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# Effect of nitriding time on microstructural characteristics, hardness, corrosion resistance and surface roughness of EN8 Steel during QPQ Salt Bath Nitriding

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## Abstract

The paper examines how QPQ salt bath nitriding affects surface modification and performance improvement of EN8 steel, which is widely used in the piston rod. Specimens were nitrided in a salt bath at temperatures of 570°C, 60, 120 and 180 minutes, and polished at 800 grid and post-oxidised at 380°C, 15 minutes. Scanning electron microscopy (SEM), microhardness testing, X-ray diffraction (XRD), corrosion resistance analysis, surface roughness analysis and endurance testing were used to characterise the modified surface layers. The conclusions proved the appearance of a compound layer of nitride and diffusion zone on the treated surface. The length of time of nitriding affected the surface hardness, with the highest hardness of 559 HV0.01 at 180 minutes as opposed to 482 HV0.01 and 528 HV0.01 at 60 and 120 minutes, respectively. The layer thickness of the compound layer grew to 18.48 µm as opposed to the initial thickness of 10.14 µm, which shows an increase in nitrogen diffusion. There was an increase in corrosion resistance, and red rust resistance rose to 96 hours in salt spray tests. The surface roughness was reduced to 0.75 µm, though not significantly compared to 0.81 µm, and the endurance life was raised by 895 min as compared to 722.9 min. These findings indicate that the QPQ salt bath nitriding is an effective process in increasing the mechanical and corrosion properties of EN8 steel, and the duration of 180 min is the most effective in nitriding EN8 steel.

**Keywords:** Corrosion Resistance; EN8 Steel; Microstructural Development; Surface Microhardness; QPQ Salt Bath Nitriding

## 1. Introduction

EN8 is a medium carbon unalloyed steel with a carbon content of about 0.35-0.45 wt.%. It is commonly used in the automotive and general engineering industry because of its good strength, machinability and low cost compared to alloy steels. Shafts, connecting rods, and piston rods are common components made out of EN8 steel due to its good tensile strength and toughness, with a remedy of heat treatment methods like quenching and tempering. The surface characteristics of EN8 steel, however, cannot be relied upon when components are subjected to high loads of contact stress, sliding wear, and corrosive conditions, which are characteristic of gas spring piston rod applications. Surface engineering techniques are widely adopted to enhance the performance of engineering steels without affecting their bulk mechanical properties. Among these techniques, nitriding is an effective thermochemical treatment in which nitrogen atoms diffuse into the surface of steel at relatively low temperatures to produce a hardened surface layer [1].

During nitriding, the surface layer typically develops a compound layer consisting mainly of ε-$Fe_{2-3}N$ and γ′-$Fe_4N$ phases, followed by a diffusion zone beneath the surface where nitrogen diffuses into the matrix. The compound layer

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contributes to enhanced wear and corrosion resistance, while the diffusion layer improves fatigue strength and load-bearing capacity [2],[3].

The Quench–Polish–Quench (QPQ) salt bath nitriding thermochemical surface treatment process is used to improve the surface integrity of steel, creating a layer of hard compounds together with a diffusion zone, which is then polished and oxidised under control to provide a better surface finish and corrosion resistance. Consequently, the QPQ process greatly enhances wear resistance as well as corrosion behaviour without compromising dimensional stability. Due to these benefits, QPQ-treated steels are widely used in engineering parts like piston rods, hydraulic shafts, as well as precision mechanical spindles, where a balanced high surface hardness as well as enhanced corrosion resistance is of paramount importance in the effective service delivery.

This research was initially conducted as a pilot project for the manufacturer of the piston rod of the gas spring. Since piston rods in gas springs are subjected to repeated sliding motion, cyclic stresses, and environmental exposure, improving their surface characteristics is essential to prevent premature failure due to wear and corrosion therefore, the present study focuses on investigating the effect of QPQ on hardness, corrosion resistance, and microstructural characteristics of EN8 steel, to enhance its suitability for piston rod applications in gas spring systems. QPQ nitriding improves hardness by forming iron nitride phases such as $\gamma'$-$Fe_4N$ and $\varepsilon$-$Fe_{2-3}N$ in the compound layer, which substantially improves the surface hardness compared to the untreated substrate. Studies have shown that the hardness of QPQ-treated steels can increase up to two to three times that of the base material, improving wear resistance and reducing friction during operation [4]. Gas Spring components often operate in moist environments, automotive systems, furniture mechanisms, and industrial machinery, where corrosion can occur due to humidity, salts, or lubricants. Corrosion of the piston rod surface may lead to seal damage, leakage of gas pressure, and eventual failure of the gas spring system. QPQ nitriding significantly improves corrosion resistance due to the formation of a dense iron oxide ($Fe_3O_4$) layer during the post-oxidation stage, which acts as a protective barrier against corrosive environments [5]. The improvement in mechanical and corrosion properties after QPQ treatment is primarily attributed to the formation of a multi-layer microstructure on the steel surface. The QPQ-treated layer typically consists of:

- Oxide Layer ($Fe_3O_4$) – provides corrosion protection.
- Compound Layer (White Layer) – composed mainly of iron nitrides such as $\gamma'$-$Fe_4N$ and $\varepsilon$-$Fe_{2-3}N$.
- Diffusion Layer – nitrogen diffused into the substrate, improving hardness and fatigue resistance.

This multilayer structure improves the tribological behaviour, fatigue strength, and surface stability of the component [6]. The polishing stage of the QPQ process is specifically designed to reduce surface roughness after nitriding. This polishing step removes irregularities from the compound layer and produces a smoother surface. A smoother surface reduces friction and wear when the piston rod moves through the sealing system. Salt bath nitriding followed by polishing has been reported to improve surface finish and reduce friction coefficient, thereby improving the tribological performance of engineering components [7].

## 2. Materials and Methods

### 2.1. Material Preparation

The material used in this study was EN8 medium carbon steel, which is widely employed for components such as shafts, piston rods, and machine parts due to its good strength and wear resistance. The nominal chemical composition of EN8 steel (wt.%) is 0.36–0.44 C, 0.60–1.00 Mn, 0.10–0.40 Si, and balance Fe [8]. Test specimens were machined into 10 mm ø × 10 mm for microstructural characterisation, hardness measurement, and corrosion testing. Prior to the surface treatment, all specimens were subjected to mechanical surface preparation using silicon carbide abrasive of finer grades to yield a uniform surface finish. These samples were then ultrasonically cleaned in acetone, followed by deionised water for approximately 5 min to remove surface contaminants such as grease, dust, and oxides before the nitriding treatment.

### 2.2. QPQ Salt Bath Nitriding Treatment

The surface modification of EN8 steel specimens was carried out using the Quench–Polish–Quench (QPQ) salt bath nitriding process widely used to enhance hardness, wear resistance, and corrosion resistance of steels [5]. Liquid nitriding is a thermochemical surface treatment in which N2 and C atoms diffuses within the surface of steels from a molten salt bath containing alkali cyanate salts. The process is usually conducted at temperatures between 560–580°C, where the molten bath provides active nitrogen and carbon species that react with the steel surface, forming iron nitride phases and improving hardness, corrosion and wear resistance. The molten bath typically contains sodium cyanate

(NaCNO) as the main nitrogen donor along with carbonate salts and small quantities of cyanide salts that maintain the chemical stability of the bath. During the treatment, the cyanate ions decompose and release active nitrogen [9]. The liquid nitriding bath contains a mixture of alkali salts that control the nitrogen potential and maintain chemical stability during the process. **Error! Reference source not found.** gives a list of salts used in the liquid nitriding bath. Among these salts, sodium cyanate acts as the primary nitriding compound, while carbonate salts stabilise the bath and control the melting characteristics [10].

**Table 1** Salts used in Liquid Nitriding

| Compound | Formula | Typical Concentration |
|---|---|---|
| Sodium Cyanate | NaCNO | 30–40 % |
| Sodium Carbonate | $Na_2CO_3$ | 35–45 % |
| Sodium Cyanide | NaCN | 5–10 % |
| Potassium Carbonate | $K_2CO_3$ | 5–10 % |
| Sodium Chloride | NaCl | 5–10 % |

During nitriding, cyanate ions ($CNO^-$) gradually convert into carbonate salts ($CO_3^{2-}$), which reduces the nitriding activity of the salt bath. To maintain the nitriding potential, the cyanate content must be regenerated through oxidation reactions occurring in the bath [10], [11]. The regeneration reaction may be written as:

$$NaCN + Na_2CO_3 \rightarrow 2NaCN$$

It is this reaction that replenishes the level of cyanate in the molten salt bath and keeps the balance between cyanate, cyanide and carbonate species constant, keeping the nitriding process a steady one with a constant transfer of nitrogen to the steel surface[10], [11].

Besides nitrogen, carbon is also added to the steel surface by the breakup of the cyanate ions in the molten salt bath.

$$2NaCNO \rightarrow Na_2CO_3 + CO + N$$

The resulting CO gas further enhances the carburization of the steel surface, causing a combined nitrocarburizing effect with nitrogen and carbon diffusing into the substrate. This diffusing together causes the creation of iron carbonitrides (ε -Fe 2 -3(N, C) and γ -Fe 4(N, C) that enhance the fatigue strength, surface hardness, followed by the wear resistance, and of the treated steel [10], [12].

Diffusion of nitrogen atoms released in the process of cyanate breakdown into the steel lattice occurs through interstitial diffusion. Nitrogen atoms are placed at the interstitial sites of the ferritic lattice, which causes a lattice distortion and enhances the strengthening of the surface layer [11], [13].

Gamma Prime Phase ($\gamma'$-$Fe_4N$)

$$4Fe + N \rightarrow Fe_4N$$

The $\gamma'$-$Fe_4N$ phase possesses an FCC crystal structure and has a hardness in the range of 700–900 HV, depending on nitriding conditions and alloy composition.

Epsilon Phase (ε-$Fe_{2-3}N$)

$$2Fe + N \rightarrow Fe_{2-3}$$

The ε-$Fe_{2-3}N$ phase has a hexagonal close-packed (hcp) structure and shows higher hardness, generally 900–1200 HV, providing improved wear resistance and surface durability in nitrided steels [13], [14]. The compound layer typically has a thickness of 10–20 μm and significantly improves the above-mentioned three parameters [15].

$$\varepsilon - Fe_{2-3}N + \gamma' - Fe_4N$$

Below the compound layer lies the diffusion layer, where nitrogen diffuses deeper into the steel matrix, forming fine nitrides and strengthening the material. These samples were kept in a salt bath furnace having 35% CNO concentration. To inspect the nitriding time effect on En8 steel surface characteristics, bath nitriding, QPQ was experimented at around 5700 °C for various nitriding times (60, 120, and 180 min). After completion of the nitriding stage, the specimens were removed from the salt bath and cleaned to remove residual salts. The samples were then subjected to mechanical polishing using 800-grit SiC paper to improve the surface finish and remove loose deposits formed during nitriding. Subsequently, the samples underwent post-oxidation treatment in an oxidising salt bath at 380 °C for 15 min, which resulted in the formation of a thin magnetite ($Fe_3O_4$) oxide layer on the surface. This oxide layer improves corrosion resistance and contributes to enhanced tribological performance.

### 2.3. Characterization Techniques

The EN8 steel specimens treated by the QPQ salt bath nitriding process were prepared for microstructural examination using standard metallographic procedures. The samples were first sectioned from the treated specimens using an abrasive cut-off machine to avoid thermal damage to the nitrided layer. The cut specimens were then mounted in thermosetting resin to facilitate handling during grinding and polishing. Subsequently, the mounted samples were ground using silicon carbide papers of progressively finer grit sizes to acquire flat surfaces. The polished specimens were then etched using 2% Nital solution to reveal the microstructure of the nitrided layer. At last, the ready samples were studied under Scanning Electron Microscopy (SEM) to see the structure of the layer of compounds formed and the diffusion zone created after QPQ salt bath nitriding. X-ray diffraction (XRD) was used to analyse the phase make-up of the specimens of the EN8 steel that had been subjected to the QPQ salt bath nitriding process. To determine the available crystalline phases on the treated surfaces, the XRD measurements were conducted with Cu-K 2 radiation (1.5406 A) at a suitable range of 2th to scan through the surface. The diversified arrays of the samples were compared to identify the development of iron nitride phases formed during the nitriding treatment.

In the ASTM E384 and IS 6416, QPQ salt bath nitride is used on EN8 steel specimens to evaluate the hardness through the Vickers microhardness test. They were measured on a micro-Vickers type of hardness tester. A test load of 0.1 kgf (H V 0.1 ) was used, and each indentation was applied with a dwell time of 10 s. The hardness was measured at 23.8 C. Several measurements were made on the treated surface in order to determine the measurement reliability and repeatability.

The surface roughness of the QPQ salt bath nitrided EN8 steel specimen was assessed on a portable surface profiler, the Mitutoyo SJ-410 Surface Roughness Tester, produced by Mitutoyo. Measures were taken according to the IS 3073 at a laboratory room temperature of 23.8 o c. The instrument is used to detect the surface irregularities and to measure the vertical movement of a diamond stylus against the surface of the specimen and translate this to roughness parameters, such as average roughness (Ra).

Five specimens were tested at every nitriding period to test the roughness of the surface. A profilometer stylus was moved across the surface of the specimen, and a roughness value was measured. Five measurements of the roughness were taken on each set of specimens, and the average roughness value was calculated.

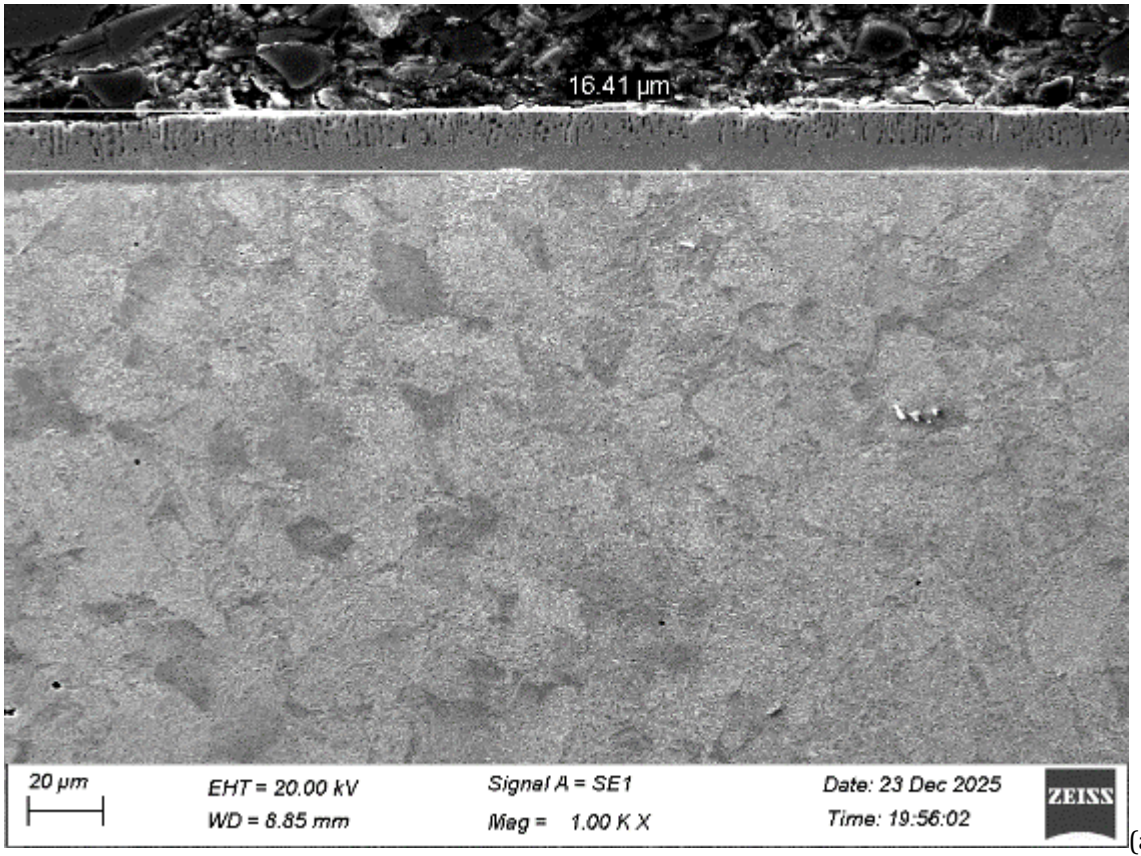
The salt spray corrosion test was conducted to evaluate the corrosion resistance of QPQ salt bath nitrided EN8 steel samples treated at different nitriding times. The test simulates a chloride-rich environment to determine the resistance of the treated surface against corrosion and to observe the formation of corrosion products such as red rust. The salt fog required for the test was produced using a sodium chloride solution prepared according to ISO 9227 specifications. Approximately 50 g of analytical grade NaCl was dissolved in 950 ml of distilled water to obtain a 5% salt solution. The pH of the solution was adjusted and maintained within the range of 6.5–7.2 before use in the salt spray chamber.

## 3. Result and Discussion

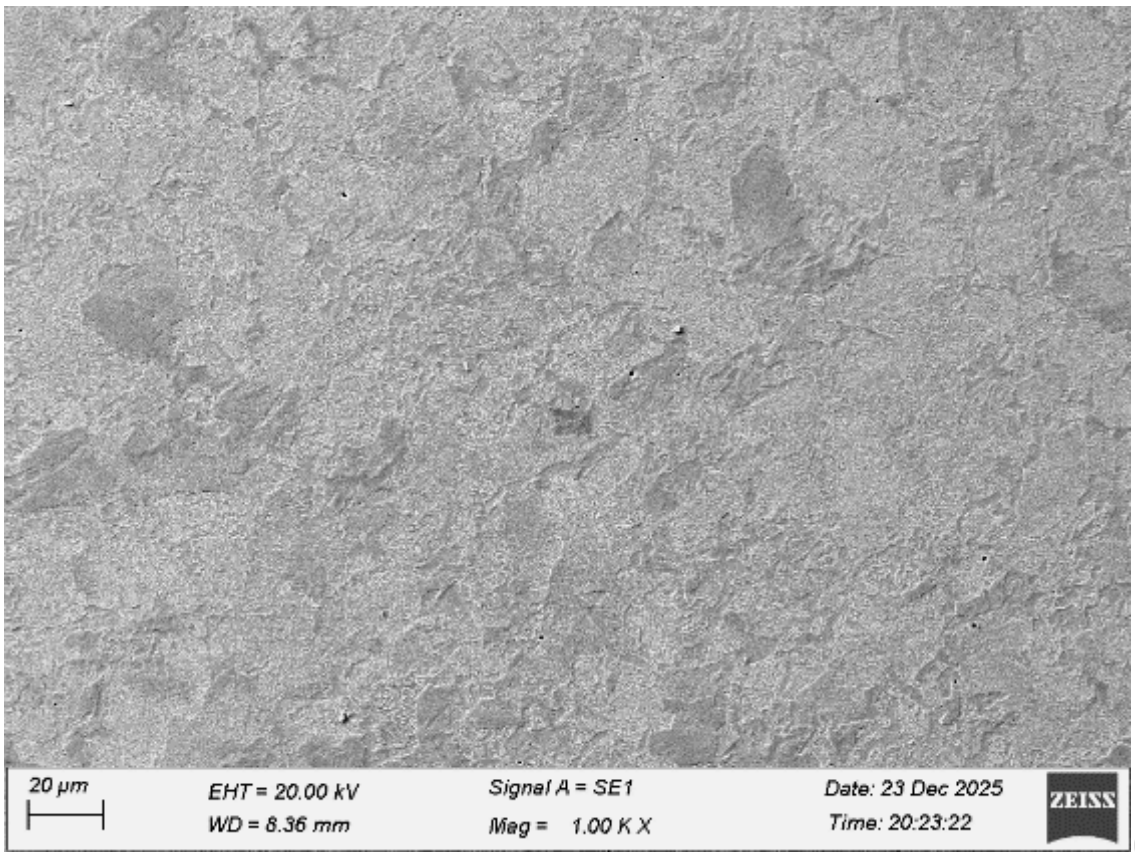
### 3.1. Metallographic Inspections

Figure 1 demonstrates the metallographs (cross-sectional) of EN8 specimen QPQ treated at $570^0$C for nitriding times of 60, 120, 120, and 180 mins. The process is followed by polishing the specimens with 800-grit Sic paper. After that, the specimen is undergone post oxidation process at 3800 C for 15 mins. For the specimen nitrided for 60 mins, Figure 1 (a), the SEM micrograph shows the formation of a relatively thin compound layer (~11.13 μm) on the steel surface. The surface morphology appears moderately smooth with fine granular features distributed uniformly across the surface. The limited nitriding duration results in restricted nitrogen diffusion, leading to a thinner compound layer and a less developed diffusion zone. A small number of micro-pores and surface irregularities can be observed, which are

typical characteristics of nitrided layers formed in cyanate-based salt baths. Shorter nitriding durations result in thinner compound layers with relatively smooth morphologies and limited diffusion depth [16], [17].




(a)

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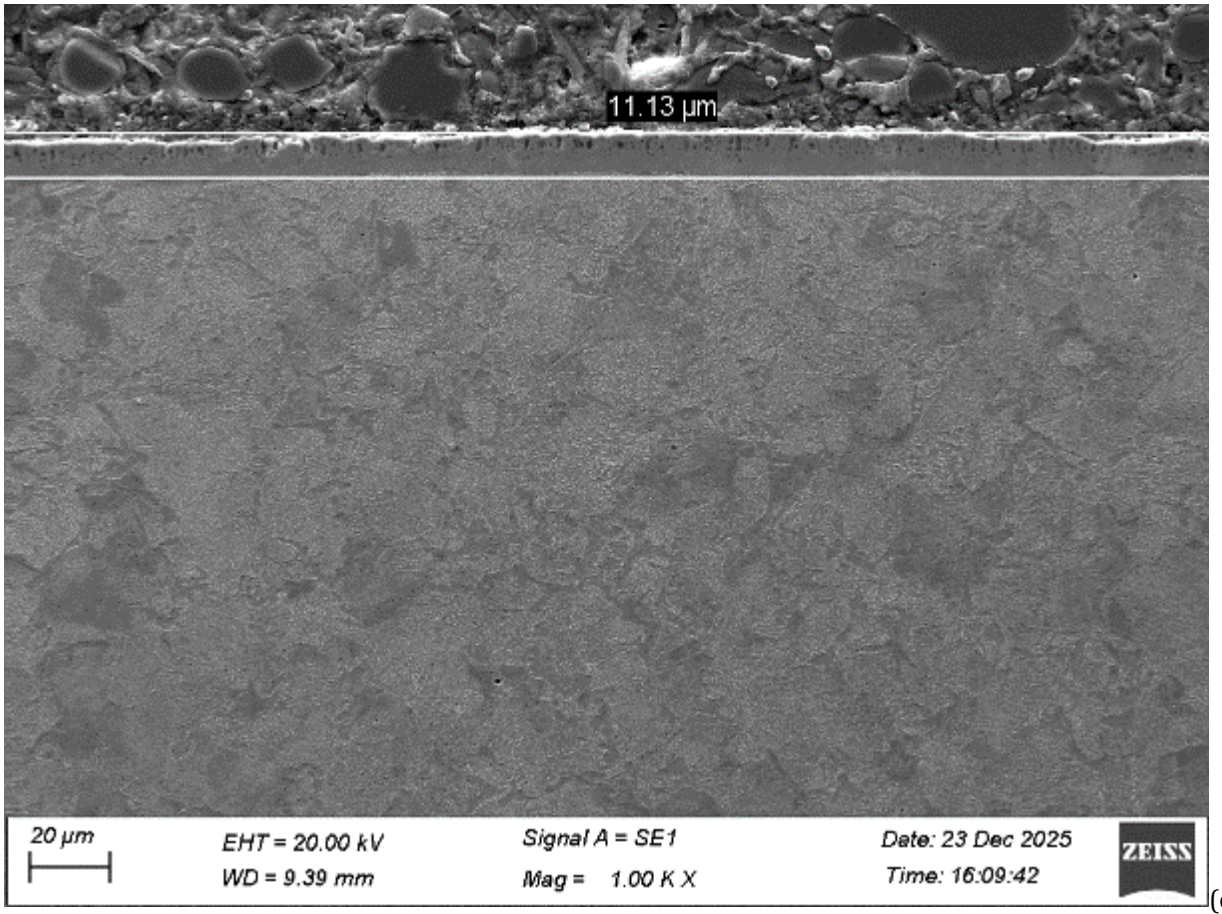

(c)

**Figure 1** Microstructure of EN8 steel specimens treated at 570$^0$C for different nitriding time (a) 60 min (b) 120 min (c) 180 min

When the nitriding duration increased to 120 mins Figure 1 (b), the compound layer formed increased to approximately 16.41 µm, indicating enhanced nitrogen diffusion into the EN8 steel matrix. The SEM microstructure shows a more continuous and denser compound layer, with improved surface uniformity compared with the 60 min sample. The surface morphology becomes slightly coarser and more compact, suggesting the growth and coalescence of iron nitride phases. The diffusion zone beneath the compound layer appears more pronounced due to the deeper penetration of nitrogen atoms into the steel substrate. The presence of fine micro-porosity within the compound layer is also evident, which is typical in salt bath nitriding due to the precipitation of nitrides during nitrogen supersaturation [18], [19].

For the specimen nitrided for 180 minutes (Figure 1 (c)), the SEM micrograph reveals the formation of the thickest compound layer (~18.16 µm) among the three conditions. The surface morphology is more packed and rough, which means that the growth and diffusion of nitrates were considerable. The compound layer is well developed and continuous, suggesting that prolonged nitriding time promotes the growth of ε and γ′ iron nitride phases and the expansion of the diffusion zone. The surface also exhibits increased micro-porosity and roughness, which is often associated with extended nitriding treatments. The thicker compound layer and deeper diffusion zone contribute to improved surface hardness and wear resistance, which have been widely reported in QPQ-treated steels [5], [16].

After nitriding and polishing, all specimens were subjected to post-oxidation at 380 °C for 15 minutes. This oxide layer improves corrosion resistance and tribological performance by acting as a protective barrier. In Figure 1, the oxide layer appears as a uniform grey surface film, indicating good adhesion and continuity. The formation of magnetite during post-oxidation has been widely reported in QPQ-treated steels and contributes to the characteristic black surface finish and enhanced corrosion resistance.

### 3.2. XRD Analysis

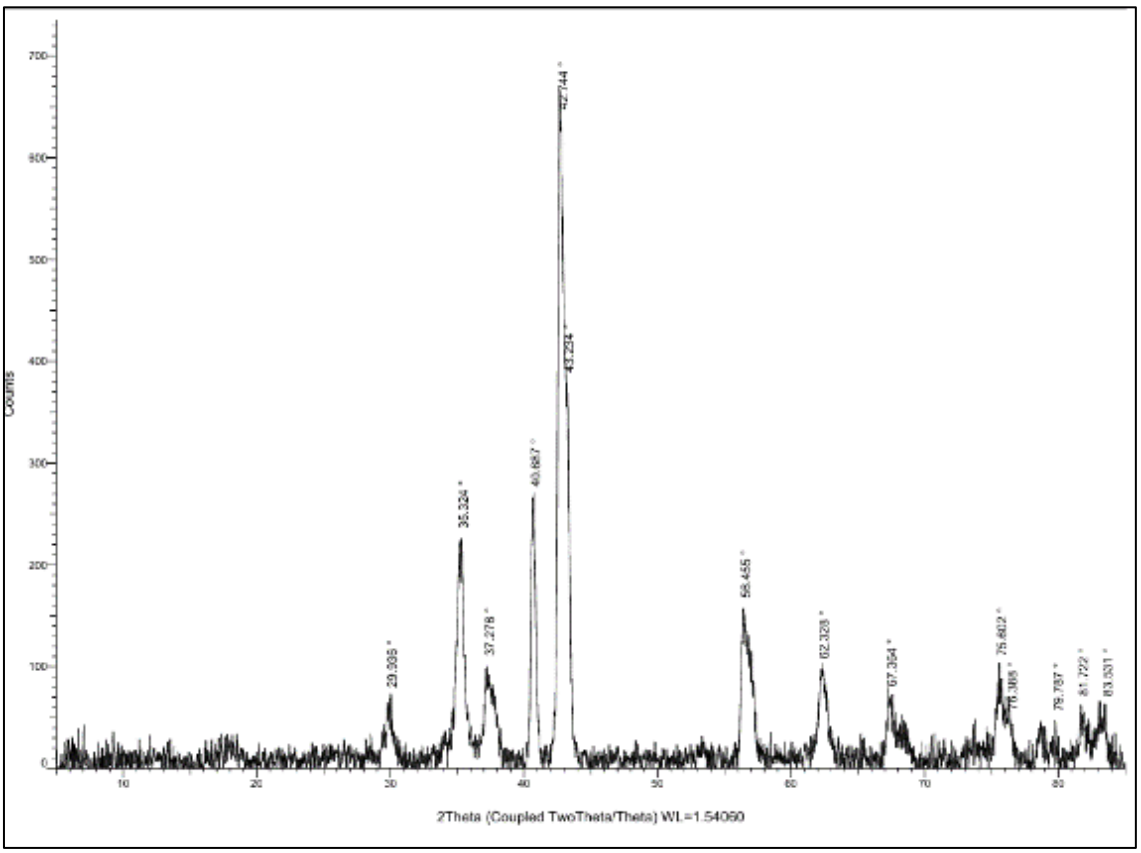


**Figure 2** XRD diffraction pattern of EN8 steel samples nitrided at 5700 C for 180 mins with post oxidation at 3800 C for 15 min

Figure 2 presents the phase composition of the QPQ salt bath nitrided EN8 steel sample for a nitriding time of 180 min, followed by polishing and post oxidation at 3800 C for 15 min. The phase composition of the QPQ salt bath nitrided EN8 steel sample was examined using XRD. The diffraction pattern obtained from the treated specimen is presented in Figure 2. The analysis was performed using Cu–Kα radiation with a wavelength of 1.5406 Å over a diffraction angle range of approximately 5°–85° (2θ). The diffraction pattern exhibits several sharp peaks, indicating the presence of crystalline phases formed during the nitriding and post-oxidation stages of the QPQ process.

The major diffraction peaks are observed around 2θ ≈ 35°, 40°, 42°, 57°, and 62°. These peaks correspond to the formation of iron nitride and oxide phases typically produced during salt bath nitriding treatments. The peak observed at approximately 2θ ≈ 40° corresponds to the γ′-$Fe_4N$ phase, while the peak located near 2θ ≈ 42° is associated with the ε-$Fe_{2-3}N$ phase. These phases are widely reported as the principal constituents of the compound layer formed during nitriding processes [20]. The presence of both ε and γ′ phases suggests the formation of a dual-phase compound layer, which is typical for steels treated using salt bath nitriding. The γ′ phase generally forms as a compact and adherent layer at the interface between the substrate and the compound layer, while the ε phase forms near the surface due to higher nitrogen concentration [21]. Besides iron nitrides, there is a peak at a 2 theta of approximately 35 degrees, which is associated with Fe 3 O 4 (magnetite). This oxide stage is formed because of the post-oxidation phase of the QPQ process, whereby the oxidation of the nitrided surface is done so that a thin layer of magnetite is formed. This coating of oxide has an important effect on enhancing tribological and corrosion resistance of the treated steel surface [22]. The sharpness and intensity of the peaks have shown that the compound layer that forms through the treatment is highly crystalline. The absence of broad amorphous peaks suggests that the surface layer consists primarily of well-defined crystalline nitride phases. Similar observations have been reported for nitrided alloy steels, where the formation of ε-$Fe_{2-3}N$ and γ′-$Fe_4N$ phases leads to significant improvements in mechanical and tribological properties [18].

During the salt bath nitriding process, nitrogen atoms are released from the molten salt bath and diffuse into the steel surface. As nitrogen concentration increases near the surface, it reacts with iron to form various iron nitride phases. The formation of γ′-$Fe_4N$ occurs initially at moderate nitrogen concentrations, while higher nitrogen activity promotes

the formation of the ε-$Fe_{2-3}N$ phase near the surface. As the nitriding process progresses, a compound layer consisting of these phases develops on the surface. The compound layer acts as a hard protective barrier, while the diffusion zone improves load-bearing capacity and fatigue resistance. Following nitriding, the polishing and post-oxidation stages of the QPQ process further modify the surface. The oxidation stage leads to the formation of a thin $Fe_3O_4$ magnetite layer, which improves corrosion resistance and reduces friction during sliding contact.

The microhardness of EN8 steel specimens treated by QPQ salt bath nitriding at 570°C, followed by post-oxidation at 380 °C for 15 minutes, was evaluated using a Micro-Vickers hardness tester. For each nitriding duration (60, 120, and 180 minutes), five samples were tested, and the hardness values were recorded. Figure 3 shows the effect of nitriding time on the hardness of EN8 steels. The hardness of the EN8 steel specimens increased significantly with increasing nitriding time. At 60 minutes, the average hardness was approximately 482 HV, which indicates the initial formation of the nitrided surface layer. During this stage, nitrogen diffusion into the steel matrix begins to form iron nitride phases such as ε-$Fe_{2-3}N$ and γ′-$Fe_4N$, leading to an increase in surface hardness. When the nitriding duration was increased to 120 minutes, the average hardness increased to approximately 527 HV.

### 3.3. Hardness Analysis

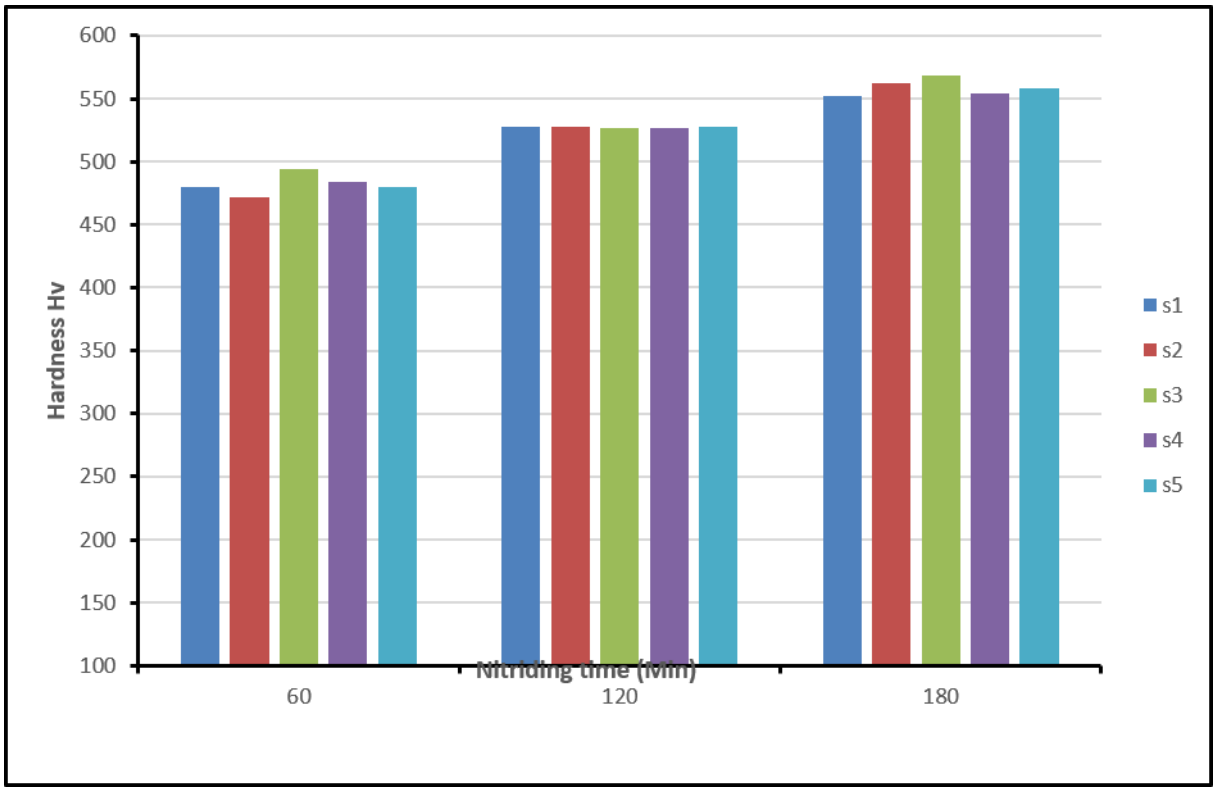


**Figure 3** Effect of nitriding time with the hardness

This increase can be attributed to the thickening of the compound layer and further nitrogen diffusion into the substrate, resulting in a more developed diffusion zone beneath the surface. The maximum hardness was achieved in the specimen, which was nitrided for 180 minutes, and the mean hardness was approximately 559 HV. Long nitriding cycle permits more nitrogen to be incorporated into the steel, leading to increased hard iron nitride phase formation and diffusion layer. This results in a drastic increment in the hardness and wear resistance of surfaces.

### 3.4. Corrosion Analysis

Corrosion performance of EN8 steel treated by the QPQ salt bath nitriding process was evaluated using a neutral salt spray test (NSS) according to ISO 9227:2017. Three different nitriding durations were investigated: 60 min, 120 min, and 180 min. The corrosion resistance was assessed by observing the time required for the appearance of red rust on the specimen surface. The corrosion test was conducted using a 5% NaCl solution with the test chamber maintained at approximately 35 ± 2 °C, pH range 6.5–7.2, and a collection rate of 1–2 ml/hr, complying with ISO 9227 standards. Table 2 shows the red rust formation in hours for the nitriding time of 60 mins, 120 minutes, and 180 mins. The corrosion resistance of EN8 steel treated by QPQ salt bath nitriding was evaluated using the neutral salt spray (NSS) test.

**Table 2** Results of salt spray test for nitriding time of 60 mins,120mins and 180 mins

| Nitriding Time | Observation after 24 h | Observation after 48 h | Observation after 72 h | Observation after 96 h | Red Rust Appearance |
|---|---|---|---|---|---|
| 60 min | No rust | Red rust observed | | | 48 h |
| 120 min | No rust | No rust | Red rust observed | | 72 h |
| 180 min | No rust | No rust | No rust | No rust | 120 h |

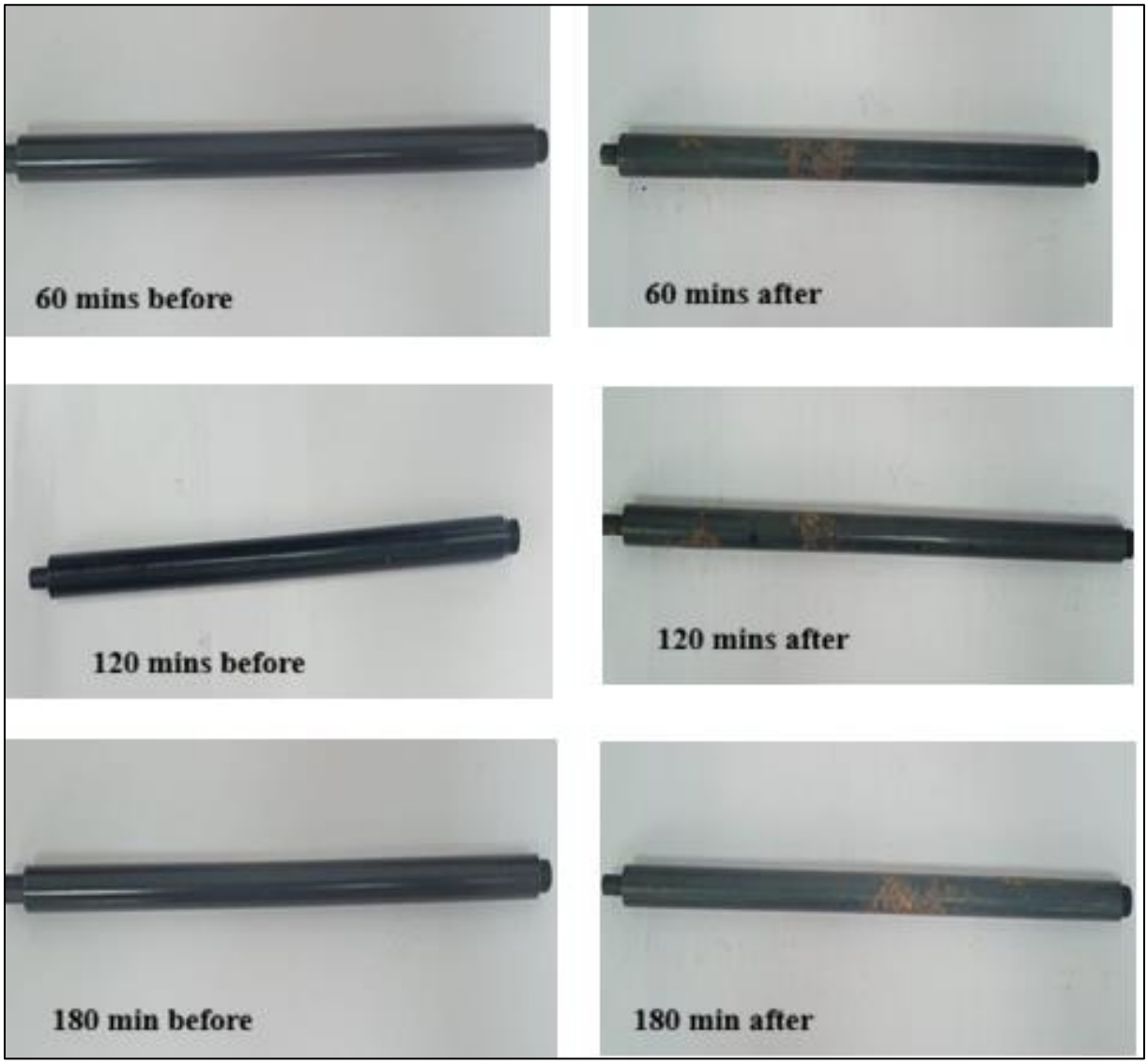


**Figure 4** Red rust formation of QPQ Salt bath nitrided EN8 Steel for Nitriding Time of 60 mins,120 mins and 180 mins by salt spray test

Figure 4 shows actual specimens tested by the salt spray test. The red rust observation time is given in Table 2. According to ASTM B117 and ISO 9227 standards commonly followed by NABL-accredited laboratories, the salt spray test is primarily a qualitative comparative corrosion test rather than a quantitative measurement method. In these standards, the performance of a material or coating is typically evaluated based on the time required for the appearance of visible corrosion products, particularly red rust formation on ferrous substrates. The evaluation criterion is therefore based on visual inspection and observation intervals, rather than numerical corrosion rate calculations or graphical trends.

## 4. Conclusions

The current research was aimed at assessing the QPQ salt bath nitriding effect on the microstructure, hardness, corrosion resistance, and roughness of EN8 steel with respect to various nitriding times (60, 120 and 180 minutes). The findings indicate that the duration of nitriding makes a great difference in the formation of the compound layer and the surface characteristics of the treated steel. The conclusions can be summarized as follows:

- Metallographic observation showed that a classic multilayer composition with a diffusion zone below the surface was formed, and a compound layer, too. As the treatment period with regard to nitriding time increased, the compound layer grew in thickness, as the results showed a thickness of about 11 μm in the 60 min treatment and almost 18 μm in the 180 min treatment, which reflects improved levels of nitrogen diffusion and progressive growth of the iron nitride phases.
- The SEM observations indicated the existence of a more continuous and thicker layer of compounds with an increase in the period of the nitriding process, which leads to a high level of surface integrity and load-carrying capacity.
- The X-ray diffraction revealed that there was an iron nitride phase like γ+-Fe 4N and ε-Fe 2 3N in the compound layer, and the development of a magnetite (Fe 3O 4) oxide layer at the end of the oxidation process in the QPQ process. The presence of these stages is significant to enhance surface toughness and corrosion.
- Measurements of microhardness showed an obvious rise in microhardness with an increase in the time of nitriding. Mean hardness went up to about 482 HV with the 60 min treatment, and 559 HV with the 180 min treatment. The increase is mainly credited to the development and enlargement of hard iron nitride phases and the enlargement of the nitrogen diffusion zone.
- The neutral salt spray corrosion test yielded a prominent steep in the corrosion resistance of the test sample following the QPQ corrosion test. The red rust appearance time was found to be longer in the 60 min nitriding condition (48 h) than in the 180 min treated samples (greater than 96 h). This enhancement is correlated to the development of a compact compound layer and the protection layer of Fe 3 O 4 oxide, which is generated during post-oxidation.
- The measurements of surface roughness showed that there was a slight decrease in surface roughness after the polishing process of QPQ, which leads to an enhanced surface finish that would be advantageous in the sliding processes, as in the case of a piston rod. The temperature and time that can help in the improvement of the Magnetite layer, the roughness parameter of the material, and the endurance strength of the material can be altered.

In general, the paper verifies that QPQ salt bath nitriding is a powerful surface alteration technique used to improve the mechanical and corrosion characteristics of EN8 steel. Out of the conditions studied, the duration of nitriding of 180 min offered the most favourable combination of compound layer thickness, hardness and corrosion resistance. It was therefore the most appropriate treatment condition to be applied in cases that needed high surface durability and corrosion resistance, such as in gas spring piston rods.

## Compliance with ethical standards

### *Disclosure of conflict of interest*

No conflict of interest to be disclosed.

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