Transactions of the Korean Nuclear Society Spring Meeting
Jeju island, Korea, May 21-23, 2025

Effect of various impurity additives on the corrosion behavior of structural materials in NaCl-MgCl₂ salt

Seok Min Yoon[a,b], Taeho Kim[a,b*], Eun-Young Choi[a,b], Seol Kim[a,b], and Chang Hwa Lee[b]
[a]University Science and Technology (UST)
217 Gajeong-ro, Yuseong-gu, Daejeon 34113, Republic of Korea
[b]*Advanced Fuel Cycle Technology Development Division, Korea Atomic Energy Research Institute(KAERI)*
111 Daedeok-daero 989 beon-gil, Yuseong-gu, Daejeon 34057, Republic of Korea
[*]*Corresponding author : Taeho Kim. tkim@kaeri.re.kr*

1. Introduction

Molten Salt Reactors (MSRs) have been extensively studied as promising next-generation nuclear reactors due to their inherent safety, efficient heat transfer, and high-temperature operation capability. Unlike conventional reactors, MSRs utilize molten salts as both fuel and coolant, allowing operation at low pressure and reducing the risk of catastrophic failures. Among various molten salts, $NaCl-MgCl_2$ eutectic salt has been considered as a candidate coolant due to its high thermal stability and favorable thermophysical properties. [1,2]

However, during long-term operation, molten salt inevitably contains various impurities, which can significantly affect the corrosion behavior of structural materials. Previous studies have primarily focused on corrosion resistance in high-purity molten salts, but the effects of such impurities remain insufficiently understood. Impurity-induced corrosion may alter the structural integrity of reactor components, posing challenges for the safe and efficient operation of MSRs. [3,4]

In this study, we investigate the corrosion behavior of structural materials in $NaCl-MgCl_2$ salt with various impurity additives. By analyzing the microstructural and compositional changes in Pure Nickel, Alloy 800 H, and Alloy 625, we aim to provide insights into the role of $Mg(OH)_2$ and $MgCl_2·6H_2O$ impurities in corrosion mechanisms. The findings of this study will contribute to a deeper understanding of material degradation in impure molten salts, which is crucial for ensuring the long-term stability of MSR systems.

2. Experimental

In this study, a $NaCl-MgCl_2$ molten salt was used to co nduct corrosion experiments at 650°C for 500 hours. Th e experiments were performed in a custom-built reactor system, designed to maintain a stable molten salt enviro nment.

Three different structural materials, Nickel 201 (N), Al loy 800H (H), and Alloy 625 (A), were tested under sev en distinct experimental conditions, as detailed in Table 1. The impurity concentrations in the molten salt were v aried to evaluate their effects on the corrosion behavior of the materials.

After the 500-hour exposure, the corroded samples wer e analyzed using scanning electron microscopy (SEM) a nd energy-dispersive X-ray spectroscopy (EDS) to exam ine microstructural and compositional changes.

Cell number	Condition
#1	$NaCl-MgCl_2$ eutectic salt
#2	$NaCl-MgCl_2$ eutectic + 0.1 mol% $Mg(OH)_2$
#3	$NaCl-MgCl_2$ eutectic + 0.5 mol% $Mg(OH)_2$
#4	$NaCl-MgCl_2$ eutectic + 1.0 mol% $Mg(OH)_2$
#5	Replace 10 % $MgCl_2$ with $MgCl_2*6H_2O$
#6	Replace 30 % $MgCl_2$ with $MgCl_2*6H_2O$
#7	Replace 50 % $MgCl_2$ with $MgCl_2*6H_2O$

Table 1. Conditions of corrosion experiment with $NaCl-MgCl_2$ salt

3. Results and Discussion

Microstructural analysis revealed that Nickel 201 (N) exhibited minimal corrosion, with no significant microstructural degradation observed. Instead, weight gain was detected due to Fe precipitation on the surface, as confirmed by SEM and EDS analysis. Figure 1 shows the SEM images and EDS data of Nickel 201 from different experimental conditions, demonstrating the Fe deposition on the surface.

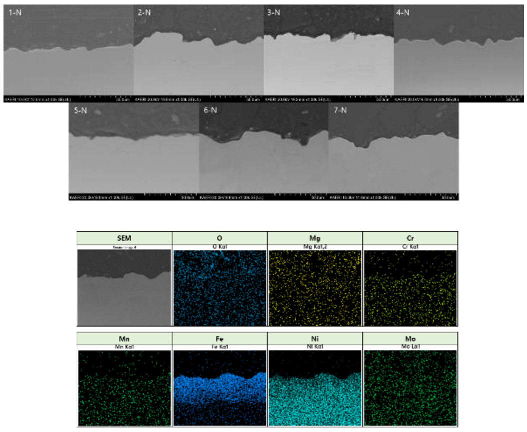

Figure 1. SEM-EDS data of Nickel 201

Among the three tested alloys, Alloy 800H (H) showed the most severe corrosion, and the extent of corrosion accelerated as the impurity concentration increased. Additionally, MgO deposition was observed in the corroded regions, which is believed to have originated either from the $MgCl_2$ pretreatment process or as a result of impurity-induced reactions. However, the influence of the $MgCl_2$pretreatment process is considered to be the dominant factor. Figure 2 presents the SEM images and EDS data of Alloy 800 H, highlighting the severe corrosion and MgO deposition under various impurity conditions.

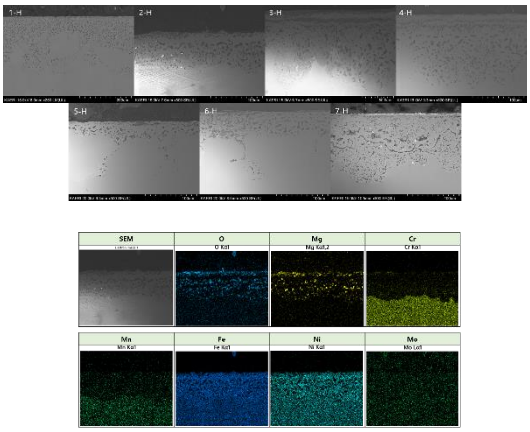

Figure 2. SEM-EDS data of Alloy 800H

For Alloy 625 (A), surface precipitates were observed across all conditions. In specimens exposed to $Mg(OH)_2$ impurities, both MgO and $MgCr_2O_4$ were detected, while in specimens exposed to $MgCl_2{\cdot}6H_2O$ impurities, only MgO was present. Furthermore, microstructural examination confirmed that the corrosion depth of Alloy 625 remained similar across different impurity types and concentrations. Figure 3 displays the SEM images and EDS data of Alloy 625, showing the surface precipitate formations and the overall similarity in corrosion depth regardless of impurity type or concentration.

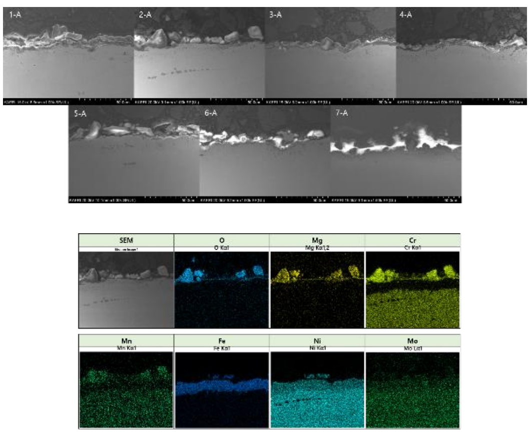

Figure 3. SEM-EDS data of Alloy 625

4. Conclusion

Candidate materials were immersed in NaCl-$MgCl_2$ eutectic salt for 500 hours under high-temperature corrosion conditions, reaching a maximum temperature of 650 °C. To assess the impact of impurities on the corrosion behavior of structural materials, $Mg(OH)_2$ and $MgCl_2{\cdot}6H_2O$ were introduced into the molten salt system. The purified chloride salt was handled within a glove box and transferred into an autoclave for controlled exposure.

Among the tested alloys, Alloy 800H exhibited the most severe degradation, with characteristic Cr depletion near the surface. In contrast, Alloy 625 demonstrated excellent corrosion resistance across all conditions.

Compared to the impurity-free condition, both $Mg(OH)_2$ and $MgCl_2{\cdot}6H_2O$ significantly accelerated corrosion, particularly in Alloy 800H. While $Mg(OH)_2$ showed a relatively consistent increase in corrosion severity with higher concentrations, $MgCl_2{\cdot}6H_2O$ had a milder effect at low concentrations but led to comparable corrosion at higher levels.

These findings provide valuable insights into the influence of impurities in high-temperature molten salt environments and underscore the importance of impurity management to improve the long-term stability of structural materials in MSR systems.

ACKNOWLEDGMENTS

This work was supported by the Molten Salt Reactor Development Agency grant funded by the Korea government (the Ministry of Science and ICT) (Project Number: 1711198911)

REFERENCES

[1] Sandhi, K.K, Szpunar, J. “Analysis of Corrosion of Hastelloy-N, Alloy X750, SS316 and SS304 in Molten Salt High-Temperature Environment” Energies 2021, 14, 543.

[2] Woodhead Publishing Series in Energy “Molten Salt Reactors and Thorium Energy” Edited by Thomas J. Dolan

[3] Gen IV International Forum 2007 annual report, Printed by the OECD Nuclear Energy Agency, 2007.

[4] S. Ghen, Q. Liu, F. Guo, L Ghen, Z. Tang “High temperature corrosion behavior of the 316 stainless steel in NaCl-KCl-$AlCl_3$ molten salt and its vapour” Corrosion Science 2024.