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# Effect of Ammonia Diffusion Time on the Microstructure, Surface Hardness and Corrosion Resistance of Gas-Nitrided C35 Steel for Gas Spring Applications

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**Abstract: This study investigates the gas nitriding process applied to C35 medium-carbon steel to improve the surface properties of piston rods used in automotive tailgate and hood gas springs. In gas spring systems, the surface characteristics of the piston rod, including hardness, wear resistance, low-friction behaviour, and corrosion resistance, have a direct influence on system performance. In particular, micro-wear occurring at the rod–seal interface may lead to stick-slip behavior, seal degradation, and reduced service life. In this study, C35 steel specimens were subjected to ferritic nitrocarburizing followed by post-oxidation (FNC + ONC) at a constant treatment temperature with different ammonia diffusion times. The nitriding treatments were performed at 570 °C for 2.45, 4.30, and 6.30 h. After treatment, the specimens were characterized by Vickers microhardness measurements, optical microscopy, and neutral salt spray corrosion tests. Surface hardness and compound (white) layer thickness were comparatively evaluated. The experimental results revealed that the optimum ammonia diffusion time under the investigated processing conditions was 4.30 h at 570 °C, resulting in an average surface hardness of 576 HV, a compound layer thickness of 18.3 µm, and a corrosion resistance of 168 h according to ISO 9227. Furthermore, increasing the ammonia diffusion time led to higher surface hardness and a thicker compound layer. These findings demonstrate that appropriate control of the ammonia diffusion time significantly enhances the surface performance of gas-nitrided C35 steel while maintaining a compound layer suitable for gas spring applications.**

***Keywords:*** *Gas Nitriding; C35 Steel; Gas Spring; Ferritic Nitrocarburizing; Surface Hardness; Compound Layer;*

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## I. INTRODUCTION

Gas springs (gas struts) are critical mechanical components widely used in the automotive, aerospace, and furniture industries for energy storage and motion control applications. During service, the piston rod is continuously subjected to reciprocating axial motion under high-pressure gas and lubricating oil. Therefore, the surface quality of the piston rod plays a decisive role in determining both the friction coefficient and the service life of sealing elements [1].

In the automotive industry, gas springs are extensively employed in tailgates, engine hoods, and various movable mechanisms. The operational performance and durability of these systems largely depend on the surface characteristics of the piston rod. Surface wear, micro-scratches, and friction-induced surface degradation gradually impair sealing performance, resulting in gas leakage and reduced service life.

Piston rods used in gas spring systems are required to possess a smooth surface finish together with high surface hardness to withstand continuous sliding contact. Although C35 medium-carbon steel is widely preferred because of its excellent machinability and low production cost, its inherent wear resistance is insufficient for severe operating conditions. Gas nitriding effectively overcomes this limitation by producing a hard nitride layer on the steel surface without causing significant dimensional distortion [2].

C35 steel is commonly selected as the base material for piston rods because of its balanced mechanical properties and economic advantages [3]. However, its initial surface hardness, typically ranging from 180 to 220 HV, is inadequate

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for dynamic wear conditions. Gas nitriding enhances the surface properties through nitrogen diffusion, resulting in significant improvements in hardness, fatigue strength, and corrosion resistance while maintaining the dimensional stability of the component [2,4]. Therefore, optimization of the nitriding process parameters is essential for achieving the desired performance in gas spring applications.

One of the critical issues associated with gas nitriding is the formation of the compound layer, commonly referred to as the white layer. Excessively thick compound layers may promote microcrack initiation during cyclic loading and adversely affect the mechanical reliability of the component [2,5]. Consequently, controlling the thickness of the white layer is of considerable importance. In gas spring applications, the compound layer has a dual effect: it significantly improves corrosion resistance while simultaneously reducing the friction coefficient. However, when the compound layer exceeds approximately 20 μm in thickness or becomes highly porous, it becomes increasingly brittle. During service, brittle fragments may detach from the surface and act as abrasive particles, accelerating the wear of hydraulic sealing elements and eventually causing gas leakage [1].

Piston rods used in gas springs are therefore expected to exhibit high surface hardness, excellent corrosion resistance, and a low coefficient of friction. For this reason, surface engineering technologies have become indispensable in gas spring manufacturing. Although hard chromium plating and salt bath nitrocarburizing have been extensively employed for many years, growing environmental concerns associated with hexavalent chromium ($Cr^{6+}$), cyanide, and cyanate compounds have encouraged the development of environmentally friendly alternative surface treatment technologies [6,7]. Among these alternatives, gas nitriding has emerged as one of the most promising processes [2].

Gas nitriding is a thermochemical surface treatment in which nitrogen atoms diffuse into the steel surface under a controlled atmosphere, leading to the formation of hard iron nitride phases [2,4]. The compound layer together with the underlying diffusion zone substantially increases surface hardness and wear resistance. However, inappropriate selection of process parameters may result in the formation of an excessively brittle compound layer, thereby reducing fatigue performance and limiting component reliability [8,9].

The present study aims to investigate the influence of ammonia diffusion time on the gas nitriding behavior of C35 medium-carbon steel used for gas spring piston rods. Particular emphasis is placed on evaluating the effects of ammonia diffusion time on surface hardness, compound layer formation, and corrosion resistance in order to determine the optimum processing condition for industrial gas spring applications.

## II. LITERATURE REVIEW

Gas nitriding is one of the most effective thermochemical surface hardening processes for components requiring high surface performance with minimal dimensional distortion, particularly in the manufacturing of gas spring piston rods. Previous studies have demonstrated that the growth kinetics of iron nitride layers are governed by nitrogen diffusion and exhibit a non-linear relationship with nitrogen potential and processing temperature. Somers and Mittemeijer [10] theoretically explained that the formation and growth of compound layers are controlled by diffusion mechanisms rather than linear reaction kinetics.

For low-alloy carbon steels such as C35, gas nitriding significantly improves surface hardness while preserving the ductility and toughness of the core material. This combination of a hardened surface and a tough substrate extends the operational life of components subjected to cyclic and dynamic loading conditions [11]. Consequently, gas nitriding has become an attractive surface treatment technique for piston rods used in automotive gas spring systems.

From the viewpoint of gas spring applications, the characteristics of the compound (white) layer are of particular importance. A thin, dense, and homogeneous white layer produced under optimized gas nitriding conditions has been reported to reduce the coefficient of friction between the piston rod and hydraulic sealing elements while improving wear resistance by up to 40% [1]. However, these improvements can only be achieved through precise control of the nitriding parameters. In particular, appropriate selection of processing temperature and diffusion time suppresses excessive grain-boundary nitride precipitation, thereby minimizing the risk of brittle fracture in carbon steels [12].

In addition to improving mechanical and tribological properties, the continuous nitride layer formed during gas nitriding acts as an effective diffusion barrier against oxygen and aggressive corrosive species. This protective layer significantly enhances the corrosion resistance of low-carbon and medium-carbon steels by preventing the penetration of corrosive media into the substrate [13]. Such improvement is particularly beneficial for gas spring piston rods operating under humid and corrosive service environments.

Numerous investigations have confirmed that gas nitriding substantially increases both surface hardness and wear resistance. Sun and Bell [8] reported that optimized nitriding conditions can produce surface hardness values approaching 700 HV, resulting in remarkable improvements in tribological performance. Nevertheless, they also emphasized that excessive growth of the compound layer may promote the initiation of fatigue cracks and adversely affect the fatigue life of nitrided components [8].

Although extensive research has been conducted on gas nitriding of carbon steels, relatively few studies have focused on optimizing the ammonia diffusion time for C35 steel specifically used in gas spring piston rods. Since these components require a balanced combination of high surface hardness, controlled compound layer thickness, excellent corrosion resistance, and reliable sealing performance, determining the optimum ammonia diffusion time remains an important research objective. Therefore, the present study aims to evaluate the influence of ammonia diffusion time on the microstructure, surface hardness, compound layer

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thickness, and corrosion resistance of gas-nitrided C35 steel for gas spring applications.

## III. MATERIALS AND METHODS

C35 steel, which is used in gas spring applications, is a widely preferred material due to its medium-carbon structure. Its high machinability and adequate core strength provide significant advantages for gas spring applications. However, because of its low alloying element content, the nitriding process parameters must be carefully selected.

➤ *Sample Preparation and Pre-treatment*

C35 steel conforming to the DIN EN 10083 standard was used in the experiments [14]. The specimens were prepared with diameters of Ø6 mm, Ø8 mm, and Ø10 mm, and a length of 360 mm. Prior to the nitriding process, surface grinding and rolling operations were performed.

The chemical composition of the material was 0.32–0.39 wt.% C, 0.50–0.80 wt.% Mn, max. 0.40 wt.% Si, max. 0.045 wt.% P, and max. 0.045 wt.% S. The C35 steel used in the experiments was supplied in the cold-drawn condition. The specimen surfaces were mechanically polished using 800- and 1200-grit abrasive papers. Degreasing was carried out in alkaline baths, followed by rinsing with deionized water and drying. The surface roughness was maintained at a maximum value of Ra 0.30 µm.

➤ *Gas Nitriding Process*

The gas nitriding treatments were carried out in an industrial nitriding furnace under a controlled atmosphere. Ammonia ($NH_3$) was used as the process gas. After the nitriding process, the specimens were cooled under controlled conditions. The industrial nitriding furnace used in this study is shown in Figure 1.

Within the scope of this study, a full factorial design was established using a combination of three different piston rod diameters and three different ammonia diffusion times. The experimental parameters are presented in Table 1.

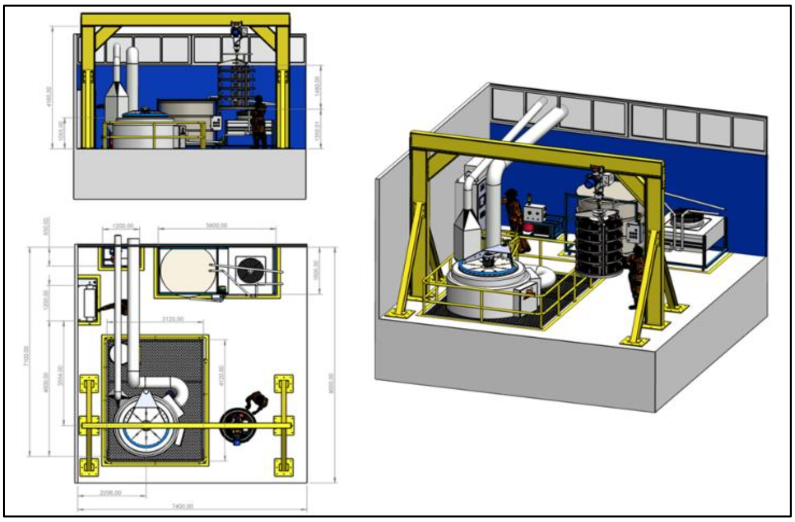

Fig 1: Gas Nitriding Furnace

Table 1. Experimental Parameters

| Exp. No | Shaft dia. (mm) | Nitriding temp. (°C) | Diffusion time (h) | Gas Flow Rate (L/min.) |
|---|---|---|---|---|
| 01 | 6 | 570 | 2,45 | 150 |
| 02 | 8 | 570 | 2,45 | 150 |
| 03 | 10 | 570 | 2,45 | 150 |
| 04 | 6 | 570 | 4,30 | 150 |
| 05 | 8 | 570 | 4,30 | 150 |
| 06 | 10 | 570 | 4,30 | 150 |
| 07 | 6 | 570 | 6,30 | 150 |
| 08 | 8 | 570 | 6,30 | 150 |
| 09 | 10 | 570 | 6,30 | 150 |

## IV. RESULTS AND DISCUSSION

➤ *Experimental Results*

To investigate the influence of ammonia diffusion time on the gas nitriding process, C35 steel specimens with three different piston rod diameters were treated at a constant temperature of 570 °C using three different ammonia diffusion times. The nitrided specimens were characterized in terms of surface hardness, compound (white) layer thickness, and corrosion resistance. The experimental results are summarized in Table 2.

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Table 2. Results of the Gas Nitriding Experiments

| Ammonia Diffusion Time (h) | Test-1 (HV) | Test-2 (HV) | Test-3 (HV) | Test-4 (HV) | Test-5 (HV) | Test-6 (HV) | Test-7 (HV) | Average (µm) | Corrosion Time (h) |
|---|---|---|---|---|---|---|---|---|---|
| 2,45 | 546,0 | 550,9 | 555,2 | 550,7 | 17 | 16 | 16 | 16,3 | 144 |
| 4,30 | 573,5 | 582,9 | 572,5 | 576,3 | 18 | 19 | 18 | 18,3 | 168 |
| 6,30 | 589,6 | 590,0 | 590,3 | 590,0 | 22 | 21 | 22 | 21,7 | 192 |

➤ *Characterization Studies*

Cross-sectional specimens were prepared using standard metallographic procedures and etched with Nital solution (4% nitric acid and 96% ethanol/methanol). Surface hardness measurements were carried out using a Vickers microhardness tester under a load of HV0.1 [15]. Microstructural observations were performed using an optical microscope at magnifications of 500× and 2000×. The thickness of the compound (white) layer was measured at five different locations, and the average value was calculated.

The experimental results demonstrated that the ammonia diffusion time had a significant effect on the surface hardness of the nitrided specimens. The surface hardness of untreated C35 steel, which ranged from 180 to 210 HV, increased to approximately 400–600 HV after the gas nitriding treatment. However, increasing the diffusion time resulted in excessive growth of the compound layer, leading to increased surface brittleness. A Vickers microhardness profile (HV0.1) was measured from the surface toward the core at intervals of 0.02 mm. The Effective Case Depth (ECD) was determined according to the 50 HV criterion, corresponding to the depth at which the hardness exceeded the core hardness by 50 HV.

➤ *Microstructure and Compound Layer Analysis*

An excessively thick compound (white) layer on the piston rod produces a brittle surface that is susceptible to the detachment of microscopic particles under frictional loading during service. These detached particles may act as abrasive debris, damaging the hydraulic seals and eventually causing gas leakage. The compound layer with an average thickness of 18.3 µm, obtained under the processing condition of 570 °C for 4.3 h, was considered to provide the optimum balance between corrosion protection and seal compatibility. The compound layer thicknesses obtained after the nitriding treatment are presented in Figures 2 and 3.

For the specimens treated at 570 °C for 6.3 h, a high degree of porosity was observed on the surface of the compound layer. This phenomenon is attributed to the ammonia dissociation rate exceeding the nitrogen diffusion rate, resulting in the formation of nitrogen voids within the compound layer.

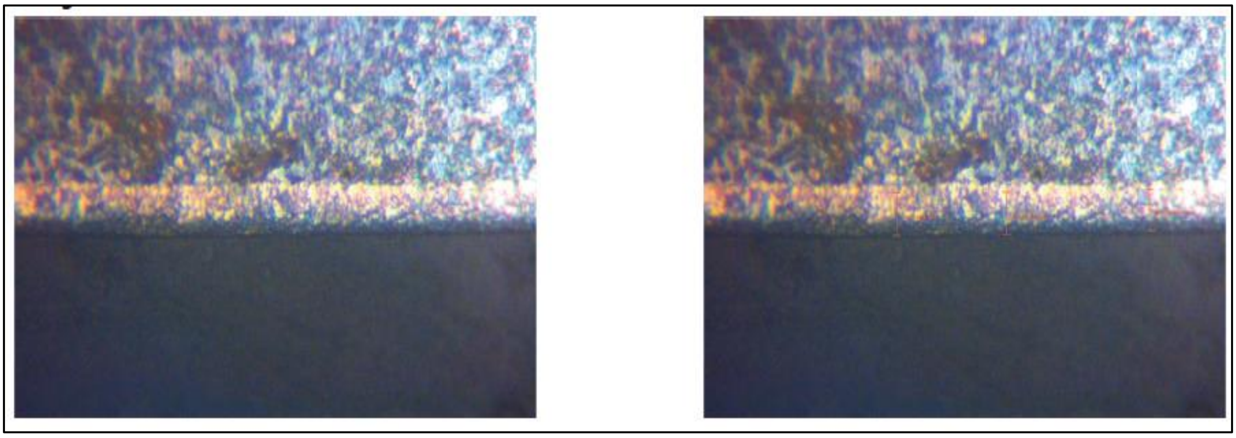

Fig 2. Cross-Sectional View of the Arcor Coating Layers with Thicknesses of 18 µm and 19 µm.

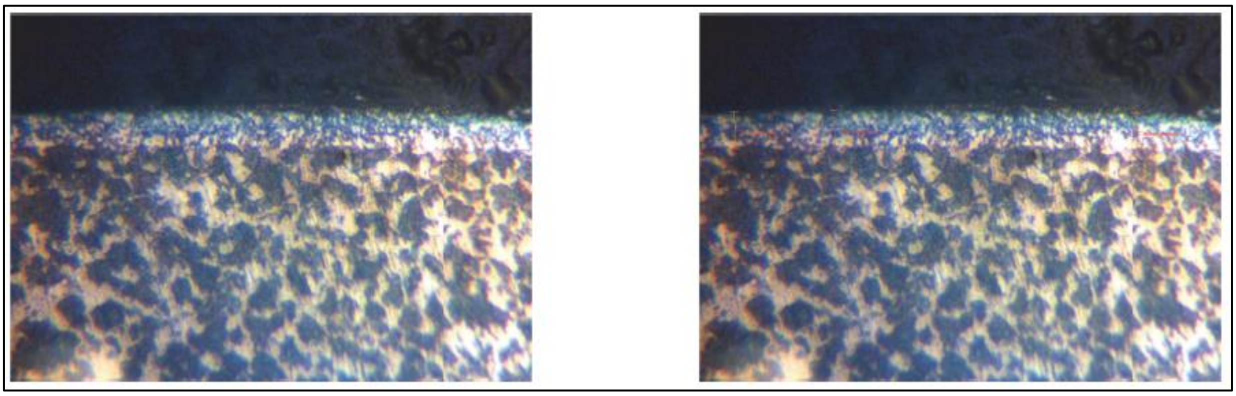

Fig 3. Cross-Sectional Micrographs of the Arcor Coating Layers Showing Thicknesses of 21 µm and 22 µm.

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➢ *Corrosion Behaviour*

The corrosion resistance and the degree of surface oxidation were evaluated by a neutral salt spray test using a 5 wt.% NaCl solution in accordance with ISO 9227 [16]. The salt spray test results demonstrated that the nitrided specimens exhibited significantly higher corrosion resistance than the untreated C35 steel. In particular, the diffusion zone was found to make a substantial contribution to surface protection. This improvement can be attributed to the passive nitride layer formed during the nitriding process, which acts as an effective barrier against oxygen penetration.

Considering the service conditions of gas springs, such as automotive tailgates, engine hoods, and similar applications, enhanced corrosion resistance is of critical importance for ensuring long-term operational reliability. The salt spray test results indicated that the corrosion resistance of the nitrided C35 steel was more than twelve times higher than that of the untreated material. In particular, the compound (white) layer formed during the nitriding process effectively protected the piston rod against corrosion in humid environments.

Among the investigated processing conditions, the specimens nitrided at 570 °C with an ammonia diffusion time of 4.3 h exhibited the optimum combination of corrosion resistance and wear performance. According to the ISO 9227 salt spray test results, the untreated C35 steel showed the first signs of corrosion after 12 h of exposure. In contrast, as illustrated in Figure 4, the specimens nitrided at 570 °C for 4.3 h maintained their surface integrity without any visible corrosion after 168 h of salt spray exposure, whereas the initial signs of corrosion were observed only after 192 h [16].

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B-1 | √ | √ | √ | √ | √ | √ | √ | 1 | | | | | | | | | | | | |
| B-1 | √ | √ | √ | √ | √ | √ | √ | 1 | | | | | | | | | | | | |
| Saat / Hour | 24 hour (1.day) | 48 hour (2.day) | 72 hour (3.day) | 96 hour (4.day) | 120 hour (5.day) | 144 hour (6.day) | 168 hour (7.day) | 192 hour (8.day) | 216 hour (9.day) | 240 hour (10.day) | 264 hour (11.day) | 288 hour (12.day) | 312 hour (13.day) | 336 hour (14.day) | 360 hour (15.day) | 384 hour (16.day) | 408 hour (17.day) | 432 hour (18.day) | 456 hour (19.day) | 480 hour (20.day) |

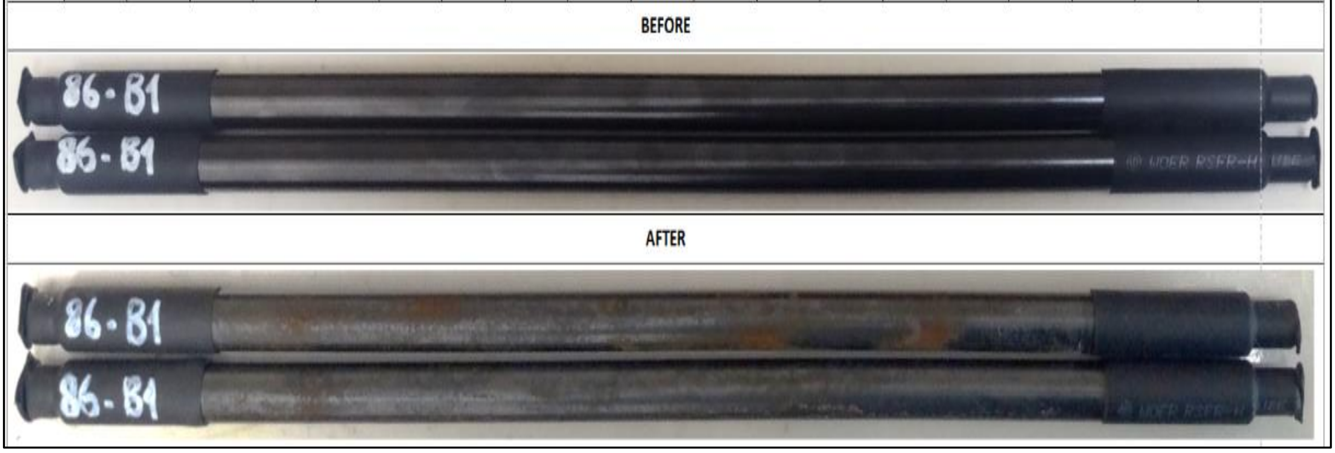


Fig 4. Corrosion Resistance of the Arcor-Coated Samples After an Ammonia Diffusion Time of 4.3 h.

## V. CONCLUSIONS

In this study, the gas nitriding process applied to C35 medium-carbon steel was investigated to improve the surface properties of piston rods commonly used in gas spring applications. Based on the experimental results obtained from the gas nitriding treatment, the following conclusions can be drawn:

- Gas nitriding significantly increased the surface hardness of C35 steel from 180–220 HV to an average value of 576 HV, corresponding to an approximately threefold improvement.
- The thickness of the compound (white) layer increased with increasing ammonia diffusion time, from 16.3 μm after 2.45 h to 21.7 μm after 6.30 h of treatment.
- Surface hardness also increased with increasing ammonia diffusion time, rising from approximately 550 HV after 2.45 h to 590 HV after 6.30 h.
- The gas nitriding treatment significantly enhanced the corrosion resistance of C35 steel compared with the untreated material.

Among the investigated processing conditions, the optimum ammonia diffusion time was determined to be 4.30 h at a treatment temperature of 570 °C. Under these conditions, the nitrided piston rod exhibited an average surface hardness of 576 HV, a compound layer thickness of 18.3 μm, and a corrosion resistance of 168 h according to the ISO 9227 neutral salt spray test.

The results demonstrate that appropriate control of the ammonia diffusion time is essential for achieving an optimum balance between surface hardness, compound layer thickness, and corrosion resistance. Therefore, the optimized gas nitriding parameters identified in this study provide an effective surface engineering solution for improving the durability and service performance of C35 steel piston rods used in gas spring applications.

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## REFERENCES

[1]. D'Oliveira, A. S. C. M., Tschiptschin, C. P., & Bell, T. (2001). Gas nitriding of unalloyed and low alloy steels. *Surface Engineering, 17*(2), 147–152. https://doi.org/10.1179/026708401101517863

[2]. Pye, D. (2003). *Practical nitriding and ferritic nitrocarburizing*. ASM International. https://doi.org/10.31399/asm.tb.pnfn.978162708350

[3]. Fuhong Steel. (2026). *C35 carbon steel (CK35 / DIN 1.0501): Properties and applications*. https://www.round-bars.com/products/c35-carbon-steel-ck35-din-1-0501

[4]. Mittemeijer, E. J., & Somers, M. A. J. (Eds.). (2014). *Thermochemical surface engineering of steels: Improving materials performance*. Woodhead Publishing.

[5]. Child, H. C. (1980). *Surface hardening of steel* (Engineering Design Guides No. 37). Oxford University Press

[6]. Davis, J. R. (Ed.). (2001). *Surface engineering for corrosion and wear resistance*. ASM International.

[7]. Liedtke, D. (1995). *Case hardening of steels: Bolt-on metallurgy*. ASM International.

[8]. Sun, Y., & Bell, T. (1991). Plasma surface engineering of low alloy steel. *Materials Science and Engineering: A, 140*, 419–434. https://doi.org/10.1016/0921-5093(91)90458

[9]. Sirin, S. Y., Yildiz, K. C., & Alsaran, A. (2008). The effect of surface hardness and case depth on the fatigue performance of nitrided steels. *Journal of Materials Science, 43*, 2575–2580.

[10]. Somers, M. A. J., & Mittemeijer, E. J. (1995). Layer-growth kinetics on gaseous nitriding of pure iron: Evaluation of diffusion coefficients for nitrogen in iron nitrides. *Metallurgical and Materials Transactions A, 26*(1), 57–74. https://doi.org/10.1007/BF02669794

[11]. Alsaran, A., Karakan, M., & Çelik, A. (2002). *The investigation of mechanical properties of ion-nitrided AISI 5140 low-alloy steel*. *Materials Characterization, 48*(4), 323–327. https://doi.org/10.1016/S1044-5803(02)00275-9

[12]. Skonieski, A. F. O., dos Santos, G. R., Hirsch, T. K., & da Rocha, A. S. (2013). *Influence of gas nitriding parameters on the microstructure and hardness of carbon steels*. *Materials Research, 16*(6), 1332–1339. https://doi.org/10.1590/S1516-14392013005000131

[13]. Hossain, S., et al. (2006). *Improving the corrosion resistance of carbon steel by gas nitriding*. *Surface and Coatings Technology, 201*(6), 2824–2830.

[14]. Deutsches Institut für Normung. (2006). *DIN EN 10083-2:2006: Steels for quenching and tempering—Part 2: Technical delivery conditions for non-alloy steels*.

[15]. ASM International. (1991). *ASM handbook* (Vol. 4, *Heat Treating*, 10th ed.). ASM International.

[16]. International Organization for Standardization. (2017). *ISO 9227:2017. Corrosion tests in artificial atmospheres—Salt spray tests*. International Organization for Standardization.