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# Corrosion Behavior of Metallic Alloys in a Molten Chloride Salt For Nuclear Reactor Coolant

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## 1. Background

Currently, fossil fuels are the main source of energy production; however, they release harmful emissions and are not sustainable due to their depletion. This has increased efforts to find alternative sources of energy, such as nuclear energy, in order to reduce harmful emissions and find sustainable energy generation. Conventional nuclear reactors are expensive, generate radioactive waste, and carry the risk of explosions from pressure build-up. To eliminate these risks, research has led to the design of Generation IV Molten Salt Reactors.<sup>1</sup> Molten salt reactors use thorium fuel cycles instead of uranium fuel cycles, which allows some radioactive by-product to be recycled and generate more energy, in turn reducing nuclear waste. Molten salts replace pressurized gas and water, thereby reducing the safety hazards accompanying the use of pressurized fluids in nuclear plants and their surroundings by reducing the chance of meltdown. These reactors currently use molten fluoride salts; however, these are hazardous to health and operationally expensive.<sup>2</sup> Also, their high corrosivity requires the use of specially-made Hastelloy N as containment material; thus substitute salts are being investigated. Chloride salts are possible alternatives because they are abundant, inexpensive and offer favorable thermal properties. Despite these benefits, they are also highly corrosive, and further research must be done to identify compatible alloys.<sup>3,4</sup>

## 2. Objective

To identify a molten salt as a nuclear reactor coolant and test the corrosion behavior of candidate alloys UNS S30400, UNS S31600 and UNS N06601 in the selected salt at 700°C using immersion testing.

## 3. Hypothesis

The UNS N06601 will exhibit the highest resistance to corrosion while the UNS S30400 will exhibit the least corrosion resistance.

## 4. Materials and Methods

Pre-test coupons were measured and weighed before being immersed in a crucible with six grams of a LiCl-KCl-MgCl<sub>2</sub> eutectic salt for testing. Immersion tests were conducted at 700°C in a stagnant argon environment for 24 hours. Post-test coupons were cleaned mechanically following the ASTM G1 standard for cleaning post-test immersion samples. Cleaned samples were weighed for mass loss measurements. The post-test coupons were mounted and then prepared to a 1 µm finish using diamond suspension. All polished samples were analyzed using scanning electron microscopy (SEM) coupled with energy dispersive spectroscopy (EDS).

	Fe	Ni	Mn	Cr	Al	Cu	Mo
UNS S30400	balance	10.5 %	2 %	20 %	0 %	0 %	0 %
UNS S31600	balance	14 %	2 %	18 %	0 %	0 %	3 %
UNS N06601	13 %	balance	1 %	23 %	1.35 %	1 %	0 %

Table 1: Composition of alloys

## 5. Results

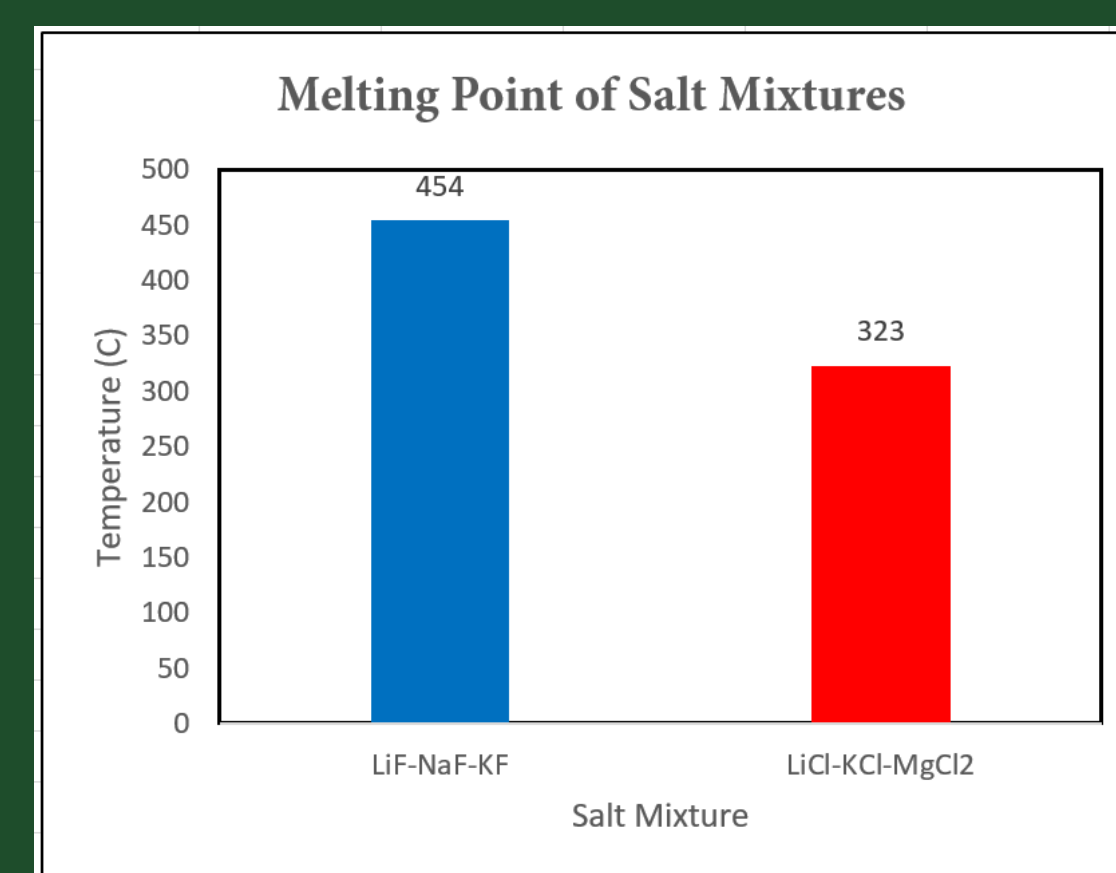


Figure 1: Melting Temperature of fluoride and chloride salts

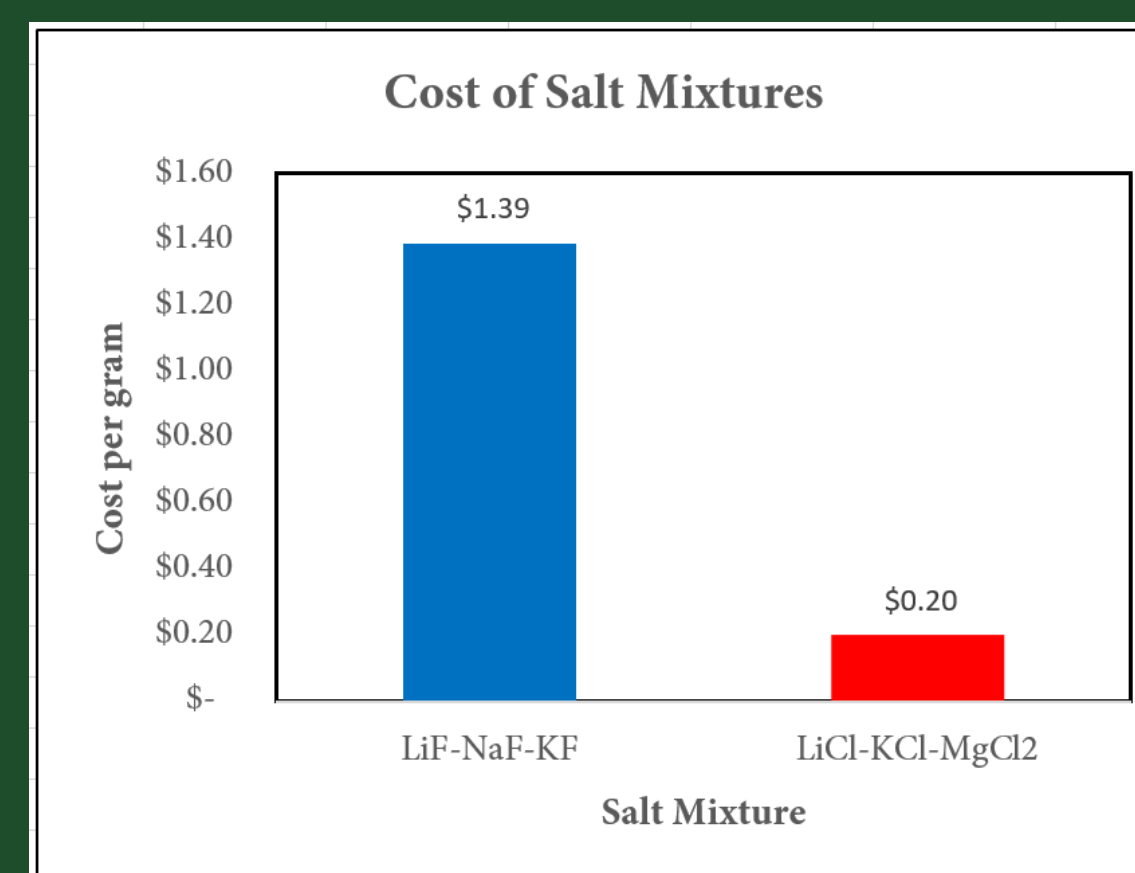


Figure 2: Costs of fluoride and chloride salts

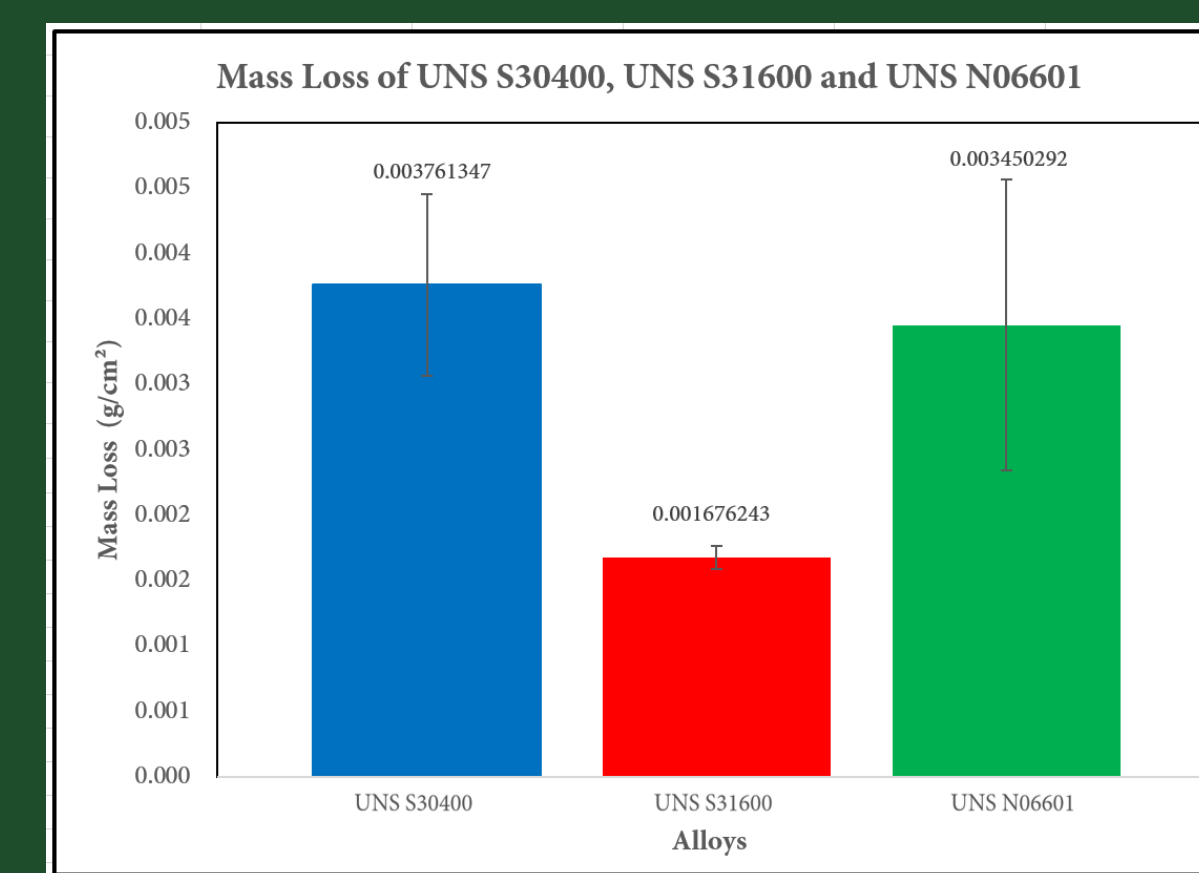


Figure 3: Mass loss per unit area for three different alloys at 700°C for a 24 h exposure

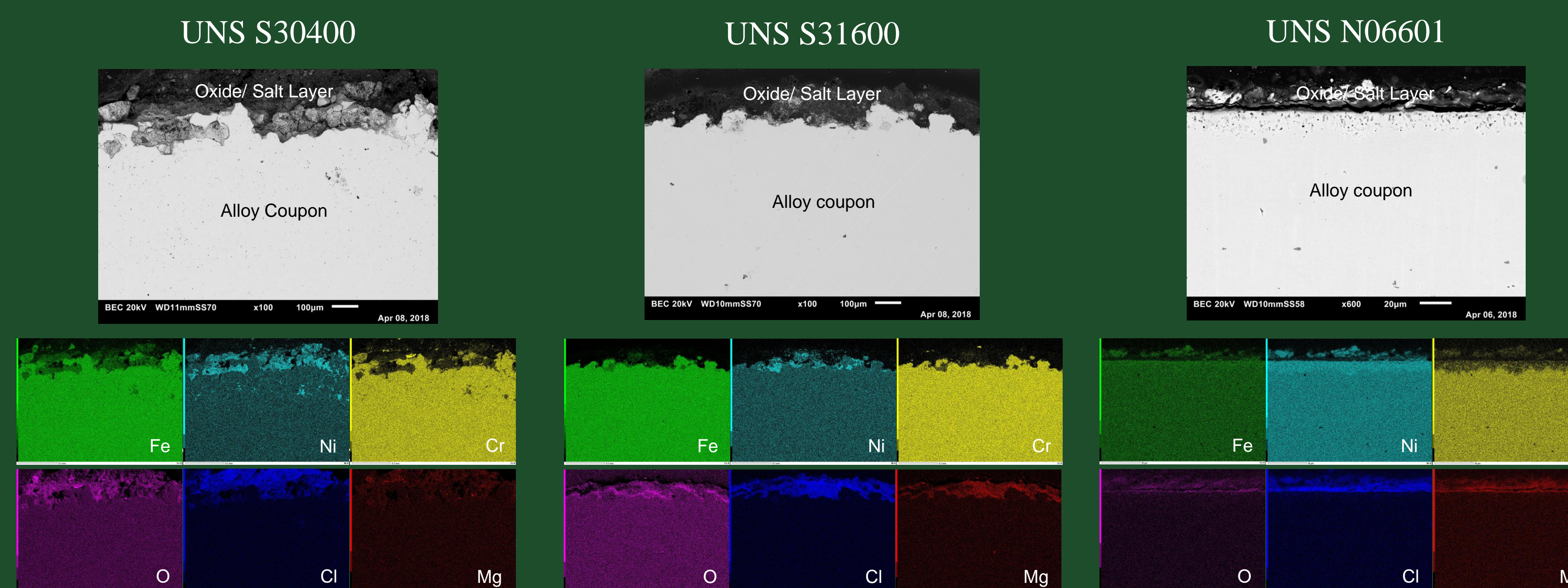


Figure 4: Backscattered electron images and elemental maps of a) UNS S30400, b) UNS S31600, c) UNS N06601

## 6. Discussion

A wide variety of candidate salts were considered, and narrowed down to a 46.50-11.50-42.00 mol% LiF-NaF-KF salt and a 14.15-13.05-72.80 mol% LiCl-NaCl-MgCl<sub>2</sub> mixture. The LiCl-KCl-MgCl<sub>2</sub> mixture was selected in preference to LiCl-NaCl-MgCl<sub>2</sub> because of its higher heat capacity. Figures 1 and 2 compare the eutectic melting points and costs of the LiCl-KCl-MgCl<sub>2</sub> and the LiF-NaF-KF mixtures, where both the cost and melting point of the chloride salt mixture were lower. Chloride salts have a larger neutron absorption coefficients and higher corrosivity than fluoride salts; yet they are cost effective, less hazardous and sustainable, making them more attractive options as coolants.

UNS S31600 exhibited the lowest mass loss indicating a greater corrosion resistance than UNS S30400 and UNS N06601(Figure 3). Despite the well-known susceptibility of stainless steels to chloride attack, UNS N06601 appeared to experience greater corrosion. The uniformity seen in the backscattered electron image chart of UNS N06601 indicates that this coupon was subjected to uniform corrosion, i.e., layer-by-layer removal.

The EDS analysis of UNS S30400 and UNS S31600 shows chromium and iron depletion along the surface of the substrate (Figure 4 a and b). The oxidation was non-uniform as evidenced by the discrete regions of oxides that were formed on all three of the alloys (Figure 4 a and b). UNS N06601 showed a depleted layer of chromium and nickel along the surface of the substrate as well as the presence of these alloying elements in the salt, suggesting dissolution of the nickel and chromium from the substrate (Figure 4 c). A thin layer adjacent to the metal/salt interface shows evidence of precipitates formed as a result of the metal dissolution.

Given that all tests were run in inert argon gas environments, it is likely that the oxygen source was either from the trace amounts in the gas or from moisture potentially entrapped in MgCl<sub>2</sub> and LiCl in the salt eutectic.

## 7. Summary and Conclusions

Based on cost effectiveness, safety, availability, sustainability, thermal properties of the salt mixture and the previously stated criteria, 41.48-46.18-12.34 mol% LiCl-KCl-MgCl<sub>2</sub>, was selected as a possible replacement for the currently used fluoride salt coolants in nuclear reactors. The corrosion behavior of UNS S30400, UNS S31600, and UNS N06601 in two molten salts was studied using immersion testing and scanning electron microscopy. The trend based on the preliminary test data appears to show that UNS S30400 exhibited the least resistance to corrosion which is in accordance with our hypothesis. The UNS S31600 had the greatest corrosion resistance amongst the three alloys. Given the instability of MgCl<sub>2</sub> and LiCl, the selected salt eutectic was not a viable salt mixture. Further testing will be conducted to validate the results.

## 8. Future Work

In the future, additional replicates will be run in order to validate the corrosion resistance of UNS S31600 and UNS N06601. Other future works include the coating of alloys as well as investigate into the dehydration of MgCl<sub>2</sub> and LiCl to increase the stability of the salts. The binary LiCl-KCl eutectic will be tested.

## 9. References

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