REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 24, No.4 (2023)
http://www.veterinaria.org
Received:08-09-2023 Revised:13-10-2023 Accepted:07-11-2023

Performance Evaluation of Plasma-Nitrided Chain Sprockets Through Experimental Wear Testing and Dimensional Analysis

T K Kandiya [1], B B Prajapati [2]

[1]Lecturer in automobile Dept, Government Polytechnic, Ahmedabad. write2bprajapati@gmail.com
[2]Lecturer in Automobile Department, Government Polytechnic, Ahmedabad. tkkandiya@gpahmedabad.ac.in

ABSTRACT
Chain sprockets experience friction, abrasive wear, contact fatigue, and dimensional deterioration during continuous power transmission, which can reduce transmission efficiency and service life. This study evaluates the wear behaviour of plasma-nitrided chain sprockets in comparison with untreated, carbonitrided, and nitrocarburized specimens using a motor-driven chain–sprocket test rig. The sprockets had 43 teeth, a 12.7 mm chain pitch, a 181 mm diameter, and a 7.2 mm thickness; wear, surface hardness, pitch variation, chain elongation, and treatment cost were assessed. After 1,000 km of operation, the plasma-nitrided sprocket exhibited tooth-wear values of 0.006 mm and 0.004 mm, compared with 0.084 mm and 0.008 mm for the untreated sprocket, corresponding to an approximately 89.13% reduction in mean wear. Surface hardness increased from 236.67 BHN to 324.72 BHN, representing an improvement of about 37.20%, while no measurable pitch change was observed after testing. These results indicate that plasma nitriding substantially improves sprocket wear resistance and dimensional stability, although confirmation of actual service-life extension requires further cumulative wear measurements, repeat testing, and a defined failure criterion.

Keywords: Plasma nitriding, Chain sprockets, Wear resistance, Surface hardness, Abrasive wear, Dimensional stability, Surface modification, Carbonitriding, Nitrocarburizing, Chain–sprocket wear testing.

1. Introduction

1.1 Background of chain–sprocket transmission systems

Chain drives are widely used in motorcycles, agricultural machinery, conveyors, industrial equipment, and power transmission systems because of their positive power transmission characteristics, compact arrangement, and ability to transmit mechanical power between separated shafts.

A typical chain transmission system consists of a driving sprocket, driven sprocket, roller chain, shafts, bearings, and supporting components. The driving sprocket transfers rotational motion and torque through the chain to the driven sprocket.

During operation, chain rollers repeatedly engage and disengage with sprocket teeth. The resulting contact stresses, sliding interactions, and repeated loading contribute to progressive wear of the contacting surfaces.

The main wear-related problems associated with chain sprockets include abrasive wear, adhesive wear, surface fatigue, tooth-profile deterioration, and loss of dimensional accuracy.

The severity of these problems depends on operating speed, transmitted load, lubrication, material properties, surface condition, and environmental exposure.

1.2 Problem associated with sprocket wear

Progressive wear of sprocket teeth can adversely affect the mechanical performance of chain drives. Excessive tooth wear changes the effective contact geometry between the chain and sprocket, potentially producing uneven load distribution, increased vibration, poor chain engagement, and premature component replacement.

In conventional steel sprockets, the surface may experience substantial deterioration under repeated loading even when the core material retains adequate strength.

Improving surface hardness while maintaining appropriate core toughness is therefore an important approach to enhancing sprocket performance.

1.3 Plasma nitriding as a surface engineering treatment

Plasma nitriding, also known as ion nitriding, is a thermochemical surface treatment in which nitrogen is introduced into the surface of a metallic component using a controlled plasma environment.

The treatment can produce a compound layer and a nitrogen-enriched diffusion zone. Depending on material composition and processing conditions, these regions can increase surface hardness, improve resistance to certain wear mechanisms, and introduce beneficial residual compressive stresses.

Unlike a separately deposited coating, plasma nitriding modifies the substrate surface through nitrogen diffusion and nitride formation.

Potential advantages include improved wear resistance, relatively low dimensional distortion under appropriately controlled conditions, and the ability to treat complex metallic components.

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 24, No.4 (2023)
http://www.veterinaria.org
Received:08-09-2023 Revised:13-10-2023 Accepted:07-11-2023

1.4 Need and significance of the investigation

Although surface hardening processes are well established for gears, shafts, dies, and other mechanical components, their comparative performance in motorcycle chain sprockets requires evaluation under representative operating conditions.
The present investigation focuses on comparing plasma nitriding with carbonitriding, nitrocarburizing, and untreated sprocket surfaces.
The significance of the work lies in combining wear measurements, hardness evaluation, dimensional stability, and preliminary economic assessment to determine the practical suitability of plasma nitriding for chain-sprocket applications.

2. Literature Background and Research Gap

2.1 Wear mechanisms in chain sprockets

Wear in chain–sprocket systems involves complex interactions between contacting metallic surfaces. Under insufficient lubrication, surface asperities may interact directly, promoting adhesive and abrasive wear.
Hard particles or debris trapped between the chain rollers and sprocket teeth can also contribute to material removal. Repeated contact loading may initiate surface or subsurface fatigue damage.
Wear behaviour depends not only on hardness but also on microstructure, residual stresses, surface roughness, lubrication, and contact conditions.

2.2 Conventional surface hardening methods

Carbonitriding introduces carbon and nitrogen into the surface of steel, commonly followed by quenching to develop a hardened case. Nitrocarburizing introduces nitrogen and carbon and can improve surface properties depending on the process conditions.
Plasma nitriding generally operates below the austenitizing temperature of steel and can therefore reduce the need for post-treatment quenching.
These treatments differ in case structure, hardness distribution, processing temperature, distortion tendency, and potential wear performance.

2.3 Research gap

The present work addresses the following research needs:

1. Comparative evaluation of wear behaviour in untreated, plasma-nitrided, carbonitrided, and nitrocarburized chain sprockets under a common experimental protocol.
2. Investigation of the relationship between surface hardness and actual sprocket-tooth wear.
3. Evaluation of dimensional stability after controlled chain-drive operation.
4. Development of a wear-based service-life estimation framework using experimentally measured data.
5. Assessment of performance improvement relative to the additional surface-treatment cost.

These are the research gaps targeted by the present investigation; a complete novelty claim requires comparison against published chain-sprocket studies.

3. Research Objectives

The main objective of the study is to experimentally evaluate the wear behaviour and service-life potential of plasma-nitrided chain sprockets.
The specific objectives are:

1. To investigate the wear characteristics of untreated and plasma-nitrided chain sprockets.
2. To compare the wear performance of plasma-nitrided, carbonitrided, and nitrocarburized sprockets.
3. To examine the influence of surface treatment on sprocket hardness.
4. To evaluate changes in tooth dimensions and chain elongation after operation.
5. To assess wear performance at different operating distances and, where experimental measurements are available, different rotational speeds and loading conditions.
6. To develop a mathematical framework for estimating sprocket service life from measured wear trends.
7. To evaluate the relative treatment cost and potential practical benefits of plasma nitriding.

4. Experimental Materials and Methodology

4.1 Selection of sprocket specimens

Four types of chain sprockets were considered for the experimental investigation.

Specimen	Surface condition	Designation
S1	Untreated / normal	UT
S2	Plasma nitrided	PN
S3	Carbonitrided	CN
S4	Nitrocarburized	NC

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 24, No.4 (2023)
http://www.veterinaria.org
Received:08-09-2023 Revised:13-10-2023 Accepted:07-11-2023

For a controlled comparison, specimens should have equivalent geometry and base-material characteristics. Material grade and treatment specifications require confirmation from the experimental records.

4.2 Specifications of chain and sprocket

Parameter	Reported specification
Sprocket type	Rear chain sprocket
Number of teeth	43
Nominal chain pitch	12.7 mm
Reported sprocket diameter	181 mm
Sprocket thickness	7.2 mm
Chain roller diameter	7.92 mm
Chain type	Motorcycle roller chain
Chain length	Approximately 106 links; variant-dependent
Chain material	High-strength steel, grade to be verified

Note: The nominal 12.7 mm pitch corresponds to a half-inch-pitch chain family. The exact chain designation and whether the 181 mm diameter is the outside or another reference diameter should be confirmed.

4.3 Experimental setup

The experimental arrangement consists of an electric motor, variable frequency drive, driving and driven sprockets, roller chain, flywheel, supporting shafts, bearings, and a rigid mounting frame.

Figure 1. Schematic representation of the experimental drive system

The VFD permits adjustment of motor frequency and consequently motor rotational speed. The flywheel provides rotational inertia and may influence transient speed fluctuations.

The actual motor rating, speed ratios, flywheel inertia, transmitted torque, and chain tension should be documented for reproducibility.

4.4 Plasma nitriding treatment

The plasma nitriding process involves specimen cleaning, placement in a controlled-atmosphere chamber, evacuation, gas introduction, plasma generation, and holding at a specified temperature for a controlled duration.

Nitrogen-bearing plasma species interact with the steel surface, enabling nitrogen uptake and diffusion.

The following process parameters must be inserted from the actual treatment certificate or laboratory record.

These parameters are necessary for correlating nitriding conditions with wear performance.

4.5 Experimental testing procedure

The experimental procedure is organized as follows:

1. Inspect the sprockets and record their initial dimensions, tooth profiles, and hardness.
2. Prepare the untreated and surface-treated specimens.
3. Install each specimen in the chain-drive experimental setup under consistent alignment and tension conditions.
4. Operate the drive under the selected speed, load, and lubrication conditions.
5. Record the accumulated equivalent operating distance.
6. Stop the equipment at predetermined intervals and measure tooth wear, sprocket dimensions, and chain elongation.
7. Compare the results across treatment conditions.
8. Calculate wear reduction, average wear rate, and conditional service-life estimates.

4.6 Experimental operating conditions

The intended distance-based measurement schedule is shown below.

Test stage	Accumulated distance
Stage I	1,000 km
Stage II	2,000 km
Stage III	3,000 km
Stage IV	4,000 km
Stage V	5,000 km

A 5,000 rpm condition has also been identified for investigation. However, actual measurements at that rotational speed, together with load, torque, and lubrication conditions, are not available in the present dataset.

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 24, No.4 (2023)
http://www.veterinaria.org
Received:08-09-2023 Revised:13-10-2023 Accepted:07-11-2023

Accordingly, the quantitative results below refer to the reported 1,000 km operating-distance condition rather than a verified multi-speed or multi-load test matrix.

4.7 Wear measurement and analysis

Linear tooth wear is expressed as:

$$W = |d_0 - d_t|$$

where:
\(W\) = measured linear wear (mm)
\(d_0\) = initial reference dimension (mm)
test conditions.

5. Experimental Results and Analysis

5.1 Comparative wear characteristics at 1,000 km

The measured tooth-wear readings are presented in Table 3.

Sprocket condition	Wear position 1 (mm)	Wear position 2 (mm)	Mean of two readings (mm)
Untreated	0.084	0.008	0.046
Plasma nitrided	0.006	0.004	0.005
Carbonitrided	0.007	0.005	0.006
Nitrocarburized	0.008	0.006	0.007

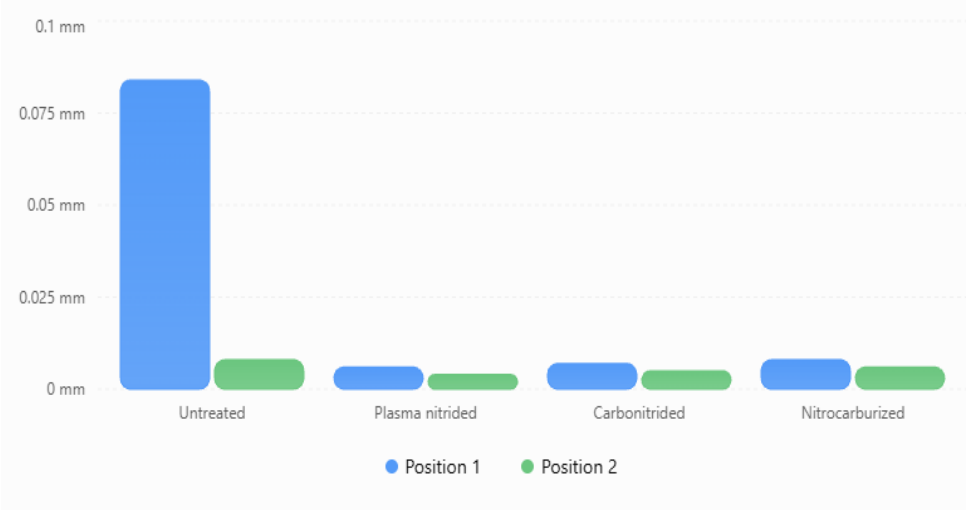


Figure 2. Comparison of tooth wear at 1,000 km

Measured wear at two tooth positions; lower is better.

■ Position 1
■ Position 2

The untreated sprocket recorded the highest wear at position 1, whereas the plasma-nitrided sprocket recorded the lowest wear at both positions.

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 24, No.4 (2023)
http://www.veterinaria.org
Received:08-09-2023 Revised:13-10-2023 Accepted:07-11-2023

$$R_{w1} = \frac{0.084 - 0.006}{0.084} \times 100$$

$$\boxed{R_{w1} = 92.86\%}$$

At
position 2:

$$R_{w2} = \frac{0.008 - 0.004}{0.008} \times 100$$

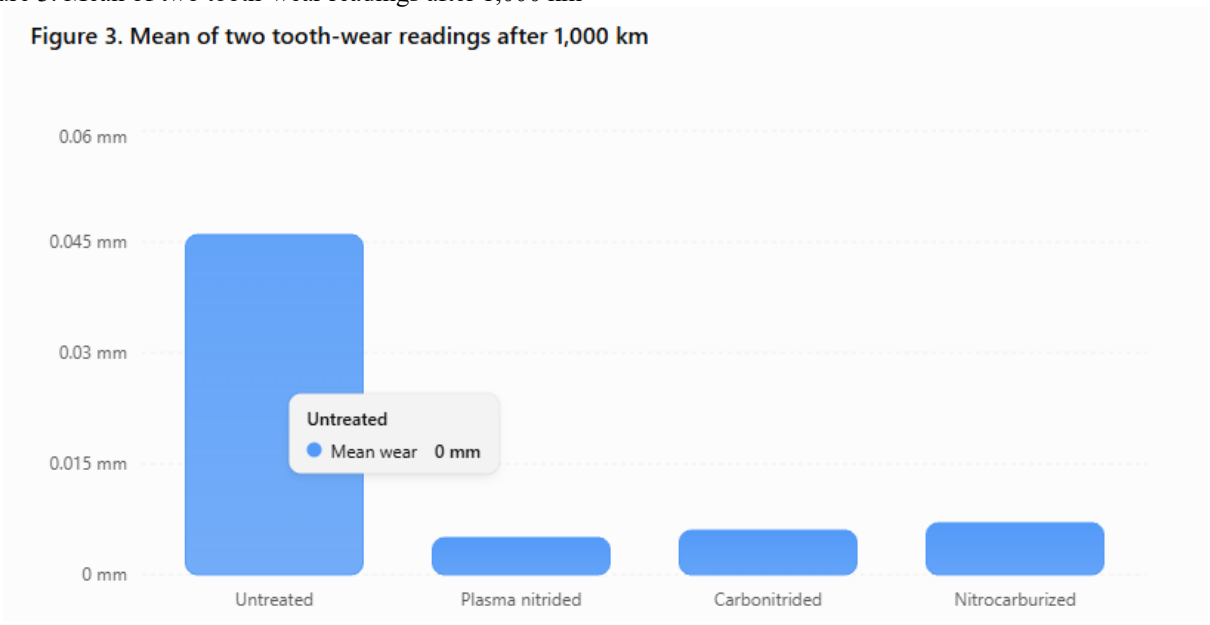
$$\boxed{R_{w2} = 50.00\%}$$

The substantial difference between the two untreated wear readings indicates that local measurement position, contact distribution, or measurement uncertainty may strongly influence the results. This should be examined before drawing conclusions about uniform tooth wear.

5.2 Mean wear reduction

The arithmetic mean of the two reported wear positions was calculated for each specimen.

Figure 3. Mean of two tooth-wear readings after 1,000 km



The percentage reduction in mean wear for the plasma-nitrided specimen was:

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 24, No.4 (2023)
http://www.veterinaria.org
Received:08-09-2023 Revised:13-10-2023 Accepted:07-11-2023

$$R_{mean} = \frac{0.046 - 0.005}{0.046} \times 100$$

$$\boxed{R_{mean} = 89.13\%}$$

This result indicates a substantial reduction in the arithmetic mean of the two measurements. However, the mean of two positions is not equivalent to a statistically representative average across multiple sprockets.

5.3 Comparative wear reduction

Surface condition	Mean wear (mm)	Reduction compared with untreated
Untreated	0.046	0%
Plasma nitrided	0.005	89.13%
Carbonitrided	0.006	86.96%
Nitrocarburized	0.007	84.78%

Figure 4. Reduction in mean measured wear relative to untreated sprocket

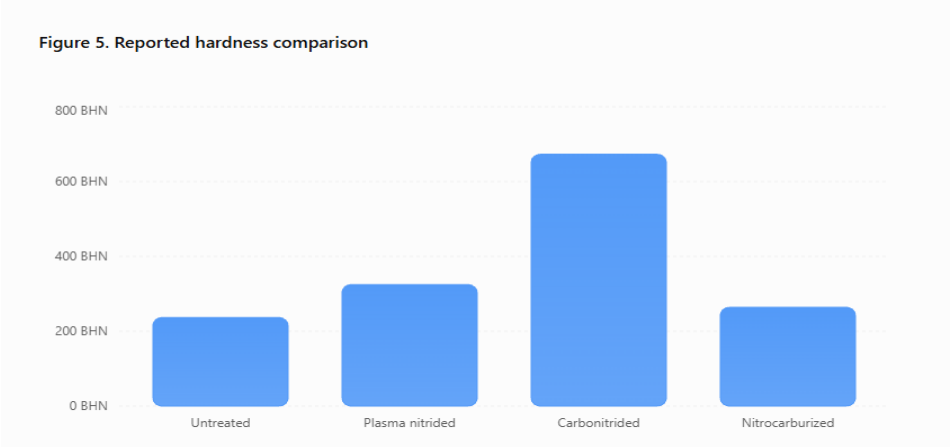
The plasma-nitrided sprocket produced the lowest mean measured wear among the investigated specimens, followed by carbonitrided and nitrocarburized specimens.
The small absolute differences between the treated specimens—0.001 mm in mean wear between successive treatments—require consideration of instrument resolution and experimental repeatability.

5.4 Hardness characteristics

Surface hardness is an important parameter influencing resistance to plastic deformation and some forms of wear.
The reported hardness values are shown below.

Sprocket condition	Reported hardness (BHN)	Increase relative to untreated
Untreated	236.67	—
Plasma nitrided	324.72	37.20%
Carbonitrided	673.00	184.36%
Nitrocarburized	264.00	11.55%

Figure 5. Reported hardness comparison



The plasma-nitrided sprocket showed an increase in reported hardness of:

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 24, No.4 (2023)
http://www.veterinaria.org
Received:08-09-2023 Revised:13-10-2023 Accepted:07-11-2023

$$H_i = \frac{324.72 - 236.67}{236.67} \times 100$$

$$\boxed{H_i = 37.20\%}$$

Although the carbonitrided specimen has the highest reported hardness, the plasma-nitrided specimen exhibited the lowest wear in the available measurements.
This suggests that hardness alone does not fully explain the observed wear behaviour. Other factors may include compound-layer characteristics, diffusion-zone structure, surface roughness, residual stress, and contact conditions.
The reported 673 BHN value should be checked against the original test method and conversion procedure. Thin hardened cases are often more appropriately evaluated using microhardness testing because conventional Brinell indentation can be influenced by the softer underlying material.

5.5 Dimensional stability and pitch variation

Pitch measurements before and after the 1,000 km test are summarized below.

Sprocket	Initial reported pitch (mm)	Final reported pitch (mm)	Signed change (mm)
Untreated	12.18	12.19	+0.01
Plasma nitrided	12.55	12.55	0.00
Carbonitrided	12.83	12.84	+0.01
Nitrocarburized	12.74	12.73	−0.01

The plasma-nitrided sprocket exhibited no measurable change in the reported pitch dimension.
This is consistent with improved dimensional stability under the tested conditions.
However, the initial reported pitch values differ substantially among specimens despite the common nominal chain pitch of 12.7 mm. The measurement definition, datum, and instrument must therefore be verified before treating these figures as directly comparable sprocket pitch measurements.
The zero change should be interpreted as no detected change at the stated measurement precision, not as proof that absolutely no deformation occurred.

5.6 Chain elongation characteristics

Sprocket condition	Reported chain elongation after 1,000 km
Untreated	0.01 mm
Plasma nitrided	0.00 mm
Carbonitrided	0.01 mm
Nitrocarburized	0.01 mm

The plasma-nitrided system recorded no measurable chain elongation, whereas the other systems recorded 0.01 mm.
These findings may indicate differences in the mechanical interaction between the chain and treated sprocket surfaces.
Nevertheless, chain elongation primarily results from cumulative wear at chain joints and is also affected by lubrication, tension, contamination, and operating load. A causal relationship between sprocket treatment and chain elongation cannot be established from these readings alone.
The measurement span and resolution should also be reported.

5.7 Wear rate analysis

The distance-normalized linear wear rate was calculated using:

$$W_r = \frac{W}{D}$$

For the untreated sprocket:

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 24, No.4 (2023)
http://www.veterinaria.org
Received:08-09-2023 Revised:13-10-2023 Accepted:07-11-2023

$$W_{r,UT} = \frac{0.046}{1000} = 4.6 \times 10^{-5}\ \mathrm{mm/km}$$

For the plasma-nitrided sprocket:

$$W_{r,PN} = \frac{0.005}{1000} = 5.0 \times 10^{-6}\ \mathrm{mm/km}$$

The calculated wear rates for all four conditions are presented below.

Sprocket	**Mean measured wear (mm)**	**Linear wear rate (mm/km)**
Untreated	0.046	0.000046
Plasma nitrided	0.005	0.000005
Carbonitrided	0.006	0.000006
Nitrocarburized	0.007	0.000007

The plasma-nitrided specimen exhibited approximately 9.2 times lower distance-normalized mean wear than the untreated specimen during the reported 1,000 km interval.
This is a comparison of observed linear wear rates, not yet a validated service-life ratio.

6. Service Life Prediction of Plasma-Nitrided Chain Sprockets
6.1 Mathematical approach
Service-life prediction is an important part of the investigation because improved wear resistance can potentially increase the operating distance before a sprocket reaches an unacceptable tooth-wear condition.
A simplified linear wear model is expressed as:

$$W(D) = W_0 + kD$$

where:
(W(D)\) = cumulative wear at distance \(D\)
(W_0\) = initial wear offset (mm)
(k\) = distance-normalized linear wear coefficient (mm/km)
(D\) = accumulated operating distance (km)
Assuming an initial wear offset of zero and a constant wear rate, the estimated distance to a specified wear limit is:

$$D_f = \frac{W_{lim}}{k}$$

where \(W_{lim}\) is the permissible wear depth established by a relevant design or maintenance criterion.
6.2 Conditional service-life improvement factor
The ratio of estimated service lives, assuming identical allowable wear limits and constant linear wear rates, is:

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 24, No.4 (2023)
http://www.veterinaria.org
Received:08-09-2023 Revised:13-10-2023 Accepted:07-11-2023

$$LIF = \frac{k_{UT}}{k_{PN}}$$

$$LIF = \frac{0.000046}{0.000005}$$

$$\boxed{LIF = 9.2}$$

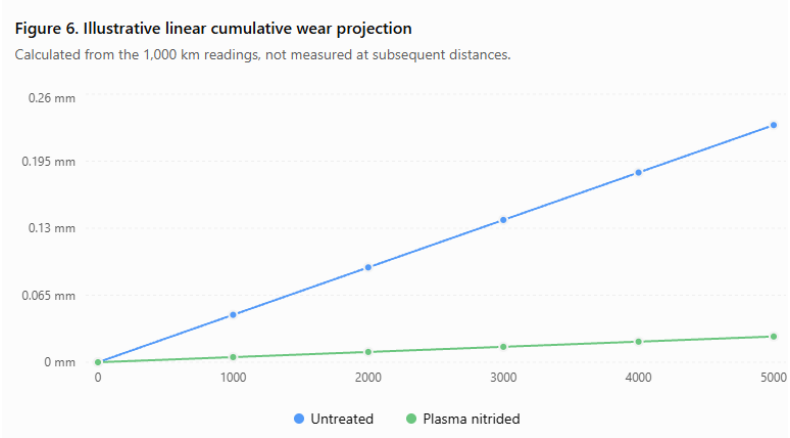
Under these assumptions, the plasma-nitrided sprocket would take approximately 9.2 times as much operating distance as the untreated sprocket to accumulate the same amount of linear wear.
This value represents a conditional model-based improvement factor, not an experimentally demonstrated increase in actual service life.

6.3 Illustrative cumulative wear projection

The following values are calculated by extending the initial 1,000 km mean wear rate linearly. They are projections, not measurements from the 2,000–5,000 km experiments.

Operating distance	Untreated projected wear (mm)	Plasma-nitrided projected wear (mm)	Projected reduction
1,000 km	0.046	0.005	89.13%
2,000 km	0.092	0.010	89.13%
3,000 km	0.138	0.015	89.13%
4,000 km	0.184	0.020	89.13%
5,000 km	0.230	0.025	89.13%

Figure 6. Illustrative linear cumulative wear projection



Calculated from the 1,000 km readings, not measured at subsequent distances.

■ Untreated
■ Plasma nitrided

The projected curves illustrate the potential effect of a sustained reduction in linear wear rate. In actual chain drives, wear may not increase linearly because of running-in, surface-layer removal, changing contact geometry, lubrication degradation, and accumulated fatigue damage.
Consequently, the model must be validated using measured cumulative wear data at subsequent operating distances.

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 24, No.4 (2023)
http://www.veterinaria.org
Received:08-09-2023 Revised:13-10-2023 Accepted:07-11-2023

6.4 Illustrative service-life calculation

To demonstrate the model, consider a hypothetical permissible wear limit of 0.10 mm. This is an assumed threshold for mathematical illustration and is not a verified rejection limit for the tested sprocket.

For the untreated sprocket:

$$D_{f,UT} = \frac{0.10}{0.000046}$$

$$D_{f,UT} \approx 2174 \text{ km}$$

For the plasma-nitrided sprocket:

$$D_{f,PN} = \frac{0.10}{0.000005}$$

$$D_{f,PN} = 20000 \text{ km}$$

Under the assumed linear wear model, the plasma-nitrided specimen would reach the hypothetical wear limit at a much greater distance.

However, these values must not be interpreted as actual sprocket replacement intervals. Real service life may be controlled by other factors, including tooth-profile deterioration, fatigue failure, chain elongation, and loss of proper engagement.

7. Influence of Operating Conditions on Wear Behaviour

7.1 Effect of rotational speed

Rotational speed influences the frequency of chain engagement and disengagement, the dynamic loading of sprocket teeth, and the sliding conditions at contacting surfaces.

At higher rotational speeds, contact frequency and dynamic effects can increase. Depending on lubrication and load, the resulting wear response may increase or decrease.

Plasma nitriding may reduce surface damage through increased hardness and modified surface structure. However, a quantitative relationship between speed and wear cannot be established without experimental readings at multiple speeds.

For future validation, a suitable experimental matrix could include the following speeds, subject to equipment safety and operating limits.

Operating condition	Suggested motor speed	Required measurement
Low speed	1,000 rpm	Wear, temperature, noise
Moderate speed	2,000 rpm	Wear, temperature, noise
Higher speed	3,000 rpm	Wear, temperature, noise
High speed	4,000 rpm	Wear, temperature, noise
Maximum proposed test speed	5,000 rpm	Wear, temperature, noise

These are proposed test conditions, not a record of completed experiments. Motor speed must also be distinguished from actual sprocket speed when the drive contains speed-reduction elements.

7.2 Effect of applied load

Increased transmitted load generally increases contact forces between chain rollers and sprocket teeth.

A simplified tangential chain force can be estimated as:

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 24, No.4 (2023)
http://www.veterinaria.org
Received:08-09-2023 Revised:13-10-2023 Accepted:07-11-2023

$$F_t = \frac{2T}{d_p}$$

where:
\(F_t\) = tangential force (N)
\(T\) = transmitted torque (N·m)
\(d_p\) = sprocket pitch diameter (m)
The load-bearing capability of the treated surface depends on the hardness and toughness of the case, its thickness, the core material, and the actual contact geometry.
Controlled load testing is required to determine whether the observed advantage of plasma nitriding remains consistent across the intended operating range.

7.3 Effect of lubrication

Lubrication plays an important role in chain-drive durability by reducing direct metal-to-metal contact, limiting frictional heating, and assisting in the removal of wear debris.
Under inadequate lubrication, surface hardening may help resist certain wear mechanisms, but it cannot eliminate the effects of severe contact, contamination, or inadequate chain maintenance.
Future testing should compare dry, boundary-lubricated, and properly lubricated conditions using a defined lubricant and application method.

7.4 Effect of operating distance

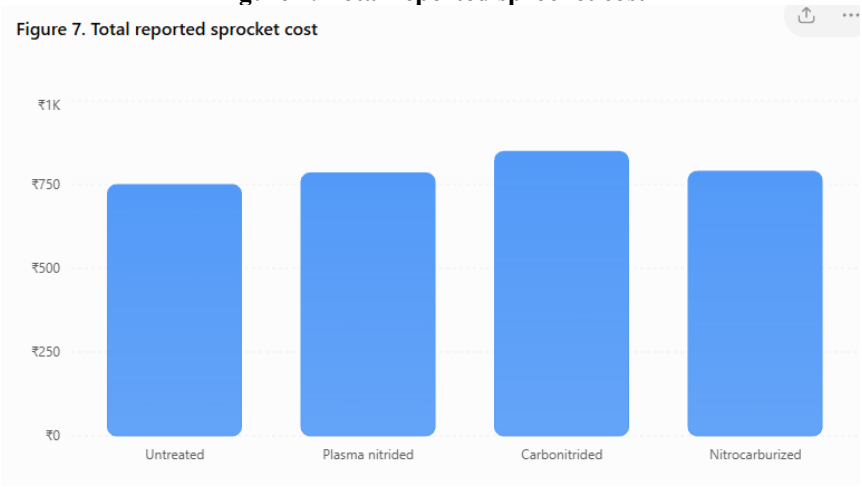
Cumulative operating distance is directly related to the number of contact cycles experienced by the sprocket teeth.
The available 1,000 km measurements demonstrate lower measured wear in the plasma-nitrided specimen.
Additional measurements at 2,000, 3,000, 4,000, and 5,000 km are required to establish the shape of the actual cumulative wear curve and determine whether the initial performance advantage persists.

8. Economic Evaluation of Surface Treatments

Treatment cost is an important consideration when selecting a surface engineering process for commercial chain sprockets. The reported cost comparison is presented below.

Sprocket condition	Base component cost (₹)	Treatment cost (₹)	Total cost (₹)
Untreated	750	0	750
Plasma nitrided	750	35	785
Carbonitrided	810	39	849
Nitrocarburized	750	40	790

Figure 7. Total reported sprocket cost



The additional initial cost of plasma nitriding relative to the untreated sprocket is:

REDVET - Revista electrónica de Veterinaria - ISSN 1695-7504
Vol 24, No.4 (2023)
http://www.veterinaria.org
Received:08-09-2023 Revised:13-10-2023 Accepted:07-11-2023

$$\Delta C = 785 - 750 = ₹35$$

The percentage increase is:

$$C_i = \frac{35}{750} \times 100$$

$$\boxed{C_i = 4.67\%}$$

The plasma-nitrided specimen therefore exhibited substantially lower measured mean wear for a reported initial cost increase of 4.67%.
A complete life-cycle cost analysis would require validated service life, replacement labour, chain replacement requirements, downtime, and maintenance costs.

9. Discussion

The experimental observations indicate that plasma nitriding has a beneficial effect on the measured wear performance of the investigated chain sprockets.
At 1,000 km, the plasma-nitrided specimen exhibited an 89.13% reduction in the arithmetic mean of the two tooth-wear measurements compared with the untreated specimen. The reported surface hardness also increased by approximately 37.20%.
The improvement in wear performance may be associated with nitrogen-enriched surface regions developed during plasma nitriding. Depending on treatment conditions and substrate composition, a compound layer and diffusion zone can contribute to increased resistance against plastic deformation and certain wear mechanisms.
An important observation is that the carbonitrided specimen exhibited a higher reported hardness than the plasma-nitrided specimen, yet showed slightly greater measured wear. This illustrates that a single hardness value is insufficient to characterize tribological performance.
Surface roughness, contact pressure, residual stress, case depth, compound-layer structure, and lubrication may all contribute to the wear response.
The absence of measurable pitch change in the plasma-nitrided specimen is encouraging, but the different initial dimensional readings and limited measurement resolution require further verification.
The preliminary economic analysis also suggests that plasma nitriding could be attractive for chain-sprocket applications, since the reported additional treatment cost is relatively small compared with the observed improvement in wear resistance.
Nevertheless, several limitations must be considered. The current analysis is based on two wear positions per condition at one verified distance interval. The number of independently tested specimens, repeatability, measurement uncertainty, and detailed operating conditions have not yet been established.
Further evidence is required before attributing all performance differences specifically to the nitriding process or making definitive claims about service-life extension.

10. Conclusions

The following conclusions are drawn from the currently available experimental observations.

1. Improved wear resistance: At the reported 1,000 km test distance, plasma nitriding reduced measured tooth wear by 92.86% at position 1 and 50.00% at position 2 relative to the untreated specimen.
2. Reduction in mean measured wear: The arithmetic mean of the two readings decreased from 0.046 mm to 0.005 mm, corresponding to an 89.13% reduction.
3. Improved reported hardness: Plasma nitriding increased the reported hardness from 236.67 BHN to 324.72 BHN, representing an improvement of approximately 37.20%.
4. Dimensional stability: No pitch change was detected in the plasma-nitrided specimen at the reported measurement precision after 1,000 km of operation.
5. Comparison with alternative treatments: The plasma-nitrided specimen exhibited lower measured wear than the carbonitrided and nitrocarburized specimens under the reported test condition.
6. Wear-based service-life potential: A simplified linear model produced a conditional wear-rate-based improvement factor of 9.2. This finding indicates potential for extended service life but requires experimental validation.

7. Economic potential: The reported initial cost of the plasma-nitrided sprocket was ₹785 compared with ₹750 for the untreated specimen, an increase of 4.67%.

Overall, the available findings suggest that plasma nitriding is a promising surface treatment for improving the wear performance of motorcycle chain sprockets. Its effectiveness over a full operating life, and across different speeds, loads, and lubrication conditions, should be established through further controlled testing.

References

1. I. M. Hutchings and P. Shipway, Tribology: Friction and Wear of Engineering Materials, 2nd ed. Oxford, U.K.: Butterworth-Heinemann, 2017.joh.cam.ac+1
2. J. R. Davis, Ed., Surface Hardening of Steels: Understanding the Basics. Materials Park, OH, USA: ASM International, 2002.
3. G. E. Totten, Ed., Steel Heat Treatment: Metallurgy and Technologies. Boca Raton, FL, USA: CRC Press, 2006.
4. ASTM G99, Standard Test Method for Wear Testing with a Pin-on-Disk Apparatus, ASTM International, West Conshohocken, PA, USA. (Supplementary tribological characterization; not a substitute for chain-drive testing.)
5. ASTM E384, Standard Test Method for Microindentation Hardness of Materials, ASTM International, West Conshohocken, PA, USA.
6. ISO 606, Short-Pitch Transmission Precision Roller and Bush Chains, Attachments and Associated Chain Sprockets, International Organization for Standardization, Geneva, Switzerland.
7. D. Sappok, R. Merz, B. Sauer, and M. Kopnarski, "Surface analysis of chain joint components after tribological load and usage of anti-wear additives," in Conference Papers in Science — European Symposium on Friction, Wear, and Wear Protection, Article ID 407048, 2015. doi: 10.1155/2015/407048.onlinelibrary.wiley+1
8. Yu. A. Vlasov, "Estimating the fatigue life subjected to cyclical loading of chains," Problemy Prochnosti, no. 10, pp. 73–76, 1971; English translation published Oct. 1972. All-Union Scientific-Research Institute of Machine Life, Kiev.ijsrd
9. S. Burgess and C. Lodge, "Optimisation of the chain drive system on sports motorcycles," Sports Engineering, vol. 7, no. 2, pp. 65–73, 2004.
10. H. Peeken and W. Coenen, "Influence of oil viscosity and various additives on the wear of roller chains," Wear, vol. 1986, pp. 303–321, 1985/1986. Elsevier Sequoia.
11. S. J. Radcliffe, "Wear mechanisms in unlubricated chains," CEGB Research Division, Berkeley Nuclear Laboratories, U.K., pp. 263–269, 1981.
12. O. Polat, A. Ebrinc, C. Ozen, and S. Akca, "Timing chain wear and effects of different types of lubricants," SAE Technical Paper 2009-01-0198, 2009.
13. T. Fink and H. Bodenstein, "Möglichkeiten der Reibungsreduzierung in Kettentrieben" ("Potential for reducing friction in chain drives"), MTZ — Motortechnische Zeitschrift, vol. 72, no. 7–8, pp. 582–587, 2011. doi: 10.1365/s35146-011-0133-0.
14. D. Nichols, "Patent No. 199,351," U.S. Patent and Trademark Office, California, 2003.
15. S. A. Metil'kov and V. V. Yunin, "Influence of wear of a roller drive chain on transmission fitness," Russian Engineering Research, vol. 28, no. 8, pp. 741–745, 2008.
16. N. C. Bremer, "Heavy duty chain drives for marine propulsion service," Transactions of the ASME, vol. 69, pp. 441–452, 1947.
17. D. Sappok et al., "Wear measurement on chain joint components using a roundness instrument," Periodica Polytechnica Mechanical Engineering, vol. 59, no. 2, pp. 51–59, 2015. doi: 10.3311/PPme.7780.
18. K. Shah et al., "Experimental investigation on effect of plasma nitriding on wear of chain-sprocket assembly used in motorcycle," International Journal for Scientific Research & Development, vol. 2, no. 3, 2014.
19. P. Sadagopan et al., "Wear and fatigue analysis of two wheeler transmission chain," Journal of Scientific and Industrial Research, vol. 66, pp. 912–918, 2007.