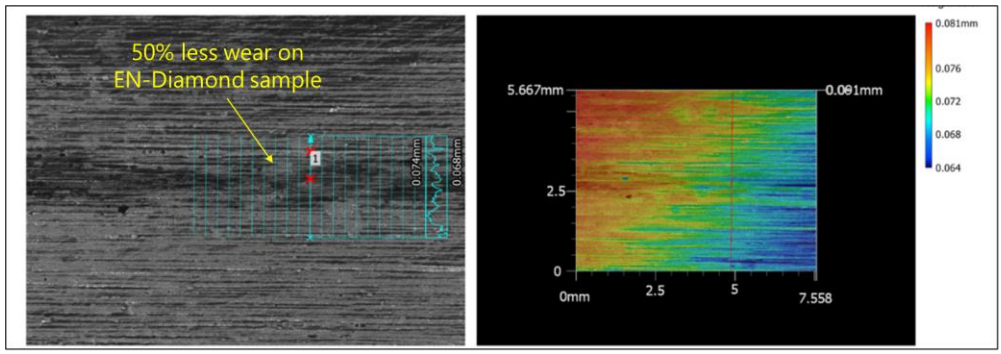


Figure 3. Coefficient of friction (COF) curves as a function of time for EN-Diamond and EN-SiC tested samples

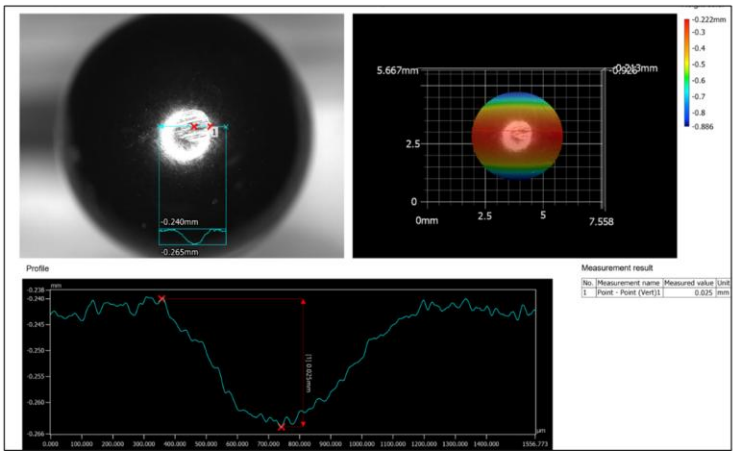
4.2.2 Wear Depth and Volume Analysis

Quantitative wear measurements are shown in Figure. 4. These results further support the observed tribological behavior of the coatings. For barrel wear evaluated using flat samples, the EN-SiC coating exhibited a wear depth of approximately 9 μm , whereas the EN-Diamond coating showed a significantly lower wear depth of approximately 4 μm . This corresponds to an approximate 50% reduction in wear depth with the EN-Diamond coating. Similarly, counterface wear measurements on the plunger side, evaluated through ball wear volume, indicate a wear volume of approximately 0.494 mm^3 for the SiC system compared to 0.353 mm^3 for the diamond-based system, representing an approximate 25% reduction in counterface wear. These results demonstrate that EN-Diamond not only enhances the durability of the coated surface but also significantly reduces wear on the mating component, which is critical in rod lift systems where both plunger and barrel degradation directly impact performance and efficiency.

EN-Diamond

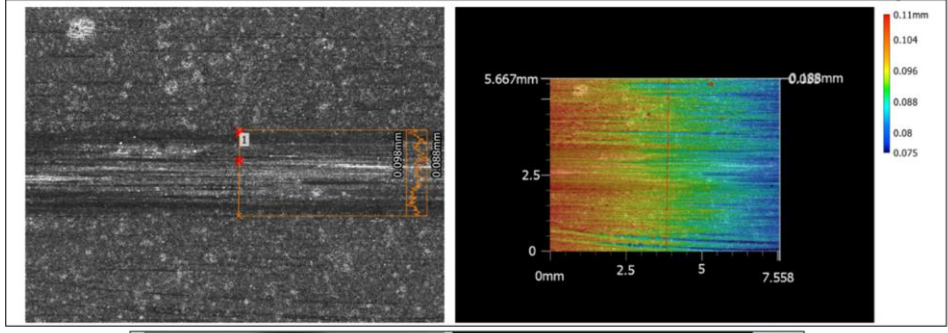


Less barrel wear

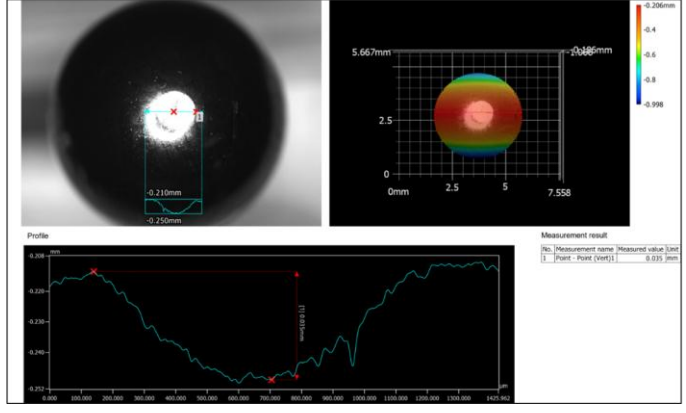


Less plunger wear

EN-SiC



More barrel wear



More plunger wear

Figure 4. surface profile measurement of the wear track after friction testing of EN-Diamond and EN-SiC samples

4.2.3 Wear Mechanism Differences (SEM Analysis)

Scanning electron microscopy (SEM) analysis of the wear track for the EN-SiC sample after wear testing is shown in Figure 5. Key observations include the presence of dislodged SiC particles from the nickel matrix, formation of voids and particle pull-out sites, and clear evidence of third-body abrasion. Although SiC particles possess high hardness, they are typically angular in morphology and may exhibit weaker bonding within the nickel matrix. Under cyclic sliding and loading conditions, these particles can become dislodged from the surface. Once detached, they leave behind exposed nickel matrix regions, which inherently exhibit lower friction compared to the composite surface. This contributes to the relatively lower and more stable coefficient of friction observed for EN-SiC during testing.

However, the dislodged SiC particles do not disappear from the system; instead, they become third-body abrasive debris within the contact interface. These loose, hard particles promote additional material removal through micro-cutting and plowing mechanisms, accelerating wear of both the coating and the mating surface. As a result, while EN-SiC exhibits lower friction behavior, it simultaneously experiences higher material loss due to progressive abrasive wear.

In contrast, the EN-Diamond coating exhibits a fundamentally different wear mechanism. The diamond particles demonstrate stronger interaction with the nickel matrix and improved retention under sliding conditions, resulting in minimal particle pull-out. Due to their superior hardness and resistance to fracture, diamond particles remain embedded within the coating and continue to act as load-bearing elements throughout the test. This stable particle retention leads to a higher effective contact interaction at the interface, which explains the higher coefficient of friction observed for EN-Diamond.

Importantly, this elevated friction is not indicative of poor performance; rather, it reflects the sustained engagement of hard, load-bearing diamond particles at the surface. Unlike the EN-SiC system, where particle loss reduces friction but increases wear, the EN-Diamond coating maintains its structural integrity and resists material removal. The absence of significant third-body debris minimizes abrasive interactions, while the retained diamond particles reduce plowing and micro-cutting damage to the surface. Consequently, EN-Diamond exhibits a higher friction but significantly lower wear response, demonstrating that friction and wear are not directly proportional in this system. The higher friction observed is therefore a result of improved coating integrity and particle retention, which ultimately leads to superior abrasion resistance and enhanced durability under simulated rod lift operating conditions.

4.2.4 Tribological Performance Summary

The combined friction and wear results demonstrate that EN-Diamond provides a significant tribological advantage over EN-SiC coatings, despite differences in friction behavior. The EN-Diamond coating exhibits substantial improvements in wear performance, including approximately 50% reduction in wear depth and 25% reduction in counterface wear, while also maintaining improved surface integrity under cyclic sliding conditions. The enhanced performance is largely attributed to the elimination of particle pull-out mechanisms and the stability of diamond particles within the coating matrix, which reduces the formation of abrasive debris and limits progressive material degradation. These improvements have direct

implications for field performance in rod lift systems. The enhanced wear resistance and surface stability associated with EN-Diamond coatings contribute to extended barrel run-life, reduced plunger wear, and improved sealing efficiency at the plunger–barrel interface. Additionally, the reduction in wear-related degradation leads to lower maintenance frequency and improved operational reliability, particularly in sand-producing wells where abrasive conditions are severe. Overall, the implementation of EN-Diamond coatings has the potential to significantly improve system performance and reduce total cost of ownership for rod lift operations.