Duplex Thermochemical Treatment of AISI 420 ESR: Boriding and Nitriding Effects

This study investigates the effect of thermochemical treatments—boriding, nitriding, and sequential boronitriding—on AISI 420 ESR stainless steel. Samples were treated and analyzed via microscopy, microhardness testing, adhesion evaluation, and energy-dispersive spectroscopy (EDS). Boriding produced the highest surface hardness (˜1250 $HV_{0.05}$), representing an increase of approximately 733% over the base material, but showed poor adhesion. Nitriding showed lower hardness (˜1050 $HV_{0.05}$), a 600% increase, with excellent adhesion. Boronitriding offered balanced results (˜842 $HV_{0.05}$), increasing hardness by ˜461%, and demonstrated good adhesion while forming a duplex diffusion zone. EDS confirmed effective diffusion of boron and nitrogen into the surface. Findings suggest boronitriding as a promising compromise when both wear resistance and coating integrity are required in mechanical applications.

Introduction

Thermochemical surface treatments are among the most effective techniques for enhancing the surface properties of metallic materials (Gale & Totemeler, 2004). These treatments introduce elements such as boron (Juijerm, 2020) and nitrogen into the surface through diffusion (Shi et al., 2023a), enhancing hardness (Shi et al., 2023b), wear resistance (Taktak & Kayali, 2017), and overall performance without affecting the material's core structure (Barut et al., 2014; Abbasi-Khazaei & Mollaahmadi, 2017). Among them, boronitriding has emerged as a promising approach for achieving a balance between surface hardness and coating adhesion in martensitic stainless steels such as AISI 420 ESR (Carrera Espinoza et al., 2024; Kayali & Taktak, 2015; Brnic et al., 2011).

Thermochemical Treatments and Methodology

Four cylindrical specimens (10 mm thick) of AISI 420 ESR stainless steel were subjected to thermochemical treatments. The sequential boronitriding involved pack boriding at 900 °C for 4 hours (Thermo Scientific FD1540M), followed by gas nitriding at 560 °C for 8 hours using NH_3 (KGO furnace). After treatment, the samples were sectioned, mounted, ground, and polished to a mirror finish.

Surface characterization included Vickers microhardness tests ($HV_{0.05}$, 50 g load, Micromet 6010), adhesion testing based on VDI 3198 (OMAG 206 EX-2), and structural and compositional analysis through scanning electron microscopy (SEM; Tescan Mira 3) and energy-dispersive spectroscopy (EDS; Bruker).

Results and Surface Performance Comparison

The borided sample displayed a surface hardness of ~1250 $HV_{0.05}$ due to the formation of FeB and Fe_2B phases but showed poor adhesion (VDI 3198: HF6) with evident cracking and spallation. High boron content (18.28 wt%, 43.49 at%) confirmed significant diffusion during the boriding process.

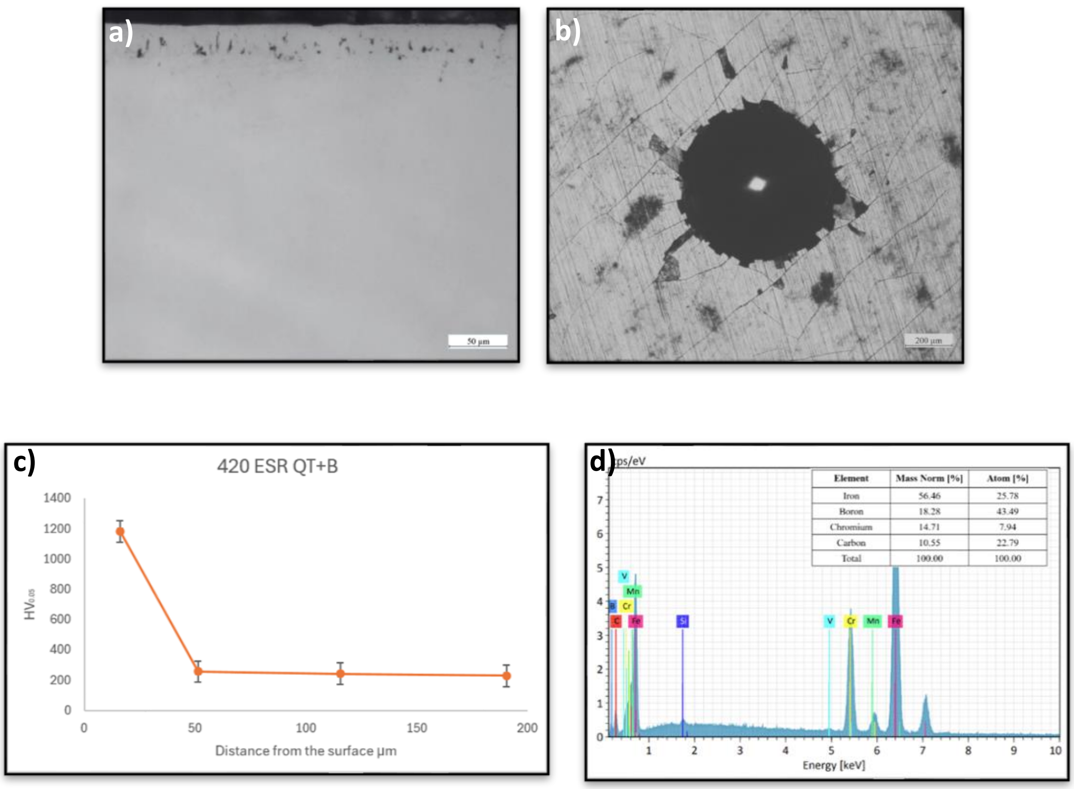

Figure 1: a) Borided layer of AISI 420 ESR steel (50×), b) VDI test of borided AISI 420 ESR, c) Vickers microhardness of the borided material, d) Energy-dispersive spectroscopy (EDS)

Nitriding produced a hardness of ~1050 $HV_{0.05}$ and excellent adhesion (HF1-HF2), with minimal cracking and no delamination. Nitrogen was identified as the dominant alloying element after iron, with 12.26 wt% and 22.83 at%, confirming successful surface incorporation.

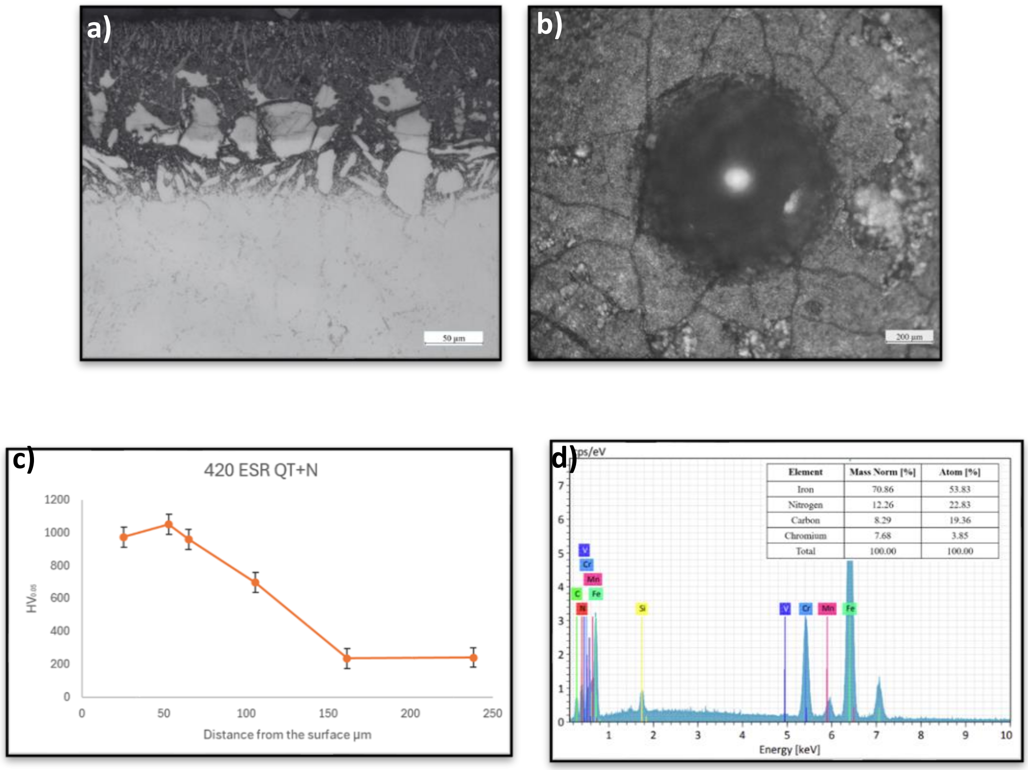

Figure 2: a) Nitrided layer of AISI 420 ESR steel (50×), b) VDI test of nitrided AISI 420 ESR, c) Vickers microhardness of nitrided AISI 420 ESR, d) Energy-dispersive spectroscopy (EDS)

The boronitrided sample showed ˜842 $HV_{0.05}$ surface hardness and moderate adhesion (HF2-HF3), combining advantages of both processes. The EDS spectra indicated the presence of both boron (5.73 wt%) and nitrogen (18.60 wt%), verifying the effectiveness of the combined treatment.

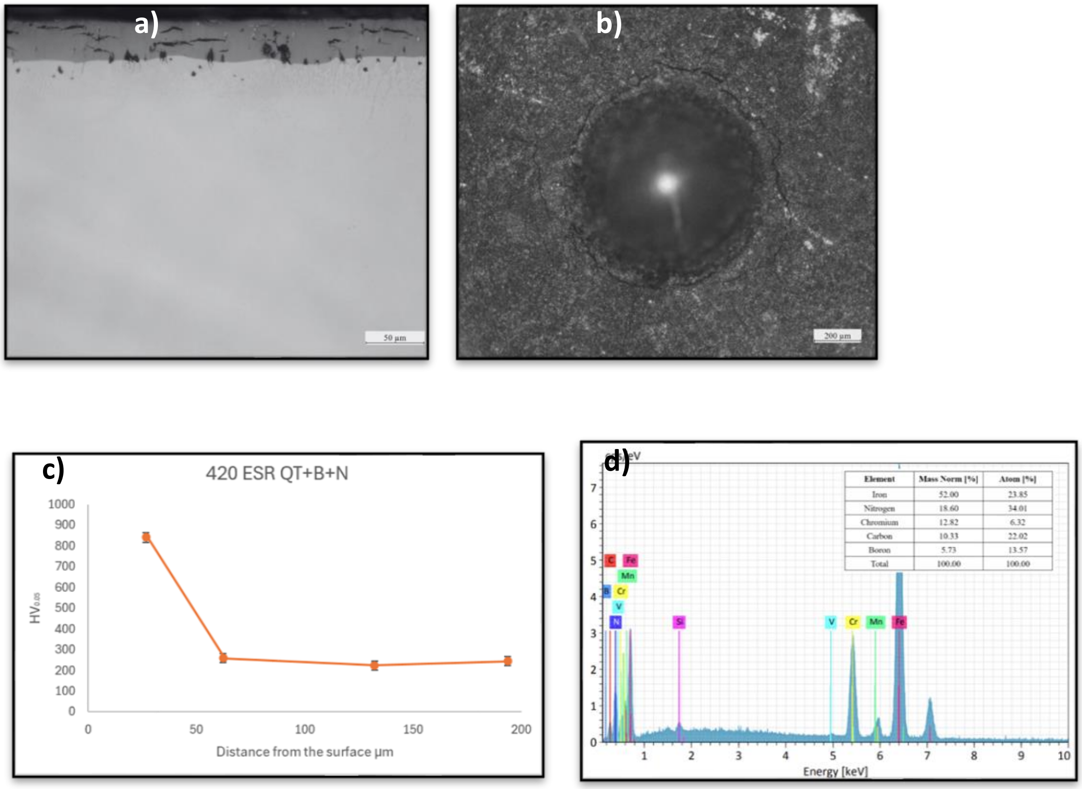

Figure 3: a) Boronitrided layer of AISI 420 ESR steel (50×), b) VDI test of boronitrided AISI 420 ESR, c) Vickers microhardness of boronitrided AISI 420 ESR, d) Energy-dispersive spectroscopy (EDS)

Conclusion

Boriding significantly improves surface hardness but compromises adhesion. Nitriding offers a balanced performance with excellent coating integrity. Boronitriding provides a compromise, combining moderate hardness and good adhesion. Treatment selection should align with performance requirements—boriding for maximum hardness, nitriding for wear resistance and toughness, and boronitriding for applications requiring both attributes.

References

- Abbasi-Khazaei, B., & Mollaahmadi, A. (2017). Rapid tempering of martensitic stainless steel AISI 420: Microstructure, mechanical and corrosion properties. *Journal of Materials Engineering and Performance, 26*(4), 1626-1633.

- Barut, N., Yavuz, D., & Kayali, Y. (2014). Investigation of the kinetics of borided AISI 420 and AISI 5140 steels. *Afyon Kocatepe University Journal of Science and Engineering*, *14*, 1-8.

- Brnic, J., Turkalj, G., Canadija, M., Lanc, D., & Krscanski, S. (2011). Martensitic stainless steel AISI 420—Mechanical properties, creep and fracture toughness. *Mechanics of Time-Dependent Materials*, *15*, 341-352.

- Carrera Espinoza, R., Alvarez Vera, M., Wettlaufer, M., Kerl, M., Barth, S., Moreno Garibaldi, P., Díaz Guillen, J. C., Hernández García, H. M., Muñoz Arroyo, R., & Ortega, J. A. (2024). Study on the tribological properties of DIN 16MnCr5 steel after duplex gas-nitriding and pack boriding. *Materials*, *17*(13), 3057. https://doi.org/10.3390/ma17133057

- Gale, W. F., & Totemeler, T. C. (2004). *Smithells metals reference book* (8th ed.). Elsevier.

- Juijerm, P. (2020). Investigation of the diffusion kinetics of borided stainless steels. *Applied Surface Science*, *506*, 144979.

- Kayali, Y., & Taktak, S. (2015). Characterization and Rockwell-C adhesion properties of chromium-based borided steels. *Journal of Adhesion Science and Technology, 29*(19), 2065-2075.

- Shi, M., Li, J., Mao, W., Li, S., Yang, Z., & Ma, X. (2023a). Mechanism and properties of plasma nitriding AISI 420 stainless steel at low temperature and anodic (ground) potential. *Surface and Coatings Technology, 458*, 129243.

- Shi, M., Li, J., Mao, W., Li, S., Yang, Z., & Ma, X. (2023b). Microstructure and hardness characterisation of laser coatings produced with a mixture of AISI 420 stainless steel and Fe-C-Cr-Nb-B-Mo steel alloy powders. *Surface and Coatings Technology*, *459*, 129345.

- Taktak, S., & Kayali, Y. (2017). Sliding wear behavior of friction couples primarily selected for corrosion resistance. *Tribology Transactions*, *60*(3), 513-522. https://doi.org/10.1080/10402004.2016.1199875

About the authors:

Dr. Rafael Carrera Espinoza

Dean of the School of Engineering.

Email: rafael.carrera@udlap.mx

Dr. Pablo Moreno Garibaldi

Academic Director of Industrial and Mechanical Engineering.

Email: pablo.moreno@udlap.mx

Dr. Melvyn Alvarez Vera

Full-time professor in the Department of Industrial and Mechanical Engineering.

Email: melvyn.alvarez@udlap.mx

Damián Gutierrez Sosa, Honours Programme student.

Email: damian.gutierrezsa@udlap.mx

Ismael López Rodríguez, Honours Programme student.

Email: ismael.lopezrz@udlap.mx

Francisco Javier Romero Álvarez

Honours Programme student.

Email: francisco.romeroaz@udlap.mx

Valeria López López

Honours Programme student

Email: valeria.lopezlzl@udlap.mx