VDMA
Fluid Power Association

23rd ISC

International Sealing Conference

Stuttgart, Germany
Sept.30 - Oct.1, 2026

Sealing the future –
Facing the challenges of tomorrow

UNI STUTTGART

Fachverband Fluidtechnik im VDMA e. V. Lyoner Str. 18
50628 Frankfurt am Main
Germany

Phone +49 69 6603-1513
E-Mail maximilian.baxmann@vdma.eu

Internet www.vdma.eu/fluid

Ni–B Coatings as a Chrome Alternative: Endurance-Test Evidence for Rod Seal Compatibility

Cebeci Unlu Mine, Tanyeri Cem, Devlen Ozan

Hard chrome plating on hydraulic cylinder rods has long been the “default” for wear and corrosion resistance, yet near-term regulatory pressure in the EU is accelerating the need for qualified alternatives. In this study, we evaluate rod seal performance on an electroless nickel–boron (Ni–B) coated rod surface as a direct substitute for hard chrome, using a controlled, like-for-like endurance comparison.
Test rods are prepared in two variants: (i) conventional hard chrome-plated rods (baseline) and (ii) electroless Ni–B coated rods. Electroless Ni–B coatings are reported to provide high hardness and wear resistance, with boron content around ~6% and hardness values of ~730 HV as-coated and up to ~1100 HV after heat treatment; the process route is commonly aligned with standards such as ASTM B607-21 and SAE AMS2433D. Post-coating heat treatment conditions are considered to reflect practical industrial approaches for reaching chrome-like hardness levels.

Rod seal sets of identical design and material are assembled against each rod surface and subjected to a life test under defined pressure, velocity, and temperature envelopes representative of hydraulic service. Performance is benchmarked using (a) leakage rate evolution, (b) friction force and stick–slip tendency, (c) seal lip wear and damage modes, (d) rod surface condition changes (roughness, transfer film, scoring). In addition, we discuss how Ni–B’s typically uniform thickness distribution and characteristic surface topography—often linked to stable lubrication—may influence mixed-lubrication behavior at the rod–seal interface compared to hard chrome.

The outcome targets an engineering-ready assessment of whether electroless Ni–B coated rods can maintain or improve sealing while supporting industry transition away from hard chrome.

1 Introduction

Hydraulic cylinders operating in demanding industrial environments rely heavily on the performance of the rod–seal interface. The interaction between the rod surface and the sealing element directly affects leakage, friction, wear, and ultimately the service life of the sealing system [1], [2]. For decades, hard chromium plating has been the preferred surface treatment for hydraulic cylinder rods due to its combination of high hardness, wear resistance, and corrosion protection [3]. Consequently, most rod seal designs and qualification procedures have historically been developed around the tribological characteristics of hard chrome-plated surfaces.

In recent years, however, increasing regulatory pressure on chromium-containing processes has accelerated the search for alternative surface technologies. In particular, restrictions associated with hexavalent chromium (Cr(VI)) within the European regulatory framework, such as the REACH regulation, have motivated manufacturers across multiple industries to evaluate replacement coatings capable of providing equivalent functional performance [4]. While numerous candidate technologies have been proposed, the sealing industry faces a specific challenge: any alternative rod coating must not only provide adequate hardness and corrosion resistance but also maintain compatibility with existing sealing systems under dynamic operating conditions [5].

Among the potential alternatives, electroless nickel–boron (Ni–B) coatings have attracted considerable attention. Electroless Ni–B deposits are known for their uniform thickness distribution, high hardness, excellent wear resistance, and good corrosion performance [6]. Depending on boron content and post-deposition heat treatment, hardness values comparable to or exceeding those of conventional hard chrome coatings can be achieved [7]. Furthermore, the autocatalytic deposition process enables highly uniform coating thicknesses even on complex geometries, reducing many of the dimensional challenges associated with electroplated coatings.

Previous studies have extensively investigated the mechanical, tribological, and corrosion properties of electroless Ni–B coatings. Research has demonstrated favorable wear resistance and low friction characteristics, supporting their use in automotive, aerospace, and industrial applications [8]. However, the majority of published work has focused on coating characterization, tribometer-based testing (such as pin-on-disk or ball-on-flat), or metal-to-metal contact conditions [9]. Comparatively little information is available regarding the interaction between electroless Ni–B coated rod surfaces and dynamic elastomer sealing systems operating under hydraulic conditions.

The present study investigates the suitability of electroless nickel–boron coatings as a direct replacement for hard chrome-plated hydraulic cylinder rods from a sealing-performance perspective. Rod seals of identical geometry and material composition were tested against both conventional hard chrome and electroless Ni–B coated rod surfaces under controlled endurance conditions representative of hydraulic service. Leakage behaviour, friction characteristics, seal wear, and rod surface condition were monitored throughout testing to assess compatibility between the coating and the sealing system.

The objective is not merely to compare coating properties, but to determine whether electroless Ni–B coated rods can maintain the functional requirements expected from established hard chrome rod surfaces while supporting the industry's transition toward more sustainable and regulatory-compliant surface technologies.

1.1 Hard Chrome Coatings in Hydraulic Rod Applications

Hard chromium plating has been widely used for hydraulic cylinder rods due to its combination of high surface hardness, wear resistance and corrosion protection. As a result, the tribological behaviour of many hydraulic rod sealing systems has historically been developed and validated against hard chrome-plated surfaces. The long-term performance of reciprocating hydraulic seals is strongly influenced by rod surface characteristics, including hardness, roughness and lubrication conditions, making the rod surface a critical component of sealing system performance [10].

In recent years, increasing regulatory pressure on hexavalent chromium (Cr(VI)) processes has accelerated the search for alternative surface technologies capable of providing equivalent functional performance. Consequently, significant industrial efforts have been directed toward identifying coating systems that can maintain the durability and wear resistance associated with hard chrome while reducing environmental and regulatory concerns.

Because hydraulic rod seals operate under mixed-lubrication conditions, the suitability of any alternative coating cannot be assessed solely through hardness or wear measurements. Instead, coating performance must ultimately be evaluated at the rod–seal system level, where friction, leakage and wear mechanisms are governed by the interaction between the coated surface, lubricant and elastomeric sealing material [10].

1.2 Electroless Nickel–Boron (Ni–B) Coatings as an Alternative

Electroless nickel–boron (Ni–B) coatings have attracted attention as a potential alternative to hard chrome in wear-critical applications. Unlike electrolytic coating processes, electroless deposition is autocatalytic and can produce coatings with highly uniform thickness, including on geometrically complex components [11].

According to ASTM B607, electroless nickel–boron coatings are produced from aqueous autocatalytic solutions and are classified according to boron content. The standard identifies engineering-grade coatings containing up to approximately 6 wt.% boron and highlights their use in applications requiring hardness and wear resistance [12].

The mechanical and tribological behaviour of Ni–B coatings has been investigated extensively. Bonin et al. reported that nanocrystalline electroless Ni–B coatings exhibited hardness values of approximately 900 HV in the as-deposited condition, increasing to approximately 1250 HV following heat treatment. The same study demonstrated a substantial reduction in the wear index after heat treatment, along with good scratch resistance under both as-deposited and heat-treated conditions [11].

These findings indicate that electroless Ni–B coatings can provide mechanical properties comparable to those typically associated with hard chrome coatings. Furthermore, the combination of high hardness, wear resistance and uniform coating thickness makes Ni–B a promising candidate for hydraulic rod applications. However, while coating-level properties have been well documented, relatively little information is available regarding the tribological interaction between electroless Ni–B coated rod surfaces and dynamic elastomer sealing systems operating under representative hydraulic service conditions. This lack of system-level validation provides the primary motivation for the present study.

2 Experimental Procedure

2.1 Test Objective

The objective of the present study was to evaluate the compatibility of electroless nickel–boron (Ni–B) coated hydraulic cylinder rods with a dynamic rod sealing system and to compare their performance against conventional hard chrome-plated rods under identical operating conditions.

The comparison focused on sealing performance and tribological behaviour during endurance testing. Particular attention was given to leakage development, friction behaviour, seal wear, and changes in rod surface condition throughout the test duration.

2.2 Rod Surface Variants

Two rod surface configurations were evaluated:

- Hard chrome-plated rod (reference condition)
- Electroless nickel–boron coated rod (alternative surface condition)

Both rod types were manufactured from the same base material and prepared with identical nominal dimensions. The hard chrome-plated rod represented the conventional surface commonly used in hydraulic cylinder applications, whereas the electroless Ni–B coated rod was selected as a potential chromium-free alternative.

Prior to testing, rod surface roughness measurements were performed to verify surface finish consistency and to ensure that observed differences in sealing behaviour could be attributed primarily to coating characteristics rather than dimensional variations.

Table 1: Rod surface roughness values before testing

Test Product	Test Cylinder	Nickel–Boron Coated Rod			Hard Chrome-Plated Rod		
		Before Test			Before Test		
		Ra (µm)	Rz (µm)	Rmr (%)	Ra (µm)	Rz (µm)	Rmr (%)
XT200	Cylinder 1	0.1445	1.2775	71	0.21	1.780	53.500
K35 & XT200	Cylinder 2	0.1495	1.555	76	0.199	1.801	64.000
K35 & K35 PU	Cylinder 3	0.1325	1.2355	76	0.206	1.921	66.000

2.3 Sealing System and Endurance Test Method

A commercially available hydraulic rod seal design was selected for the investigation. Identical seal geometries and material formulations were used throughout the study.

For all tests, new sealing elements were used to eliminate the influence of prior wear. The seals were installed following Kastas assembly procedures and quality standards. Identical installation and test preparation conditions were maintained for both hard chrome-plated and electroless nickel–boron coated rod surfaces to ensure a consistent comparison of tribological performance.

2.3.1 Test Bench

Figure:1 Test image

A hydraulic rod seal test system is a multi-station test rig designed to evaluate the performance of rod-sealing elements in hydraulic cylinders under realistic operating conditions. The system enables the simultaneous testing of six rod seals (1A–1B, 2A–2B, and 3A–3B) mounted on a common reciprocating shaft. A servo-controlled drive applies linear motion at speeds ranging from 0.01 to 0.5 m/s with stroke lengths between 20 and 500 mm, while hydraulic pressure from 10 to 450 bar and temperatures from 10°C to 150°C can be applied to simulate actual service conditions. The system is controlled via a PLC with a touchscreen interface, allowing continuous monitoring and recording of test data. In accordance with ISO 7986, interchangeable seal housings and groove dimensions enable testing under various extrusion gap conditions. In addition, both static and pulsating pressure tests can be performed to evaluate seal extrusion behaviour. During testing, critical performance parameters such as leakage rate, friction force, wear, extrusion resistance, and stick-slip behaviour are measured, providing a comprehensive assessment and comparison of different seal designs and materials.

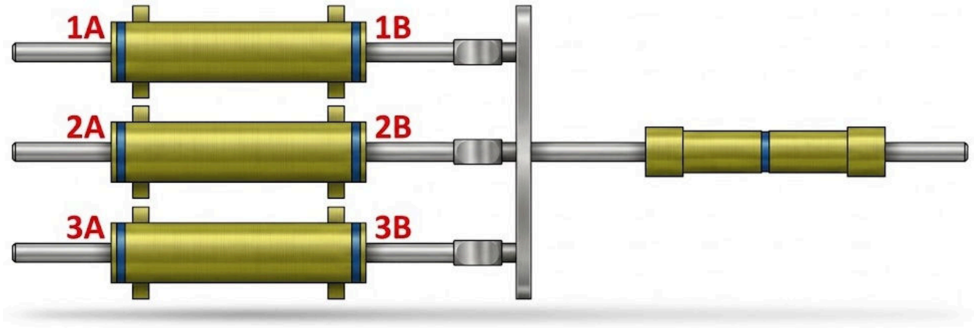


Figure 2: Test schematic

Table 2: Seal configurations used in test product set 1

Test Product-1						
Test Cylinder	**1A**	**1B**	**2A**	**2B**	**3A**	**3B**
Product Code:	XT200	XT200	K35	K35	K35	K35
Product Dimension:	50x65x10	50x65x10	50x65,1x6,3	50x65,1x6,3	50x65,1x6,3	50x65,1x6,3
Material Code:	PU9414	PU9414	PT6003/NB7001	PT6003/NB7001	PT6003/NB7001	PT6003/NB7001

Table 3: Seal configurations used in test product set 2

Test Product-2						
Test Cylinder	**1A**	**1B**	**2A**	**2B**	**3A**	**3B**
Product Code:	-	-	XT200	XT200	K35-PU	K35-PU
Product Dimension:	-	-	50x65x10	50x65x10	50x65,1x6,3	50x65,1x6,3
Material Code:	-	-	PU9414	PU9414	PU6001/NB7001	PU6001/NB7001

The test matrix was designed to investigate both design-related and material-related effects on seal performance. By including different seal geometries (XT200 and K35) and different materials (PU9414, PT6003/NB7001, and PU6001/NB7001), it was possible to evaluate whether the observed differences in friction, leakage, and wear behaviour originated primarily from the rod surface condition, the seal design, or the seal material system.

2.3.2 Test Conditions

The endurance tests were performed under dynamic operating conditions representative of hydraulic cylinder rod applications. To evaluate the sealing performance on the different rod surface variants, a three-stage pressure profile was applied while maintaining constant speed, temperature, and lubrication conditions throughout the test.

The test sequence consisted of an initial running-in period at 50 bar, followed by a high-pressure endurance phase at 315 bar, and a final verification period at 150 bar. The rod velocity was maintained at 0.3 m/s during all test stages. The target travel distances were 10 km, 80 km, and 10 km for the first, second, and third periods, respectively, resulting in a total accumulated sliding distance of 100 km.

The test temperature was controlled at 60 °C to represent typical operating conditions encountered in hydraulic systems. A radial extrusion gap of 0.15 mm was used throughout the test program. VG 46 mineral-based hydraulic oil provided lubrication.

The selected test parameters were intended to subject the sealing system to prolonged dynamic loading and high-pressure conditions, allowing the influence of the rod surface coating on seal performance, leakage behaviour, and wear characteristics to be assessed under comparable operating conditions.

Table 4: Test conditions

Test Parameter	1st Period	2nd Period	3rd Period
Pressure (bar)	50	315	150
Speed (m/s)	0.3	0.3	0.3
Target Distance (km)	10	80	10
Temperature (°C)	60	60	60
Extrusion Gap (mm)	0.15	0.15	0.15
Test Medium	VG 46 Hydraulic Oil	VG 46 Hydraulic Oil	VG 46 Hydraulic Oil

2.3.3 Performance Evaluation Criteria

The compatibility of the electroless Ni–B coated rod surface with hydraulic rod sealing systems was assessed using several performance indicators measured during and after the endurance test.

During testing, the friction force generated by the sealing system was continuously monitored in both forward and backward directions. Stable friction behaviour throughout the test was considered an indication of consistent lubrication conditions and the absence of abnormal seal degradation.

Leakage performance was evaluated at the end of each pressure stage and reported as oil leakage per 100 m of rod travel. Leakage measurements were used as the primary functional criterion for assessing sealing effectiveness under both moderate and high-pressure operating conditions.

Following completion of the 100 km endurance cycle, all seals were removed and subjected to dimensional and visual inspection. Seal wear was quantified by measuring the reduction in seal cross-sectional dimensions and reporting the resulting abrasion loss. In addition, the reduction in sealing preload was determined from dimensional changes before and after testing.

The influence of the rod surface on seal integrity was further assessed through post-test visual examination. The seals were inspected for wear patterns, lip damage, extrusion marks, cracking, and other signs of mechanical damage.

To evaluate possible changes in the rod surface condition, roughness measurements were performed before and after testing. The roughness parameters Ra, Rz, and Rmr were recorded and compared to determine whether the sliding contact generated significant surface modification during the endurance test.

The combined evaluation of friction behaviour, leakage performance, seal wear, preload, visual condition, and surface roughness provided a comprehensive assessment of the suitability of the Ni–B coating for hydraulic rod sealing applications.

3 Results and Discussion

Surface roughness measurements of the working surface were taken before and after the test.

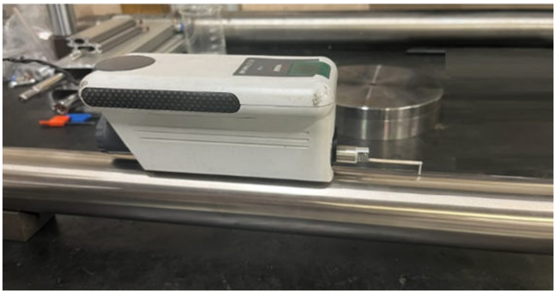


Figure 3: Surface roughness measurement device

Table 5: After test rod surface roughness

Test Product	Test Cylinder	Nickel–Boron Coated Rod After Test			Hard Chrome-Plated Rod After Test		
		Ra (µm)	Rz (µm)	Rmr (%)	Ra (µm)	Rz (µm)	Rmr (%)
XT200	Cylinder 1	0.0385	0.4045	99	0.130	1.570	76.500
K35 & XT200	Cylinder 2	0.024	0.1965	99	0.111	0.801	90.500
K35 & K35 PU	Cylinder 3	0.05	0.627	99	0.109	1.160	74.000

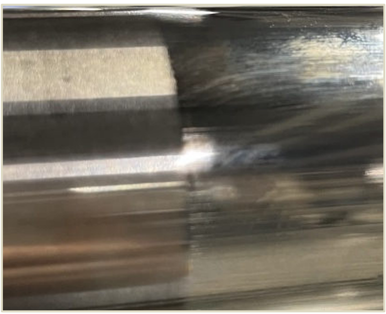


Figure 4:
Ni-B Coating Rod Before-After Test

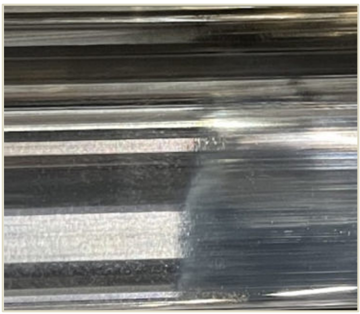
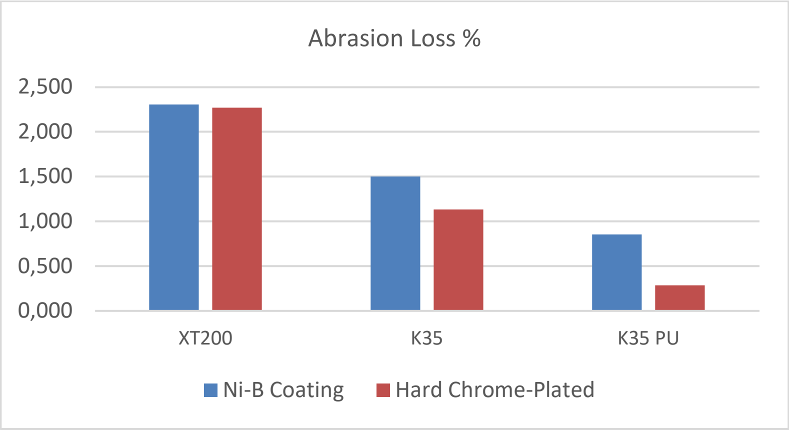


Figure 5:
Hard Chrome Plated Rod Before-After Test

Although both surface treatments exhibited acceptable wear performance throughout the tests, the electroless Ni–B coated rods generally showed slightly less favorable tribological characteristics compared to the hard chrome-plated rods. The Ni–B surfaces experienced greater variations in roughness parameters after testing and, in several test configurations, exhibited marginally higher friction and wear-related responses. While these differences did not result in critical sealing failures or severe functional degradation, the overall results indicate that hard chrome plating provided a more stable surface condition and slightly better tribological performance under the investigated operating conditions. Therefore, the Ni–B coating can be considered a viable alternative to hard chrome plating, although its performance was generally somewhat inferior in the present study.

Table 6: Abrasion Loss Values



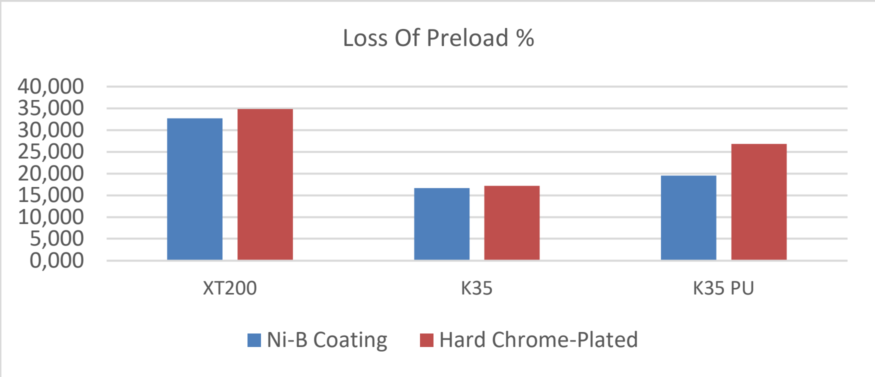
This study compared the tribological performance of electroless Ni–B coating and hard chrome plating on different systems (XT200, K35, and K35 PU) in terms of abrasion loss. The results demonstrate that coating performance is not solely governed by the coating material itself, but is strongly influenced by material–coating interactions and system-specific tribological conditions.

For XT200, Ni–B coated and hard chrome-plated specimens exhibited comparable abrasion loss values, indicating similar wear resistance under the tested conditions. This suggests that Ni–B coatings can provide a viable alternative to hard chrome plating in appropriately matched systems.

In contrast, for K35 and K35 PU, hard chrome plating showed significantly lower abrasion loss compared to Ni–B coatings, indicating superior wear resistance. The pronounced increase in wear for Ni–B coated K35 specimens highlights the sensitivity of this coating system to substrate-dependent tribological compatibility.

Overall, the findings indicate that electroless Ni–B coatings may achieve performance comparable to hard chrome plating under certain operating conditions; however, their tribological response is highly application-dependent. Therefore, the substitution of hard chrome with Ni–B coatings requires careful system-level optimization considering material and contact conditions.

Table 7: Loss of preload



The loss of preload results for Ni–B coated and hard chrome-plated rod surfaces indicate that both coating systems exhibit a comparable influence on seal preload retention, while differences are strongly dependent on the substrate type.

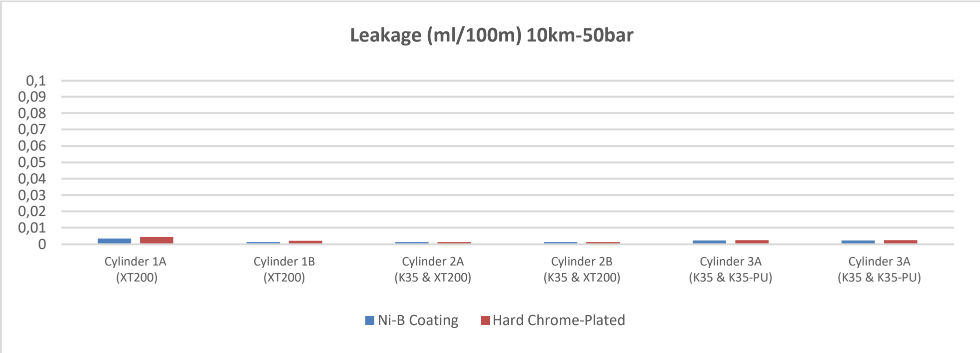
For XT200, both Ni–B coating (32.7%) and hard chrome plating (34.8%) show similar levels of preload loss. This suggests that, under these conditions, the coating type has a limited effect on preload, and both surface treatments provide comparable sealing system stability.

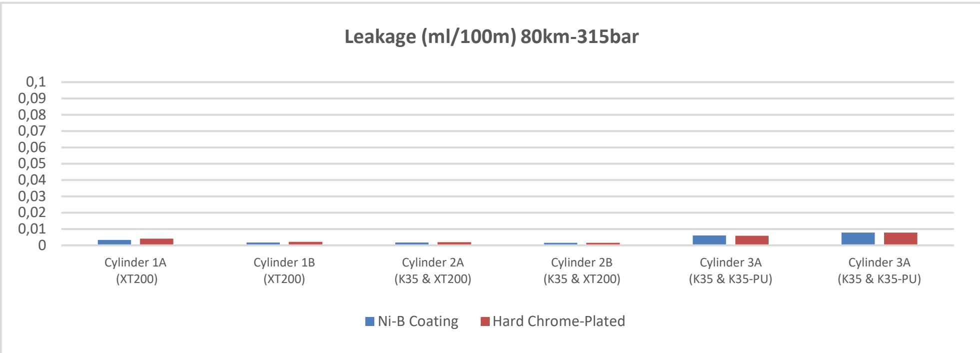
For K35, a slight improvement is observed for Ni–B coating (16.6%) compared to hard chrome plating (17.1%), although the difference is minor. This indicates that Ni–B coating can achieve at least equivalent preload performance to hard chrome in this configuration.

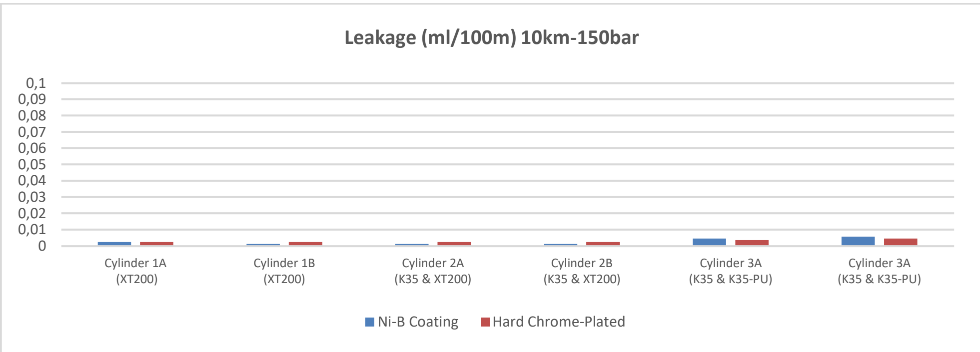
For K35 PU system, a more significant difference is observed, where Ni–B coating (19.5%) results in significantly lower preload loss compared to hard chrome plating (26.8%). This suggests that Ni–B coating provides better compatibility with elastomeric sealing elements in PU-based systems, potentially due to more favorable surface interaction or reduced frictional degradation.

Overall, the results demonstrate that Ni–B coatings can achieve comparable or improved preload relative to hard chrome plating, particularly in elastomer-compatible (PU) systems. However, the effect remains system-dependent, highlighting the importance of coating–seal interaction in determining long-term sealing performance.

Table 8: Leakage Status For Each Period







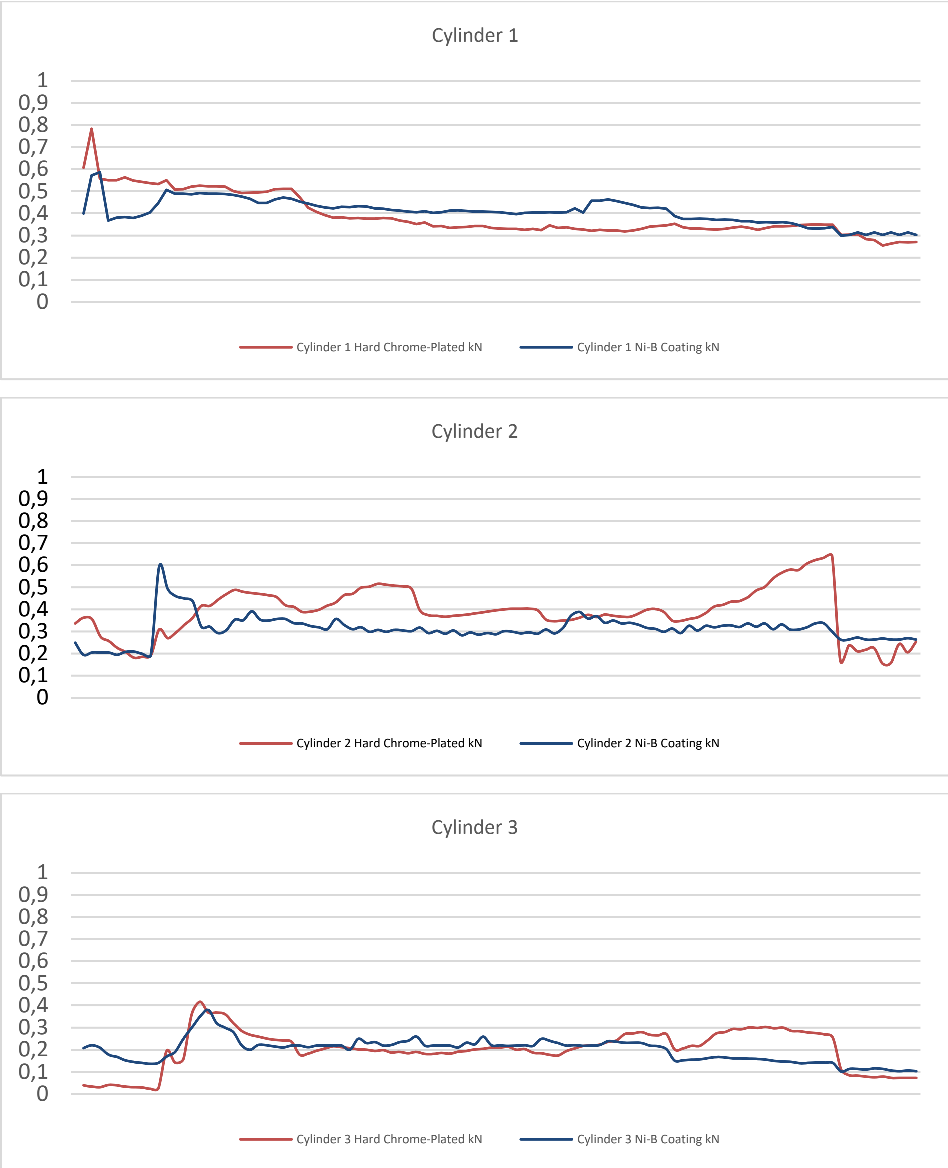
The leakage measurements (ml/100 m) obtained under different test conditions (10 km–50 bar, 80 km–315 bar, and 10 km–150 bar) indicate that both Ni–B coated and hard chrome-plated rod surfaces perform well below the literature-based acceptance threshold of 0.25ml/100m equivalent leakage criterion. Across all cylinder configurations and test conditions, no result approaches the critical limit, confirming that both surface systems ensure adequate sealing integrity.

For XT200-based cylinders (Cylinder 1A and 1B), leakage values remain consistently low for both coating types, with only minor differences observed between Ni–B and hard chrome surfaces. This suggests that coating type has a negligible influence on leakage behaviour for this material group.

For K35-based configurations (Cylinder 2A and 2B), similarly low leakage levels are observed, again with no significant distinction between Ni–B and hard chrome coatings. This indicates stable seal performance and good compatibility between the sealing system and both surface conditions.

In contrast, the K35–PU hybrid system (Cylinder 3A series) exhibits relatively higher leakage values compared to the other configurations, particularly under the 80 km–315 bar condition. However, even in this case, leakage remains well below the acceptance threshold, confirming that the system still operates within acceptable sealing limits.

Table 9: Friction Force For Each Cylinder



The friction force results indicate that both hard chrome-plated and Ni–B coated rods maintained stable tribological behaviour throughout the endurance tests, with no evidence of severe stick–slip phenomena. Although the Ni–B surfaces exhibited lower Ra and Rz values after testing, their significantly higher Rmr values suggest an increased load-bearing contact area at the seal–rod interface. This may explain the slightly higher friction responses observed in some configurations despite the smoother surface finish. Overall, the friction behaviour remained comparable for both surface treatments, indicating that the Ni–B coating provides tribological compatibility with hydraulic rod sealing systems at a level similar to conventional hard chrome plating.

4 Conclusion

This study evaluated the suitability of electroless nickel-boron (Ni-B) coatings as a potential alternative to hard chrome plating for hydraulic cylinder rods, with particular emphasis on rod seal compatibility under endurance test conditions. The comparison was carried out using identical sealing systems, controlled operating parameters, and a total sliding distance of 100 km, enabling a direct assessment of frictional behaviour, leakage performance, seal wear, preload loss, and rod surface condition.

The results showed that Ni-B coated rods provided sealing performance comparable to hard chrome-plated rods in terms of overall functional leakage behaviour. For all tested seal and cylinder configurations, leakage levels remained clearly below the acceptance criterion throughout all pressure stages, indicating that the Ni-B surface did not create any critical sealing deficiency under the applied hydraulic conditions. This is one of the most important outcomes of the study, since leakage is the primary functional requirement in dynamic rod sealing systems.

In terms of surface condition, both coating systems remained operationally stable after testing. The post-test roughness measurements indicated that the Ni-B coated rods experienced a stronger reduction in roughness values and a marked increase in material ratio, suggesting the development of a smoother running surface during operation. Although this change was more pronounced than for hard chrome, it did not lead to deterioration in sealing behaviour. On the contrary, the results suggest that the Ni-B surface adapted favorably to the tribological contact conditions of the seal interface.

Regarding seal wear and preload retention, the performance of Ni-B coating was found to be system-dependent. For the XT200 configuration, Ni-B and hard chrome exhibited similar abrasion loss and similar preload loss, indicating equivalent behaviour. For the K35 configuration, hard chrome showed lower abrasion loss, while preload retention remained very close for both surfaces. In the K35 PU configuration, Ni-B demonstrated a noticeable advantage in preload retention, even though wear-related behaviour still differed depending on the seal system. These findings confirm that the performance of an alternative rod coating cannot be judged solely on coating hardness or coating-level wear data; instead, it must be assessed through the complete rod-seal-material interaction.

Overall, the endurance test results demonstrate that electroless Ni-B coating is a technically promising alternative to hard chrome plating for hydraulic rod applications, particularly from the perspective of seal compatibility and leakage performance. However, the tribological response varied depending on seal design and material combination, which indicates that successful industrial implementation requires application-specific validation rather than direct one-to-one substitution in all cases.

In conclusion, the present findings support the view that electroless Ni–B coatings can contribute to the transition away from hard chrome by delivering comparable sealing functionality under representative hydraulic service conditions, provided that the seal/coating pairing is validated for the intended application. For practical adoption, further work should focus on long-term field correlation, corrosion performance, optimisation of post-treatment and surface-finishing parameters, and broader validation across different seal materials and operating environments.

5 References

[1] Nikolas, G., & Zaoutsos, S. (2019). "Tribological behavior of hydraulic cylinder seals: A review." *Wear*, 426, 1220-1230.

[2] Paddenberg, J., & Murrenhoff, H. (2015). "Investigation of the friction and leakage behavior of hydraulic rod seals." *International Journal of Fluid Power*, 16(2), 75-85.

[3] Newby, J. (2002). "Hard chromium plating for wear and corrosion resistance." *ASM Handbook, Volume 5: Surface Engineering*, ASM International.

[4] European Chemicals Agency (ECHA). (2013). "Inclusion of substances of very high concern (SVHC) in the Candidate List: Hexavalent chromium compounds." *ECHA Regulation Report*.

[5] Legg, K. O., Graham, M., Chang, P., & Rastagar, F. (2002). "The replacement of electrodeposited chromium." *Surface and Coatings Technology*, 151, 491-500.

[6] Vela-Anaya, S., & Delaunois, F. (2018). "Properties and applications of electroless nickel–boron coatings: A review." *Surface and Coatings Technology*, 349, 891-912.

[7] Vitry, V., & Delaunois, F. (2013). "Formation and characterization of electroless nickel–boron coatings: Effect of heat treatment." *Materials & Design*, 49, 856-864.

[8] Mukhopadhyay, A., Barman, T. K., & Sahoo, P. (2015). "Tribological behavior of electroless Ni-B coatings under dry and lubricated conditions." *Surface Engineering*, 31(11), 834-841.

[9] Bala Srinivasan, P., & Szklarska-Smialowska, Z. (1997). "Corrosion and wear behavior of electroless Ni-B coatings." *Journal of Materials Science*, 32, 4125-4131.

[10] Nikas, G.K., Eighty years of research on hydraulic reciprocating seals: review of tribological studies and related topics since the 1930s, Proceedings of the

Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology, 224 (2010), 1–23.

[11] Bonin, L., Vitry, V., Delaunois, F., Mechanical and wear characterization of electroless nickel-boron coatings, Surface and Coatings Technology, 206 (2011), 1879–1885. DOI: 10.1016/j.surfcoat.2011.08.008.

[12] ASTM International, ASTM B607-21: Standard Specification for Autocatalytic Nickel Boron Coatings for Engineering Use, ASTM International, West Conshohocken, PA, USA, 2021. ASTM B607

6 Authors

Kastas Sealing Technologies,
Atatürk Plastik OSB 3. Street No:5 35660 Menemen / IZMIR / TURKEY:

Mine UNLU CEBECI1, ORCID 0009-0008-4200-7530 mcebeci@kastas.com

Cem TANYERI1, M. Sc., ORCID 0000-0002-1290-2875, ctanyeri@kastas.com

Devlen Ozan1 , M. Sc., ORCID 0000-0002-8079-0553, odevlen@kastas.com

https://doi.org/10.61319/O0DR2IK7