
Effect of Salt Bath Nitriding Temperature on Electrochemical Corrosion Behavior of Al 7075

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Abstract

Aluminium (Al) alloys are widely used in aerospace and marine applications due to their high strength-to-weight ratio and thermal conductivity. However, Al 7075 is susceptible to pitting corrosion, which compromises its structural performance. While plasma nitriding improves surface characteristics, it is cost-intensive and time-consuming. This study proposes an economical salt bath nitriding method using a KNO_3 bath at 400°C, 450°C, and 475°C for 3 hours. Results indicate that nitriding temperature positively influences AlN layer thickness and micro-hardness. The 475°C-treated sample exhibited nearly double the hardness of the solution-annealed alloy. Electrochemical analysis revealed a substantial enhancement in corrosion resistance, with a tenfold reduction in corrosion current density compared to the untreated sample. These findings establish salt bath nitriding as a practical surface engineering method for improving the corrosion and mechanical properties of Al 7075.

Keywords: Aluminium alloy; Salt bath nitriding; Corrosion; Hardness; Surface engineering.

1 Introduction

Corrosion is an irreversible degradation process that occurs when materials react with their environment. Though unavoidable, its effects can be mitigated through surface engineering techniques such as shot peening, powder coating, carburizing, and nitriding. Among these, nitriding offers significant advantages for aluminium (Al) alloys, improving the surface hardness and corrosion resistance without altering the core microstructure [1]. Al 7075, a high-strength structural alloy, is commonly used in aircraft and marine applications but suffers from poor pitting resistance. Various studies have investigated ion implantation and plasma nitriding to address this limitation. McCafferty et al. reported enhanced pitting resistance in nitrogen-implanted pure aluminium [2], while Massiani et al. demonstrated the formation of a 200nm AlN layer on Al-Cu alloys, improving corrosion resistance in Na₂SO₄ environments [3]. Plasma-based ion implantation also yielded promising results for Al 6061 and Al 2025 [4, 5], though these methods remain cost- and time-intensive, limiting their industrial scalability. As an alternative, gas and salt bath nitriding have gained interest due to their cost-effectiveness and process simplicity. Girish et al. employed ammonia gas nitriding on reinforced Al 6061 and observed improved corrosion performance [8]. Hamdy et al. demonstrated that salt bath nitriding using KNO₃ at 475°C enhanced corrosion resistance in Al 2024, particularly when followed by water quenching to ensure uniform AlN distribution [9]. In this context, the present work investigates salt bath nitriding of Al 7075 alloy at 400°C, 450°C, and 475°C, each for a duration of 3 hours in a fused KNO₃–KNO₂ bath. This study focuses on the correlation between nitriding temperature and AlN layer thickness, hardness enhancement, and corrosion resistance as assessed through scanning electron microscopy (SEM), X-ray diffraction (XRD), and potentiodynamic polarisation techniques.

2 Materials and Methods

2.1 Material Preparation

Commercial Al 7075 alloy with the chemical composition shown in Table 1 was used. Sheets of 7 mm thickness were sectioned into 1 cm × 1 cm coupons using wire electrical discharge machining (EDM). Samples were cleaned in deionised (DI) water via ultrasonic agitation for 10 minutes, then solution annealed at 480°C for 1 hour in a muffle furnace and water quenched.

Table 1 Chemical composition of Al 7075 alloy.

Element	Zn	Mg	Cu	Fe	Si	Mn	Cr	Al
Wt.%	5.6	2.5	1.6	0.5	0.4	0.3	0.23	Bal.

2.2 Sample Preparation

Solution-annealed (SA) samples were mechanically polished using SiC abrasive papers from 600 to 2500 grit, followed by fine polishing with 3 μm alumina slurry on velvet cloth to eliminate surface scratches. A final 10-minute ultrasonic cleaning in DI water was performed before nitriding.

2.3 Salt Bath Nitriding Process

Nitriding was conducted in a fused KNO_3 salt bath with a small amount of KNO_2 added to suppress volatilisation. The process was carried out in a graphite crucible within a muffle furnace, ensuring the molten salt fully covered the samples. SA-polished specimens were suspended in the bath using copper wire and nitrided at 400°C, 450°C, and 475°C for 3 hours. Post-nitriding, the samples were quenched in DI water and cleaned in an ultrasonic bath to remove residual salt.

2.4 Characterisation of Nitrided Layer

Cross-sectional SEM analysis was performed using a JEOL JSM-6380A microscope with Oxford EDS detector to measure nitride layer thickness and element distribution. Samples were prepared by mirror polishing transverse cross-sections. Phase identification was conducted via X-ray diffraction (XRD) using a PANalytical X'Pert Pro diffractometer with $\text{Cu K}\alpha$ radiation (45 kV, 40 mA) over a 2θ range of 32–90°. Peak analysis was done using X'Pert HighScore software and matched with ICDD standards.

2.5 Micro-Hardness Testing

Micro-hardness measurements were performed using a Mitutoyo HM-112 Vickers microhardness tester. A 100 g load was applied for 10 seconds. Average hardness values were obtained from multiple indentations on each sample.

2.6 Electrochemical Corrosion Testing

Corrosion behaviour was evaluated via potentiodynamic polarisation (PDP) using a Bio-Logic potentiostat with frequency response analyser in a three-electrode setup. Tests were conducted in 0.1 M NaCl solution prepared using Thermo Fisher NaCl and DI water. Open circuit potential was recorded for 3600 s before polarisation scans, which were performed from -500 mV to $+100$ mV (vs. OCP) at a scan rate of 0.5 mV/s. Tafel extrapolation was used to determine corrosion potential (E_{corr}) and current density (i_{corr}). Post-testing, samples were ultrasonically cleaned and dried. SEM imaging was used to observe surface morphology after corrosion.

3 Results and Discussion

3.1 Characterisation of the Nitrided Layer

3.1.1 X-ray Diffraction (XRD)

The XRD patterns of the solution-annealed (SA) and nitrided Al 7075 samples are shown in Figure 1. The SA sample exhibited characteristic aluminium peaks at $2\theta = 38.27^\circ$, 44.49° , 64.88° , and 78.00° , corresponding to the (111), (002), (022), and (311) planes. These sharp reflections, with no visible intermetallic peaks, confirm the dissolution of precipitates during the SA process. Nitrided samples revealed additional peaks corresponding to AlN, confirming nitride layer formation. The AlN peak intensity increased with nitriding temperature, indicating greater AlN phase fraction at elevated temperatures. A slight peak shift towards higher 2θ values was also observed, attributed to lattice distortion due to interstitial nitrogen. Literature confirms that nitrogen's limited solubility in Al promotes AlN phase formation over solid solution [9]. Furthermore, peaks corresponding to $\text{Mg}_2\text{Zn}_{11}$ precipitates were noted in nitrided samples. Their increased density and size at higher temperatures suggest thermal growth of precipitates during prolonged exposure.

3.1.2 Energy Dispersive Spectroscopy (EDS)

EDS elemental mapping (Figure 2) was used to visualize nitrogen distribution on nitrided surfaces. Uniform nitrogen distribution was observed in all samples, with increasing nitrogen concentration at higher nitriding temperatures. The 475°C sample exhibited the densest nitrogen presence, indicating enhanced diffusion at elevated temperatures.

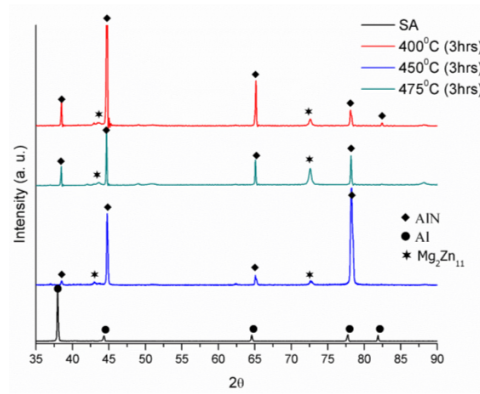


Figure 1 XRD patterns of SA and nitrided Al 7075 samples at various temperatures.

Some nitrogen-lean zones were observed near Mg₂Zn₁₁ precipitates, possibly due to their interference with nitrogen uptake.

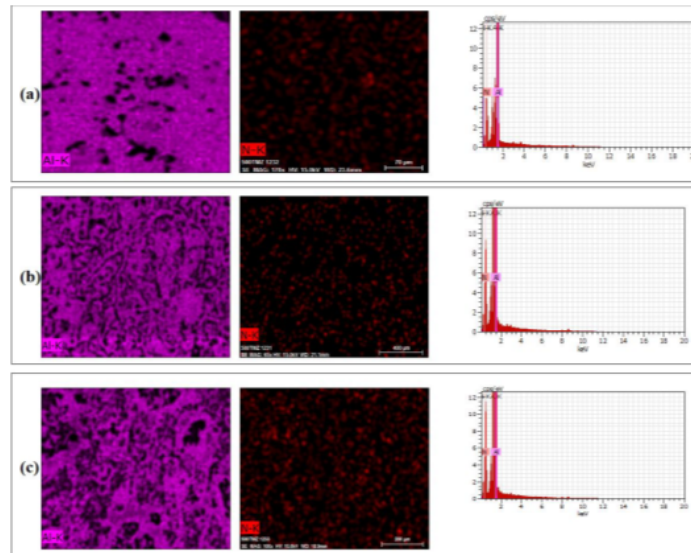


Figure 2 EDS nitrogen mapping of samples nitrided at (a) 400°C, (b) 450°C, and (c) 475°C.

3.1.3 Scanning Electron Microscopy (SEM)

SEM micrographs of transverse cross-sections (Figure 3) revealed compact AlN layers formed at all three temperatures. Layer thickness increased from $2.54\ \mu\text{m}$ (400°C) to $4.95\ \mu\text{m}$ (475°C), as shown in Figure 4. The nitride layer appeared dense, with no visible porosity or delamination at the interface. Nitriding at higher temperatures accelerates AlN formation due to increased diffusion rates. Given nitrogen's negligible solubility in aluminium, Al diffuses outward to react with nitrogen, forming a surface-bound AlN layer [5]. The layer's confinement to the sub-surface confirms a typical compound-type case structure.

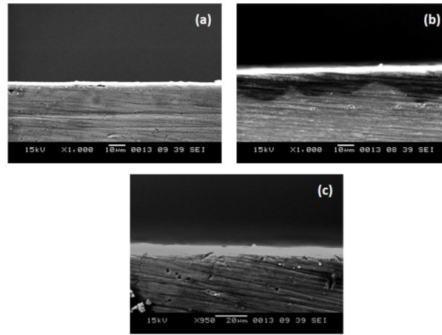


Figure 3 SEM images of Al 7075 cross-sections nitrided at (a) 400°C , (b) 450°C , and (c) 475°C .

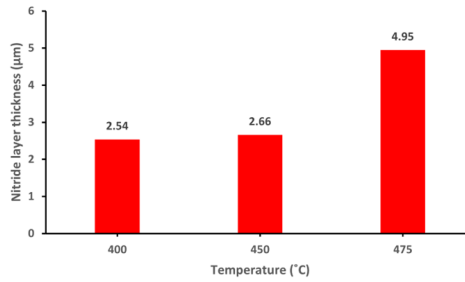


Figure 4 Comparison of AlN layer thickness at different nitriding temperatures.

3.2 Micro-Hardness Analysis

Figure 5 shows the variation in Vickers micro-hardness of SA and nitrided Al 7075 samples. The SA alloy exhibited a baseline hardness of 106 HV. Nitriding significantly enhanced hardness, with values increasing to 143.1 HV at 400°C, 178.8 HV at 450°C, and 209.1 HV at 475°C. This increase is attributed to the formation of a hard AlN surface layer, which impedes dislocation motion. Additionally, Mg_2Zn_{11} precipitates formed during nitriding may contribute to hardening, although their excessive growth can reduce strengthening efficiency. Literature suggests that post-nitriding re-ageing can restore or further enhance hardness if precipitate coarsening occurs [11].

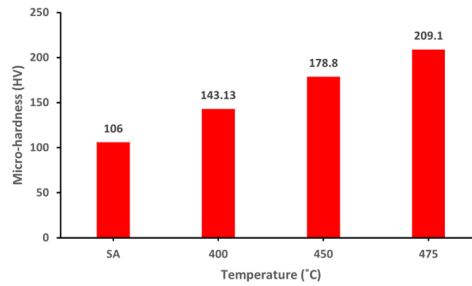


Figure 5 Vickers micro-hardness of SA and nitrided Al 7075 samples.

3.3 Electrochemical Testing

The corrosion performance of SA and nitrided samples was evaluated using potentiodynamic polarisation (PDP) in 0.1 M NaCl. Figure 6 presents the Tafel plots, and corresponding E_{CORR} and i_{CORR} values are summarised in Table 2. The SA sample showed the highest corrosion current density ($2.57 \times 10^{-5} \mu\text{A}/\text{cm}^2$), while the 475°C nitrided sample recorded the lowest ($9.52 \times 10^{-7} \mu\text{A}/\text{cm}^2$), indicating a 27-fold reduction. The corrosion potential (E_{CORR}) shifted in the noble direction with increasing nitriding temperature, affirming improved thermodynamic stability. The cathodic region slope indicates that the corrosion process is cathodically controlled. The AlN layer acts as a physical and chemical barrier, reducing ion/electron transport and inhibiting electrochemical reactions. The enhanced charge transfer resistance at higher temperatures aligns with the increase in nitride layer thickness. Post-corrosion SEM analysis (Figure 7) revealed extensive pitting in the SA sample, while nitrided surfaces showed fewer and shallower pits.

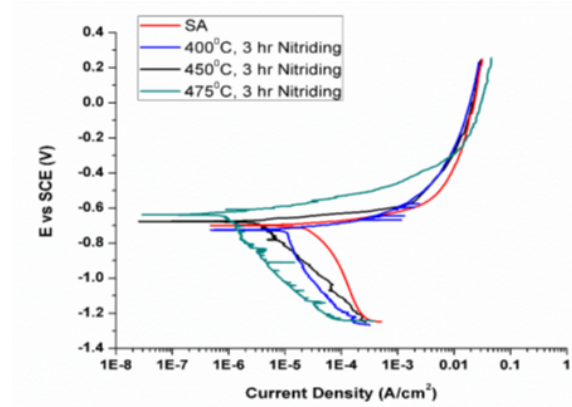


Figure 6 Potentiodynamic polarisation curves for SA and nitrated Al 7075 samples.

Table 2 Corrosion potential and current density values of tested samples.

Sample	E_{CORR} (mV vs. OCP)	i_{CORR} ($\mu\text{A}/\text{cm}^2$)
SA	–	2.57×10^{-5}
400°C	Shifted Noble	1.65×10^{-5}
450°C	Shifted Noble	5.50×10^{-6}
475°C	Most Noble	9.52×10^{-7}

The 475°C sample showed minimal damage, demonstrating the role of a well-formed AlN layer in pitting resistance. Precipitates like $\text{Mg}_2\text{Zn}_{11}$ can act as local cathodes, promoting galvanic corrosion, but a uniformly distributed AlN layer reduces such effects [12].

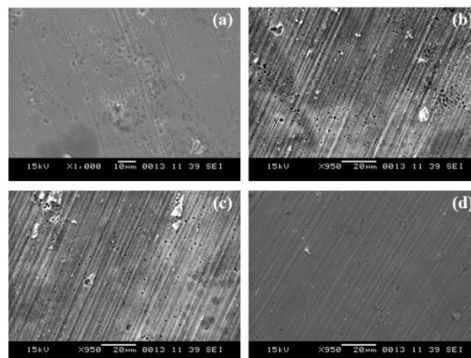


Figure 7 SEM images after corrosion: (a) SA, (b) 400°C, (c) 450°C, (d) 475°C.

4 Conclusion

This study evaluated the influence of salt bath nitriding temperature on the surface hardness and electrochemical corrosion resistance of Al 7075 alloy. Based on the results, the following conclusions are drawn:

1. Salt bath nitriding using a KNO_3 – KNO_2 fused salt mixture effectively forms an AlN surface layer on Al 7075. The thickness of the nitride layer increased with higher nitriding temperatures.
2. A direct correlation was observed between nitride layer thickness and micro-hardness. The sample nitrided at 475°C exhibited the highest hardness, nearly double that of the solution-annealed alloy.
3. Potentiodynamic polarisation testing revealed enhanced corrosion resistance with increasing nitriding temperature. The corrosion current density reduced by over an order of magnitude for the 475°C -treated sample.
4. Post-corrosion surface analysis confirmed reduced pitting in nitrided samples. The uniform and compact AlN layer acted as a barrier against ion diffusion and galvanic effects, especially at elevated nitriding temperatures.
5. Salt bath nitriding emerges as a cost-effective, time-efficient, and scalable technique for improving the mechanical and corrosion properties of Al 7075 alloys, offering a promising alternative to plasma and ion implantation methods for industrial surface engineering applications.

References

- [1] C.X. Li and T. Bell. A comparative study of low temperature plasma nitriding, carburising and nitrocarburising of AISI 410 martensitic stainless steel. *Materials Science and Technology*, 23(3):355–361, 2007.
- [2] E. McCafferty, P.M. Natishan, and G.K. Hubler. Pitting behavior of aluminum ion implanted with nitrogen. *Corrosion*, 53(7), 1997.
- [3] Y. Massiani, J. Creus, P. Bonino, and M. Touzet. Electrochemical study of multiple-energy nitrogen-ion-implanted aluminium alloys. *Materials Science and Engineering A*, 116:53–57, 1989.
- [4] L. Zhang, T. Takahashi, Y. Ueda, and S. Miyazaki. Anti-corrosive surface modification of 6061 aluminum using plasma source ion implantation. *Materials Letters*, 22(1–2):29–33, 1995.
- [5] M. Moradshahi, S.M. Rozati, and S.M. Aghaei. Plasma nitriding of Al alloys by DC glow discharge. *Surface and Coatings Technology*, 201(3–4):567–574, 2006.
- [6] D. Pye. *Practical Nitriding and Ferritic Nitrocarburizing*. ASM International, 2003.
- [7] *Heat Treatment: Conventional and Novel Applications*. IntechOpen, 2012.

- [8] B.M. Girish, M. Somashekar, S. Basavarajappa, and V.S. Aithal. Effect of nitriding on corrosion behaviour of graphite reinforced aluminium alloy composites. *Corrosion Engineering, Science and Technology*, 48(1):51–54, 2013.
- [9] A.S. Hamdy, M. El-Kashif, and A.A. El-Bellihi. Electrochemical studies on the film formed by direct nitridation of AA2024 in a KNO_3 salt bath. *Materials Chemistry and Physics*, 127(1–2):253–258, 2011.
- [10] N. Khan, A.A. Khan, M. Qasim, and M. Abdullah. Nitriding of aluminium alloy in nitrogen and nitrogen-helium mixture using pulsed DC glow discharge. *Plasma Science and Technology*, 12(4):452–460, 2010.
- [11] R.J. Flynn and J.S. Robinson. Application of quench factor analysis to the heat treatment of 7010 aluminium alloy. *Journal of Materials Processing Technology*, 153–154:1021–1026, 2004.
- [12] C.D. Lee, S.H. Han, and S.K. Hong. Effect of galvanic corrosion between precipitate and matrix on corrosion behaviour of as-cast magnesium-aluminum alloys. *Metals and Materials*, 6:351–358, 2000.

Biography



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