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High Temperature Corrosion Behaviour Of Cold Rolled Additively
Manufactured Stainless Steel 316L in Molten Solar Salt

SCHOOL OF WATER, ENERGY AND ENVIRONMENT
Advanced Mechanical Engineering

MSc
Academic Year: 2024 - 2025

Supervisor: Dr Stefano Mori
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**This thesis is submitted in partial fulfilment of the requirements
for the degree of MSc Advanced Mechanical Engineering**

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Abstract

This thesis examines the high-temperature corrosion behaviour of cold-rolled additively manufactured stainless steel 316L (SS316L) in a molten solar salt environment, with a focus on its suitability for Concentrated Solar Power (CSP) thermal energy storage systems. SS316L samples were fabricated by Wire Arc Additive Manufacturing (WAAM), with some subjected to 120 kN cold rolling on each layer. These samples were exposed to a $\text{NaNO}_3\text{-KNO}_3\text{-KCl}$ eutectic salt (molar ratio 10:78:12) at 607°C , under inert nitrogen, for up to 500 hours. Corrosion was assessed using mass change measurements, dimensional metrology, and detailed surface characterisation by SEM-EDS. The results showed that all samples initially gained mass, primarily due to oxide and salt deposition. Cold-rolled samples experienced significantly greater uniform metal loss ($179\text{ }\mu\text{m}$ after 500 hours) compared to as-printed samples, indicating that grain refinement from rolling promotes more aggressive and uniform corrosion under prolonged exposure. SEM-EDS analysis revealed differences in corrosion mechanisms: cold-rolled specimens suffered from extensive salt infiltration and dissolution of surface oxides, while as-printed samples displayed thicker and more protective oxide scales but were more prone to localised corrosion and pitting. These findings indicate that microstructural modification by post-processing strongly influences corrosion response in molten salts, impacting material lifespan and system reliability for CSP. The results highlight key considerations for designing and selecting advanced steels for next-generation, high-temperature thermal storage environments.

Keywords:

Concentrated solar power, Thermal Energy Storage, SEM, Cold rolling, WAAM (Wire Arc Additive Manufacturing), Corrosion

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List of Abbreviations

IT	Information Technology
CSP	Concentrated Solar Power
PTC	Parabolic Trough Collectors
LFR	Linear Fresnel Reflectors
SPT	Solar Power Towers
PDC	Parabolic Dish Collectors
PV	Photovoltaic
TES	Thermal Energy Storage Systems
THS	Thermochemical Heat Storage
CRS	Central Receiver Systems
HTF	Heat Transfer Fluid
AM	Additive Manufacturing
LHS	Latent heat storage
TCS	Thermochemical Heat Storage
WAAM	Wire Arc Additive Manufacturing
BSI	British Standards Institution
SEM	Scanning Electron Microscopy
EDS	Energy-Dispersive Spectroscopy
GHG	Green House Gas
IEA	International Energy Agency

1 Introduction

1.1 Background of the Study

The world is currently grappling with an unprecedented increase in both global energy demand and the adverse environmental impacts of greenhouse gas (GHG) emissions. With the global population projected to reach 9.8 billion by 2050, the demand for energy is expected to continue its upward trajectory, placing even greater strain on existing energy infrastructure ((*World Population Projected to Reach 9.8 Billion in 2050, and 11.2 Billion in 2100*, n.d.; *World Population Prospects: The 2017 Revision*, n.d.)) and contributing to the intensification of climate change. This growing demand for energy, coupled with the urgent need to reduce GHG emissions, has led to a global call for a transformation towards sustainable energy solutions that not only meet the world's needs but also ensure the health and well-being of future generations. The challenge lies in decoupling economic growth and development from carbon emissions, which have historically been a primary driver of climate change.

The increase in energy-related CO₂ emissions has been closely tied to the expansion of fossil fuels, the dominant source of global energy for over a century. In 2024, energy-related CO₂ emissions reached a record high of 37.8 gigatons, as shown in Figure 1-1-1, with a rise in concentration to 422.5 ppm in 2024. Fossil fuels still account for approximately 60% of global energy needs(*Global Energy Review 2025*, n.d.) Despite the increasing adoption of renewable energy technologies. This alarming trend is exacerbated by the rapid urbanization and industrialization occurring worldwide, particularly in emerging economies. According to the International Energy Agency (IEA), developing countries are expected to account for more than 80% of the global energy demand increase through 2040(*World Energy Outlook 2024*, n.d.). As energy consumption continues to rise in tandem with population growth, the need to transition to cleaner, more sustainable energy sources becomes ever more pressing.

Global energy related CO₂ emissions and their annual change, 1990-2024

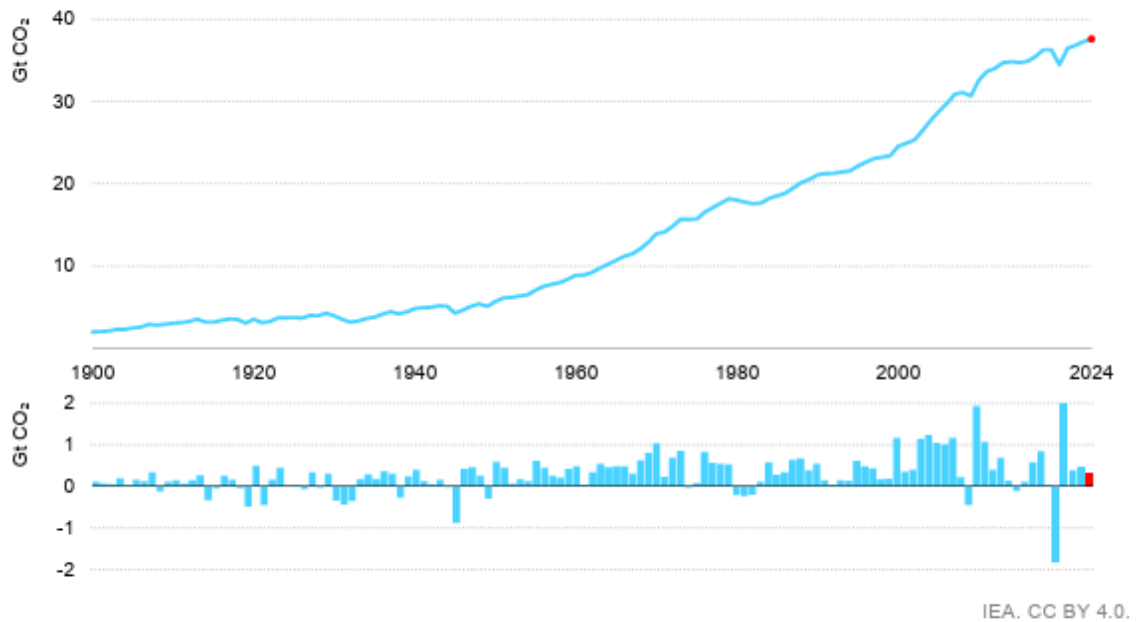


Figure 1-1-1: Global CO₂ emissions. (Global Energy Review 2025, n.d.)

At the heart of this global challenge is the urgent need for scalable renewable energy solutions that can provide reliable, clean power while reducing the environmental footprint of traditional fossil fuels. Solar energy, being one of the most abundant and widely distributed renewable resources, stands at the forefront of this transformation. While solar photovoltaic (PV) systems have become mainstream due to their cost-effectiveness and simplicity, their intermittent nature, limited by daylight hours, poses a significant challenge to their ability to provide consistent power. To address this issue and better integrate solar energy into the global grid, Concentrated Solar Power (CSP) has emerged as a promising technology. CSP not only generates electricity by using mirrors or lenses to concentrate sunlight into heat but also offers the advantage of thermal storage, enabling electricity generation even after sunset.

As the world strives for a more sustainable future, CSP technologies offer a critical solution. CSP has the potential to contribute to a reliable and dispatchable renewable energy supply by storing thermal energy, which can be used to generate power during periods when sunlight is unavailable. The inherent ability of CSP to provide continuous energy is what sets it apart from traditional PV

systems, making it an ideal candidate for large-scale integration into the global energy mix. Moreover, CSP technologies can be deployed in regions with high solar insolation, such as parts of the Middle East, North Africa, and the southwestern United States, where optimal conditions exist for large-scale solar power generation.

However, despite these advantages, the widespread adoption of CSP has been limited by cost, efficiency, and technological challenges. Recent innovations in CSP, including advancements in receiver design, thermal storage materials, and power cycle optimization, have paved the way for improved performance and reduced costs. These advancements, coupled with strategic hybridization that integrates CSP with PV or energy storage systems, hold the key to unlocking the full potential of CSP.

In this thesis, the focus is on the thermal energy storage system, where material in a storage tank is exposed to heat and used as a medium of a heat exchanger to generate electricity when required. The storage tank and the TES medium should be selected to ensure they are compatible with combating corrosion, thereby reducing costs and increasing the efficiency of CSP technologies compared to PV. There are already a variety of solid and liquid-based mediums to store heat in SHS, most of which are related to different types of molten salt compositions and their corrosion mechanisms(Alami et al., 2023). Many works on technology aim to improve efficiency and increase the durability of the materials used for TES.

Curious research is being conducted regarding additive-manufactured substances and how to reduce the corrosion of additively manufactured materials in molten salts. Various components of the TES and CSP can be manufactured using additive manufacturing. Since additive manufacturing offers better resistance to corrosion than traditional manufacturing techniques, it also reduces costs and increases durability. The difference in additive manufactured material and post-processed additive manufactured materials is the grain structure and the change in metal properties. Observing that is the main aim of the report

1.2 Aim and Objectives

The primary aim of the present study is to investigate the effect of cold-rolled additively manufactured SS316L in a Molten salt environment, with the goal of understanding and improving the material constraints for CSP applications.

To achieve this aim, the following objectives are set at the beginning of the research:

- To conduct an extensive literature review on the topic of interest.
- To confirm the experimental plan.
- Exposing different samples in an already chosen Salt environment.
- To assess the results obtained from the experiment and understand the parameters

2 Literature Review

2.1 Concentrated Solar Power (CSP) Technologies

Concentrated Solar Power CSP technologies are used to harness and convert solar energy into thermal energy, which is then used to generate electricity. CSP systems have garnered significant attention, as they can be integrated with thermal energy storage (TES), enabling dispatchable power even when the sun is not shining. (Zhang et al., 2013) CSP technologies are most effective in regions with high Direct Normal Irradiance (DNI), such as deserts and sunny areas. CSP systems encompass various configurations, each optimized for specific energy demands and environmental conditions. (Islam et al., 2018; Rodat & Thonig, 2024)

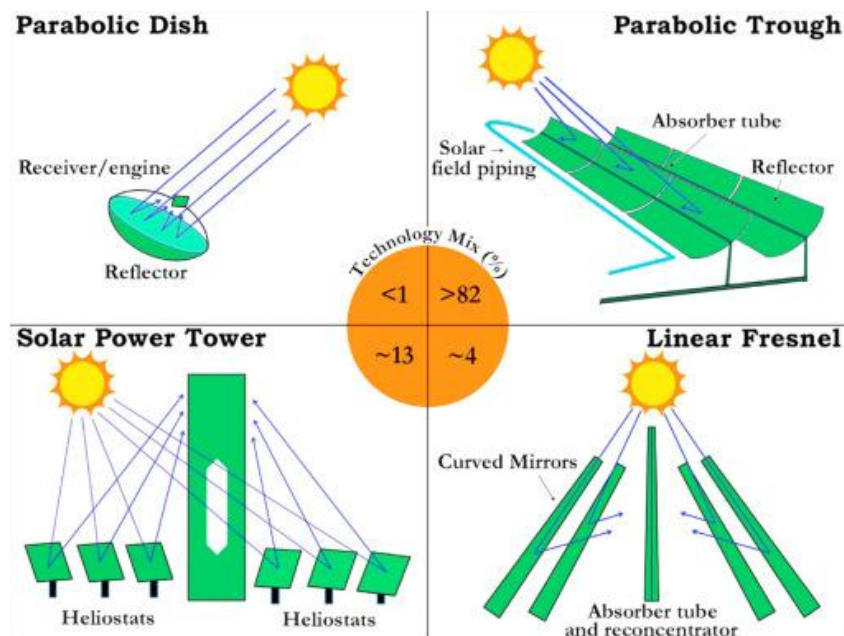


Figure 2-1-1: Types of CSP Technologies (Islam et al., 2018)

2.1.1 Parabolic Trough Collectors (PTC)

The Parabolic Trough Collector (PTC) system is the most reliable CSP technology (Jebasingh & Herbert, 2016). It uses parabolic mirrors to concentrate sunlight onto a receiver tube placed along the trough's focal line. The receiver tube typically contains molten salt or synthetic oil, which absorbs the concentrated sunlight and is used to generate steam. PTC systems are suitable

for medium-temperature applications (300°C to 400°C) and have been deployed in large CSP plants due to their relatively high efficiency and commercial maturity (Al-Farajat et al., 2022).

One limitation of PTC systems is that they typically require large tracts of land for installation, making them more suitable for arid or semi-arid regions where land availability is less of a concern (Alrikabi, 2014). Recent advancements have focused on enhancing the efficiency of PTC systems by utilizing high-temperature molten salts and refining the optical performance of the mirrors (Gage et al., 2021).

2.1.2 Linear Fresnel Reflectors (LFR)

Linear Fresnel reflectors (LFRs) are one of the most promising solar technologies for medium- and high-temperature operation (Bellos, 2019). Use flat mirrors arranged in parallel rows to concentrate sunlight onto a fixed receiver. The advantage of LFRs over PTCs lies in the simpler design and lower cost of the mirrors, which makes them more economical for smaller-scale projects. However, LFR systems have a lower concentration ratio, which means they operate at lower temperatures (250°C to 400°C) than PTC systems (Al-Farajat et al., 2022). LFRs can also utilize direct steam generation (DSG), which eliminates the need for HTFs and reduces the overall system cost (Schiel & Keck, 2012).

2.1.3 Solar Power Towers or Central Receiver Systems (SPT)

Solar power towers (SPTs) or central receiver systems (CRSs) are among the most advanced CSP technologies. In an SPT system, a large field of heliostats mirrors concentrates sunlight onto a receiver located at the top of a tower. The concentrated sunlight is absorbed by the receiver, which heats the Heat Transfer Fluid (HTF), typically molten salts, used to produce steam and drive a turbine. SPT systems can operate at extremely high temperatures (up to 1000°C), enabling high-efficiency electricity generation and large-scale energy storage (Bauer et al., 2021).

One challenge of SPT systems is the high initial capital investment and land area requirements. Nevertheless, SPT systems offer greater scalability and efficiency compared to other CSP technologies (Gage et al., 2021).

2.1.4 Parabolic Dish Collectors (PDC)

Parabolic dish collectors (PDC) use parabolic-shaped mirrors to concentrate sunlight onto a receiver located at the focal point of the dish. The receiver is typically connected to a Stirling engine, which converts heat into mechanical energy that can then be used to generate electricity. PDC systems have high optical efficiency and can operate at very high temperatures (up to 1000°C); however, they are typically used in small-scale applications due to their high cost and complex installation requirements (Schiel & Keck, 2012).

PDCs are particularly useful in off-grid or remote areas where smaller, distributed energy generation systems are required. The high concentration ratio of PDCs makes them highly efficient, with concentration ratios ranging from 1300 to 2000 (Al-Farajat et al., 2022). However, the technology remains less commercially viable compared to other CSP systems.

2.2 Thermal Energy Storage Systems (TES)

Thermal Energy Storage (TES) plays a crucial role in enhancing the viability and dispatchability of solar energy systems, particularly CSP. TES systems store thermal energy generated during periods of high solar irradiation for use when sunlight is unavailable. This ability to store energy enables CSP systems to produce electricity continuously, unlike photovoltaic (PV) systems, which rely on direct sunlight (Pelay et al., 2017). TES can be divided into three primary categories: sensible heat storage (SHS), latent heat storage (LHS), and thermochemical heat storage (TCS).

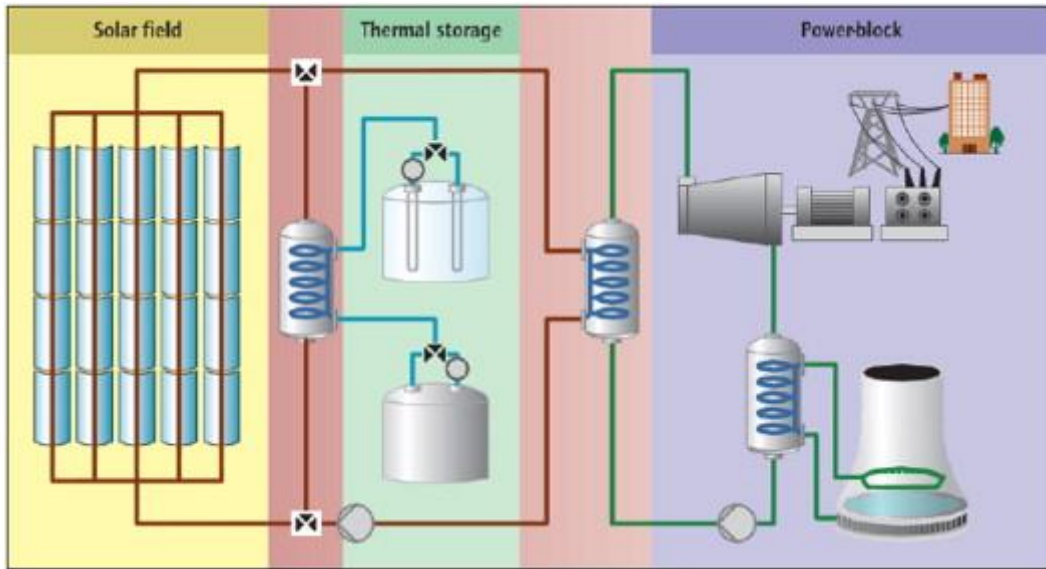


Figure 2-2: Flowchart of CSP System with TES (Power, C. S. (2010)).

2.2.1 Sensible Heat Storage (SHS)

Sensible heat storage is the most used method in CSP plants. This technique involves raising the temperature of a medium, such as water, solid materials, or molten salts, to store thermal energy. The heat is stored because of the change in temperature of the medium. Molten salts, specifically Solar Salt ($\text{NaNO}_3\text{-KNO}_3$), are preferred for SHS in CSP due to their high thermal stability and heat capacity, allowing them to efficiently store energy at temperatures between 400°C and 600°C (Bauer et al., 2021). Solar Salt has been extensively used in Parabolic Trough Collectors (PTC) and Solar Power Towers (SPT) due to its cost-effectiveness and proven performance in long-term storage (Liu et al., 2016).

Properties	Desirable characteristics
Thermo–physical properties	High energy density (per unit mass or volume), high thermal conductivity, high heat capacity, high density, long-term thermal cycling stability
Chemical properties	Long-term chemical stability with no chemical decomposition, non-toxic, non-explosive, low corrosion potential or reactivity to HTFs, and compatible with materials of construction
Economic properties	Cheap and abundant materials with a low cost of manufacturing into suitable shapes
Mechanical	Good mechanical stability, low coefficient of thermal expansion, high fracture toughness, and high compressive strength
Environmental	Low manufacturing energy requirement and CO ₂ footprint

Table 1: SHS Characteristics (Khare et al., 2013)

2.2.2 Latent Heat Storage (LHS)

Latent heat storage involves the use of phase change materials (PCMs), which absorb or release thermal energy during a phase transition, such as the solid-to-liquid transition. This method offers high energy density and can store more energy per unit mass than SHS materials. However, LHS systems typically face challenges such as slower charge/discharge rates and difficulties in selecting suitable PCMs (Pelay et al., 2017). Despite these challenges, LHS is gaining attention in the development of advanced TES technologies for CSP ((Mahmood et al., 2018).

2.2.3 Thermochemical Heat Storage (TCS)

Thermochemical heat storage utilizes reversible chemical reactions to store thermal energy. Energy is stored in chemical bonds during endothermic reactions and released when the reaction is reversed. TCS offers higher energy density than SHS and LHS but remains an area of active research due to material limitations and the complexity of the reaction processes (Bauer et al., 2021).

2.3 Molten Salts for Thermal Energy Storage and CSP Systems

Molten salts are a key component in (TES) systems, especially for (CSP) technologies. They offer significant advantages, including high thermal stability, high specific heat capacity, and low vapor pressure, making them ideal for storing and transferring thermal energy at high temperatures. These properties enable molten salts to store energy efficiently, allowing CSP systems to generate electricity even when sunlight is unavailable, such as during nighttime or cloudy periods ((Bauer et al., 2021)

2.3.1 Molten Salts

Molten salts are attractive as heat-transfer and thermal-energy-storage media due to their high specific heat, low vapor pressure, and stability at elevated temperatures, enabling near-atmospheric operation and reduced vessel costs (Summers & Chidambaram, 2021). Molten salts used in CSP systems are typically mixtures of nitrate, chloride, or carbonate salts, each offering specific benefits and limitations. The corrosive strength of the salts is ranked (chloride salt mixture > carbonate salt mixture > Nitrate salt mixture) (Wei et al., 2025)

Molten salts composition (wt. %)	Melting point (°C)	Stability limit (°C)	Viscosity (mPa s)	Density (g cm ⁻³)	Heat capacity (kJ kg ⁻¹ K ⁻¹)	Cost (\$/kg)
Solar Salt NaNO ₃ /KNO ₃ (60/40)	220 [3]	600 [3]	3.26 [3] (300°C)	~1.84 [4]	~1.5 [4] (560°C)	0.5 [3]
Hitec NaNO ₃ /KNO ₃ /NaNO ₂ (7/53/40)	142 [3]	535 [3]	3.16 [3] (300°C)	~1.9 [4]	1.56 [3] (300°C)	0.93 [3]
LiNaK carbonates Li ₂ CO ₃ /Na ₂ CO ₃ /K ₂ CO ₃ (32.1/33.4/34.5)	~400 [3]	800-850 [3]	4.3 [3] (800°C)	1.85 [4]	~1.4-1.5 [3]	~1.2-1.3 [3]
LiNaK fluorides KF/LiF/NaF (59/29/12)	454 [4]	>700 [4]	N/A	1.89 [4]	1.89 [4] (700°C)	>2*
ZnNaK chlorides ZnCl ₂ /NaCl/KCl (68.6/7.5/23.9)	204 [3]	850 [3]	4 [3] (600-800°C)	~2 [5]	0.81 [3] (300-600°C)	<1 [3]
MgNaK chlorides MgCl ₂ /NaCl/KCl (68.2/14.0/17.8)	380 [6]	>800	4 [5] (500-800°C)	~1.65 [5]	~1.0 [5] (500-800°C)	<0.5*

Table 2 : Various Salt Composition and Properties

2.3.1.1 Nitrate-Based Molten Salts

Nitrate-based salts, such as Solar Salt (NaNO₃-KNO₃), are the most widely used in CSP systems. Solar salt operates effectively at temperatures up to 565°C and is relatively cost-effective, making it the industry standard for many CSP plants (Ding et al., 2018). These salts are chemically stable, non-toxic, and have a high specific heat capacity, allowing for efficient energy storage. However, they do have low thermal conductivity, which limits their heat transfer efficiency in some CSP designs (Pelay et al., 2017).

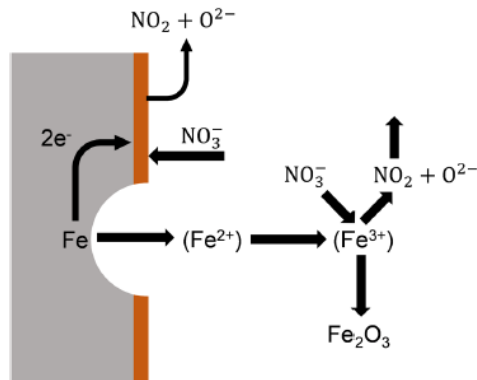


Figure 2-3: Nitrates reaction with Fe

2.3.1.2 Chloride-Based Molten Salts

Chloride-based molten salts, including mixtures such as $\text{MgCl}_2/\text{NaCl}/\text{KCl}$, exhibit higher thermal conductivity ($>800^\circ\text{C}$) and good thermal stability, making them suitable for higher-temperature CSP applications. They can operate at temperatures exceeding 700°C , offering greater efficiency in power generation (Al-Farajat et al., 2022). However, chloride salts are more corrosive, posing challenges for material selection and long-term durability of CSP components (Sarvghad et al., 2018).

2.3.1.3 Carbonate-Based Molten Salts

Carbonate-based salts, like $\text{Li}_2\text{CO}_3\text{-Na}_2\text{CO}_3\text{-K}_2\text{CO}_3$, are another alternative. These salts offer higher energy density and are effective at storing heat at even higher temperatures (above 700°C). However, carbonates are less commonly used in CSP systems due to their cost and the complexity involved in handling and maintaining these materials (Gage et al., 2021).

2.4 Corrosion Mechanism in High Temperature

High-temperature corrosion is a critical challenge for molten salt (TES) systems, especially in CSP plants, affecting their design, life cycle, and economic viability (Bell et al., 2019). The complex mechanisms of corrosion are heavily influenced by factors such as impurities, atmosphere, temperature, and metal composition,

making general corrosion rate data often inapplicable. Corrosion mechanisms largely depend on the salt anion species, which are typically categorized as oxyanionic (e.g., nitrates) or halide-based (e.g., chlorides). These species are often explained using an acid-base model, where the oxide ion (O^{2-}) defines the melt's basicity (Bell et al., 2019).

2.4.1 Corrosion Mechanism with Nitrate Salts

Nitrate salts, such as sodium and potassium nitrate, are widely used in operational CSP plants below 600 °C due to their relatively low melting points and acceptable corrosion rates. As oxyanionic species, corrosion in these salts is dependent on the melted acidity, which is determined by the dissociation of nitrate ions into nitrite and oxide ions. Below 600 °C, these salts typically form a weak basic melt where iron forms a passive oxide layer, primarily magnetite (Fe_3O_4), which protects an inner iron-chromium spinel layer, limiting chromium migration from the metal and resulting in minimal corrosion rates for stainless steels. (Bell et al., 2019) However, above 600 °C, the melt's basicity increases significantly, causing the protective Fe_3O_4 outer layer to convert into a non-protective sodium ferrite ($NaFeO_2$), which rapidly increases the corrosion rate. The presence of impurities, particularly chloride ions, significantly exacerbates corrosion in nitrate salts, shifting the corrosion rate from parabolic at low concentrations to linear at higher concentrations (e.g., above 0.1 Molal for mild steel or 0.5 wt% for stainless steels). Thermal cycling can also moderately increase corrosion rates, potentially due to stresses that cause cracks in protective oxides. Stainless steels (e.g., 304, 316, 347 grades) offer acceptable corrosion resistance up to 565 °C; however, even high-nickel alloys experience increased corrosion above 600 °C.

2.4.2 Corrosion Mechanism with Chloride Salts

Chloride salts are promising for next-generation CSP systems operating at higher temperatures (600–1000 °C) due to their lower cost and superior thermal stability compared to nitrates. However, they are highly corrosive to metallic materials. In pure chloride melts, stable, protective oxide scales are generally unlikely to form on structural alloys; if they do, they are often unstable or dissolve, especially in

acidic or basic melts. (Wei et al., 2025) Chromia-forming alloys and Fe/Ni-based alloys tend to perform poorly, as their oxides are often soluble (Summers & Chidambaram, 2021), Click or tap here to enter text. with chromium oxides having higher solubility than iron or nickel oxides. The presence of impurities is the dominant factor driving corrosion. Water/moisture is a major impurity, reacting with halide ions to produce hydrogen halides, such as HCl gas, which provides a "thermodynamic shortcut" to chlorination reactions. This process forms metal chlorides that are often soluble. Oxygen also significantly exacerbates corrosion, leading to higher mass loss as alloys form oxides that subsequently dissolve in the molten chloride, thereby perpetuating the oxidation process. Key corrosion types include selective dissolution of chromium, which creates subsurface voids and porous layers (Wei et al., 2025), as well as intergranular and pitting corrosion. Stress corrosion cracking has also been observed in stainless steels in molten chloride environments under inert atmospheres. Given the critical role of impurities, purification techniques (e.g., thermal, electrolytic, gas injection) are essential for mitigating corrosion. Stainless steels generally show poor resistance, while nickel-based alloys tend to perform better, though they still face significant corrosion challenges, particularly in the presence of impurities.

2.5 Selection Of Material For TES

Steel is one of the most commonly used materials in pipe manufacturing and tube production for industrial purposes. Carbon steel has fairly better corrosion resistance at temperatures up to 540°C. When temperatures rise, the corrosion resistance of these materials decreases, and they can degrade, which can impact the performance and longevity of the pipes. The pipes and tubes are stable at 400°C in a nitrate environment of CSP. Stainless steel, which typically has a higher Cr content, can withstand temperatures ranging from 600-700°C (Pelay et al., 2017). In high-nitrate environments, the 300-series stainless steel with high Cr content has been shown to exhibit better corrosion resistance and no degradation in its mechanical properties after prolonged testing (Goods & Bradshaw, 2004). In contrast, in a chloride environment, the stainless steel exhibits a huge drop in steel level at temperatures exceeding 550°C. Some Ni-

based alloys, such as Hastelloy C-22 and C-276, exhibit better corrosion resistance than Fe-based alloys; however, in extreme environments, they can experience severe corrosion in molten chloride environments. (Ding, Shi, et al., 2018). Advanced manufacturing technologies can be explored, such as additively manufactured SS316L, the low-carbon version of SS316. In additive manufacturing, the rapid cooling and local segregation of Cr, Ni, and Mo stabilize the passive oxide film, thereby enhancing corrosion resistance. However, the presence of process-induced porosity or surface defects can act as localized corrosion initiation sites, and if not controlled or post-processed, can result in lower resistance in harsh environments. (Nie et al., 2021)

2.6 Additive Manufacturing

Additive manufacturing (AM) encompasses a wide range of technologies that build components layer by layer directly from digital models, resulting in rapid innovation across various industries, including aerospace, medicine, and energy (Rodrigues et al., 2019). Among the various AM techniques, Wire Arc Additive Manufacturing (WAAM) has gained recognition for its high deposition rates, cost-effectiveness, and ability to fabricate large metallic structures, particularly using commonly employed engineering alloys like stainless steels.

2.6.1 Wire + Arc Additive Manufacturing (WAAM)

WAAM utilizes an electric arc as a heat source to melt metal wire, enabling the flexible and scalable production of complex parts. While WAAM offers significant advantages in terms of speed and production scale, challenges remain due to its characteristic layer-by-layer thermal cycling, which induces residual stresses, anisotropy, and defects such as porosity and coarse grains, all of which influence the mechanical and corrosion properties of the deposited material (Gürol et al., 2023) (de Lima et al., 2024). Stainless steel 316L (SS316L) is a preferred feedstock in WAAM due to its excellent corrosion resistance, mechanical toughness, and weldability, which make it suitable for critical components in harsh service environments (Shah et al., 2023). However, conventional WAAM-fabricated SS316L may display inhomogeneous microstructures, residual stress

concentration, and variable performance compared to wrought counterparts unless further processed.

2.6.2 Post-Processing and Corrosion Resistance

Layer-by-layer cold rolling at room temperature is applied after each WAAM pass to tackle these issues. This in-situ deformation densifies the build, relieves residual stresses, and converts coarse columnar grains into finer, more uniform structures, consistently improving strength, ductility, and toughness beyond as-printed levels(Xu et al., 2023)

The refined, homogeneous microstructure also enhances corrosion resistance, as fewer defects and a more stable passive film reduce pitting and crevice attack, often matching or exceeding that of wrought 316L. When followed by post-deformation annealing, passivation stabilises further, enhancing long-term durability.

3 METHODOLOGY

3.1 Material Selection

The material chosen for this study is SS316L, a low-carbon variant of stainless steel 316. There are two types of samples, each type consists of 2 samples for the study. One of the samples is additively manufactured from SS316L with WAAM technology, and the other sample has been manufactured using WAAM but has undergone 120KN cold rolling on each layer of the material. The chemical composition of the additively manufactured SS316L is shown in Table 3. All samples have been cut to a size with a height of approximately 10mm, a mean outer diameter of 10 mm, and a notch has been made on top of the sample to identify the top side and for measurement purposes. All samples were cleaned with acetone and propanol for 15 minutes each in an Ultrasonic cleaner to remove any trace of impurities in Figure 3-1 and then dried in a laboratory oven at 60 °C for 24 hours. The metal samples are depicted in Figure 3-2 .The numbers 250 and 500 indicate the Exposed hours. The notation “/1” means the sample has no rolling effect, and “/4” means it has 120KN of rolling done.



Figure 3-1 Ultrasonic cleaning

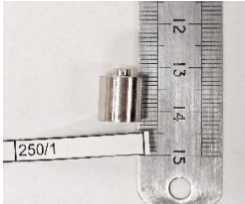
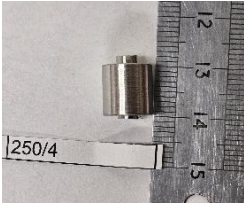
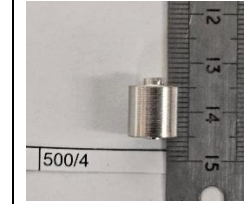
250/1	250/4	500/1	500/4
			

Figure 3-2: Samples before testing

Label	C	Co	Si	Cr	Mn	Fe	Ni	Mo	Total
Composition	0.03	0.48	0.67	17.15	1.09	Balance	9.73	2.77	100%

Table 3 :SS316L Composition

3.2 Molten salt mixture

The molten salt mixture used for the study is inspired by a study by **Sang et al. (2023)**. Two types of salts, with chlorides and carbonates, are used to find a salt that has a better decomposing temperature than typical solar salt. The salt was made into a mixture using the same proportions used in (Joy et al., 2025) The suggested mixture is $\text{NaNO}_3\text{-KNO}_3\text{-KCl}$ in a Molar ratio of 10:78:12. The chemical properties of the salt are listed in Table 4 below. Salt mixtures are heated in a laboratory oven for 24 hours at 60°C to remove any traces of moisture, as the salts are considered hygroscopic substances.

Chemical Property	Values
Melting Point	206.12°C
Decomposition temperature	641.73°C
Latent heat	110.48 J/g
Specific heat capacity	1.5298 J/(g.K) (from 250 to 450°C)

Table 4: Salt Properties

3.3 Test Parameters

Starting with the temperature settings for the furnace for this test, which were set at 607 °C. During the literature review, it was observed that current CSP technologies operate at temperatures ranging from 450°C to 550 °C. Since the current material is being tested at a higher temperature, it can be operable at higher temperatures in the future. The salt is claimed to have a decomposition temperature of 641.73°C, which is higher than that of traditional solar salt, which has a decomposition temperature of 585 °C, as explored in the literature review.

3.4 Experimental Setup

The experiment was conducted in a horizontal furnace in an inert nitrogen N_2 environment, with a flow rate of 100 cm^3/min . The inner walls of the furnace were

cleaned with a solution of propanol to remove any previous residues. A temperature profiling was done on the furnace to find the usable “hot zone”. The “Hot zone” is a length in the furnace where the temperature is between 600 ± 5 °C, where the samples will be placed for exposure at the given temperatures as shown in the Figure 3-3 . The samples were placed in alumina crucibles, each filled with 5g of salt, and placed on a tile Figure 3-4. In Figure 3-5, it can be observed how the crucibles are placed inside the furnace.

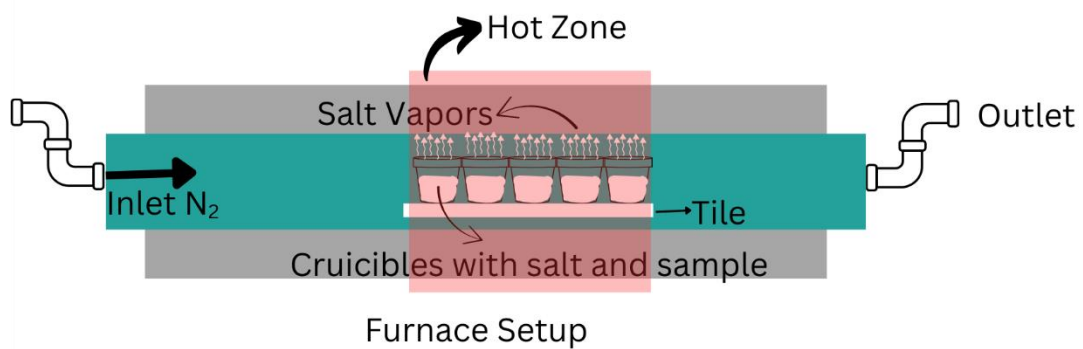


Figure 3-3: Furnace setup for the experiment



Figure 3-4: Test setup



Figure 3-5 Samples in the furnace

3.5 Post experiment procedures and analysis

All dimensions of the samples were measured using a micrometer prior to the start of the experiment. Additionally, the mass of the sample and its respective crucibles were also recorded prior to the experiment to understand the mass change and other parameters. Once the sample is removed from the furnace, its mass is recorded to compare with other samples and prepare it for further analysis. Further, the image of the samples is captured once every cycle is done Figure 3-6. It helps us assess the extent of the corrosion on the sample. Although it is less helpful to know the byproducts of corrosion, we can observe the patterns and oxide scales.

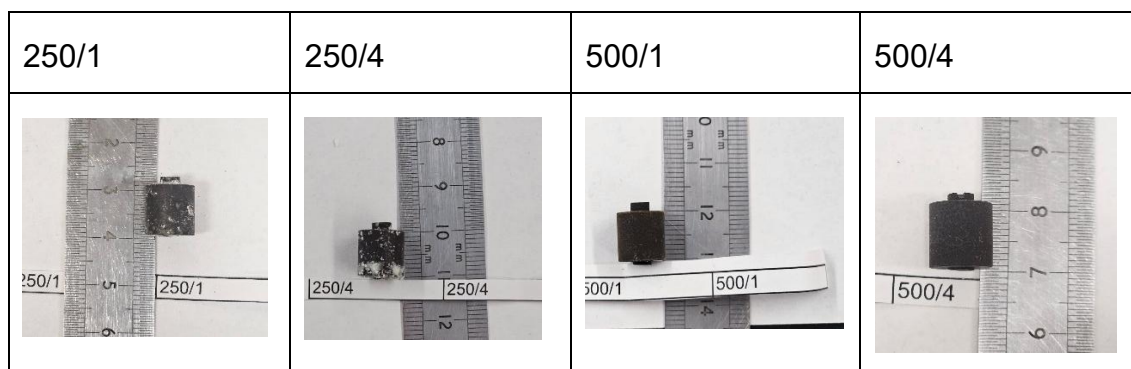


Figure 3-6: All four samples after the experiment

3.5.1 Mounting sample

The samples are first carefully mounted onto a mounting mold. With the use of two pillars, a base, and a blade. The samples are mounted in the mounting mould just like in Figure 3-7. Once mounted, we prepare the resin mixture, which consists of resin, hardener (in a 4:1 ratio), and ballotini beads. The ballotini beads help in making the mixture less shrink-prone, mainly during cutting, grinding, and polishing procedures. We place them in a vacuum-sealed chamber for 10 minutes and 3 cycles, allowing the resin to flow throughout the mould/mount. We wait for a minimum of 24 hours before we remove the sample from the moulds. Once the samples are out, we cut them using the Brilliant 220 machine, which employs continuous oil flow and a feed rate of 0.3mm/sec and 1700 RPM. Once the mould is cut in cross-section shown in Figure 3-8, the samples are ground into finer

grinding sheets in stages (P120, P600, P1200, P2500). The P120 grinding is performed twice, each for 4 minutes, and the same procedure is followed for P600 and P1200. P2500 grinding is done once for 2.5 minutes. After every cycle of grinding, the samples are cleaned with IPA to prevent higher grinding particles from contaminating the small grinding sheets. The samples, once ground they undergo polishing with (6 μ and 1 μ sheets) respectively, so that materials are prepared for analysis to evaluate the corrosion and corrosion products that have formed.



Figure 3-7: Mounted sample

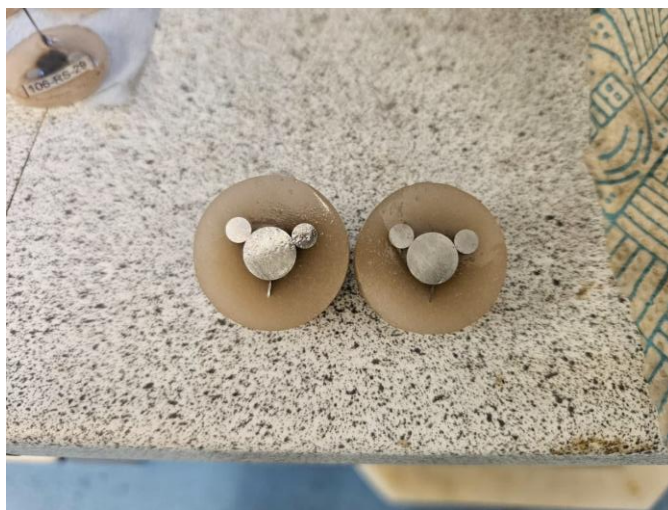


Figure 3-8 : Sample after cutting

3.5.2 Mass change calculations

This analysis examines the total mass change of the sample, which helps us understand the extent of the oxide formation on the samples. It can be calculated using the Equation.

Equation 1: Mass Change Calculations

$$\frac{\text{Mass change}}{\text{total surface area}} = \frac{\text{initial mass} - \text{final mass}}{\text{total surface area}}$$

The data acquired from this study provide insight into how corrosion progresses over time, enabling us to measure it both quantitatively and qualitatively.

3.5.3 Dimensional metrology

Dimensional metrology is a type of analysis where the samples are placed under the microscope to measure their precise dimensions after corrosion. It is one of the most effective techniques for measuring and determining the extent of corrosion and material loss, as it involves taking precise measurements of the sample's morphological state with the aid of high magnification. The data received reveal valuable insights into how the metals interact with the salts. This method allows us to quantify the regions with varying damage and the extent of damage on the metals. Ultimately, the whole study is used to understand the thermo-physical compatibility of the material and the salts by evaluating the corrosion damage. It fully complies with the standards established by the British Standards Institution (BSI) (*ISO 26146:2025 - Corrosion of metals and alloys — Method for metallographic examination of samples after exposure to high-temperature corrosive environments*) for examining the samples exposed to high temperatures. By using the already recorded measurements from the sample's pre-exposure and post-exposure, the metal change and sound metal change data can be analyzed, which helps us understand and analyze the total extent of corrosion scale formation and the extent of the damage. The metal change data we acquire indicates the amount of material thickness we have lost during exposure, and the sound metal loss indicates how well the metal has been

penetrated or damaged during the exposure. In this study, since we have a cylindrical sample, we measure the sample at 12-degree intervals and capture 30 high-resolution images to observe and understand the loss of metal during salt exposure.

3.5.4 SEM/EDS

SEM stands for Scanning Electron Microscopy, and EDS stands for Energy-Dispersive Spectroscopy, which are two sophisticated imaging techniques used to observe and analyse the surface of a sample with high magnification and high resolution. The SEM works by forcing a beam of high-energy electrons onto the surface of the sample. The primary electron beams interact with the atoms present in the samples, producing various signals that cause the backscattered electrons to be detected and recorded, thereby capturing an image of the sample's surface. The intensity of the BSE depends on the atomic number of the sample material. The higher the atomic number, the more BSE is produced. Energy Dispersive Spectroscopy (EDS) is a technique used to analyse the elements in a material. It works by using an electron beam to excite the atoms in the sample, causing them to emit X-rays. These X-rays are collected and analysed to identify the elements present. EDS is often combined with Scanning Electron Microscopes (SEM) to provide detailed information about the sample's composition and structure.

4 Results

4.1 Macroscopic assessment

As the samples emerge from the furnace, the initial step is to take the samples and capture an image for a macroscopic view to assess the extent of the corrosion. The samples in Figure 4-1 represent the samples after 250 hours of testing. As we can see, some salt remains on the samples (250/1 and 250/4) due to incomplete evaporation of the salt. An attempt was made to remove the salt without affecting the corrosion residues. We tried to remove as much as possible, as shown in the figure below. However, there was no salt left on the samples

(500/1 and 500/4). To study this, we conducted a salt evaporation test to determine if the placement of the samples in the furnace affects the experiment. As we approach the 500-hour samples, we can clearly see scales of corrosion formed on them, which are mildly adhered to the main body. We can observe uniform corrosion on all 500 samples.

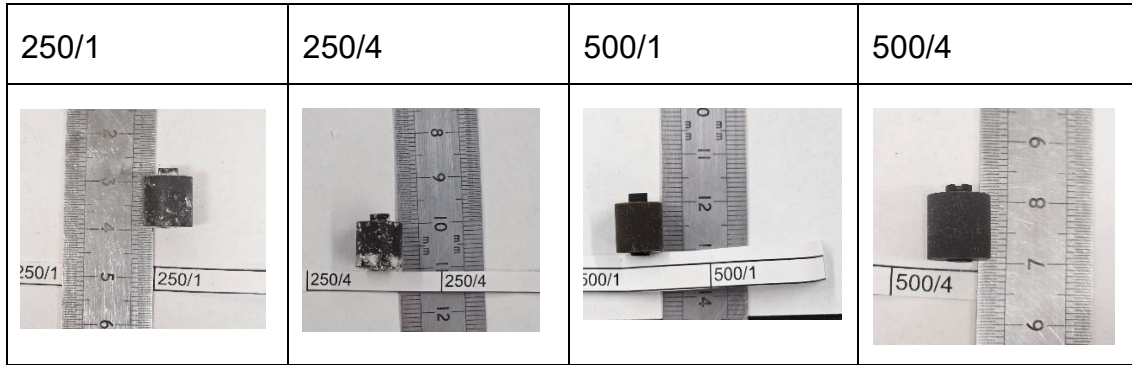


Figure 4-1: All four samples after the experiment

4.2 Mass change analysis

As the samples are captured for macroscopic observation, they are weighed to observe the trend in weight change every 250-hour cycle. It has been observed that all the samples have gained mass during the experimental cycles; this may be due to oxide formation or salt deposition that occurred over the period of the experiment. We can observe that sample 500/1 has slightly more corrosion than 500/4.

From the weights obtained and calculations, we can observe that 250/1 and 240/4 have a high salt content. During macroscopic observation, salt was observed to be deposited on the samples. As a result, samples 250/1 and 250/4 showed greater mass addition than samples 500/1 and 500/4. Comparing samples 250/1 and 250/4 they have gained 4.979 mg/cm^2 and 29.786 mg/cm^2 respectfully. Comparing samples 500/1 at 250 hours, it had a gain of 0.832 mg/cm^2 . In the next phase, it gained 0.499 mg/cm^2 , resulting in a cumulative gain of 1.331 mg/cm^2 . In the case of 500/4, during the first 250 hours, the sample gained a mass of 0.864 mg , and in the next phase, it gained 1.433 mg/cm^2 , for a total weight gain of 2.296 mg/cm^2 . It has been observed that 500/4 had a higher weight

gain than 500/1, with 2.296 mg/cm² and 1.331 mg/cm², respectively as show in Figure 4-2.

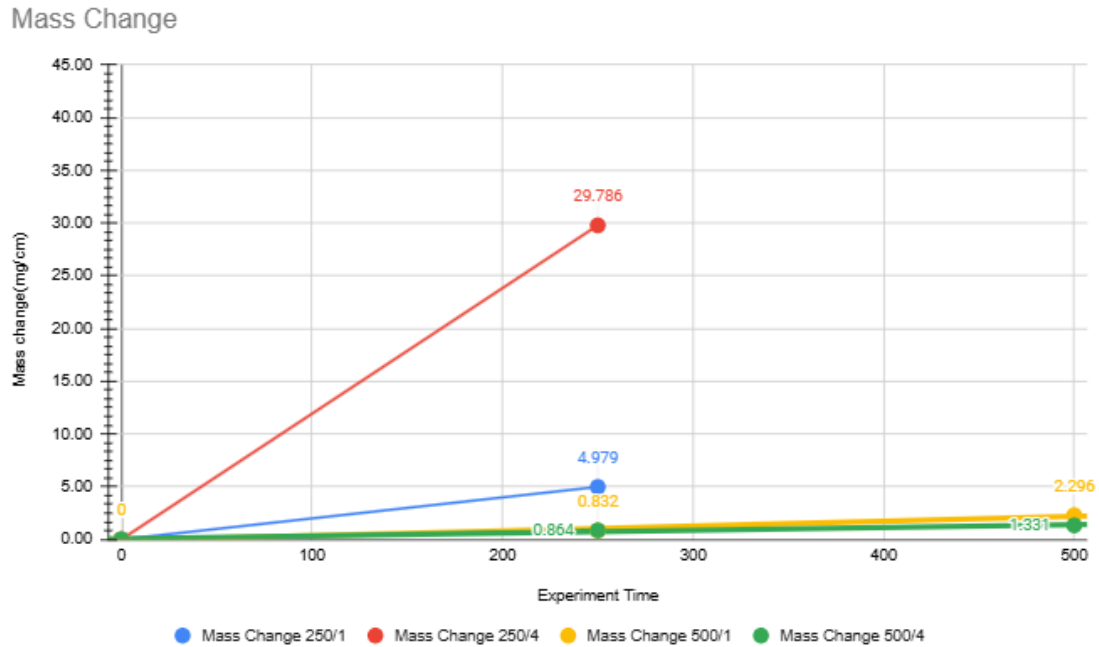


Figure 4-2: Mass change data

4.3 Dimensional Metrology

Dimensional metrology is a type of analysis used to measure the corrosion rate under high magnification and high-resolution images. The results obtained from the analysis are presented in the following subsection. By looking at the data of 250-hour samples, 250/1 had no or 0µm total metal loss, while the sample 250/4 had a total metal loss of 93.857µm. Here, for these samples, we can observe that sample 250/4 is experiencing metal loss. Regarding the 500-hour samples, 500/1 exhibits a total metal loss of 75.036 µm, whereas 500/4 shows a total metal loss of 179.109 µm. The analysis shows us that 500/4 has nearly twice the metal loss. We cannot analyse the internal damage the samples are undergoing here, so it is possible that 500/1 has more internal damage. Figure 4-3.

Figure 4-4 Displays the sound metal change for all samples from 250/1 to 500/4, revealing internal damage that may have occurred during the experimental period. Starting from 250/1, the total sound metal loss is -126.547 µm, whereas

the total sound metal loss for 250/4 is -172.357 μm . As the time increases for the 500 samples, there is some recovery, but also some additional losses. For example, we can observe in 500/1 that the sound metal loss is positive, indicating a material gain of 19.463 μm . In contrast, for sample 500/4, there is a negative total sound metal loss of -179.109 μm as shown in Figure 4-4.

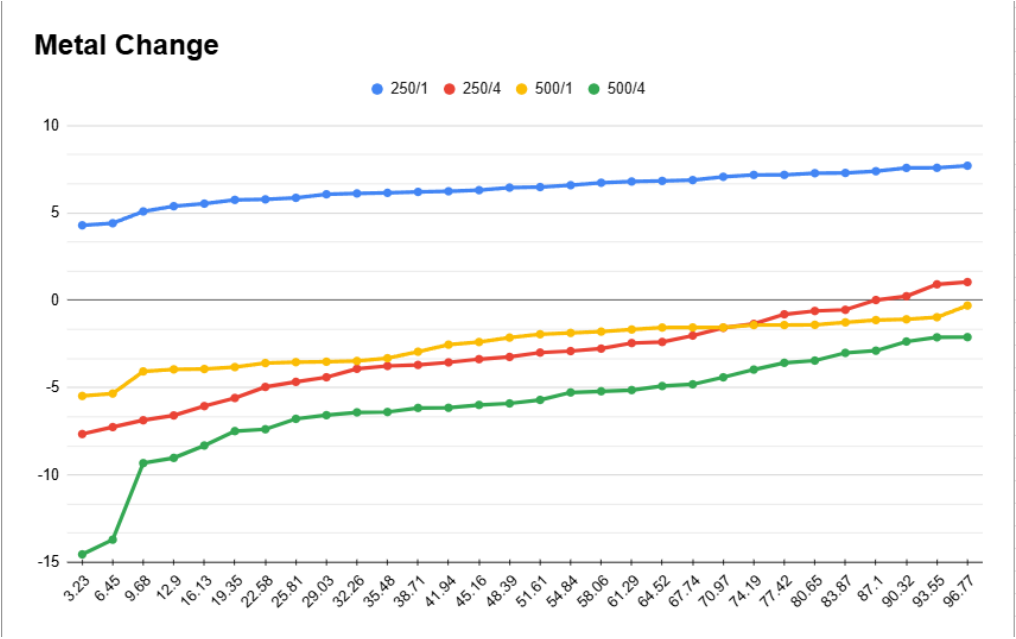


Figure 4-3: Metal Change Graph

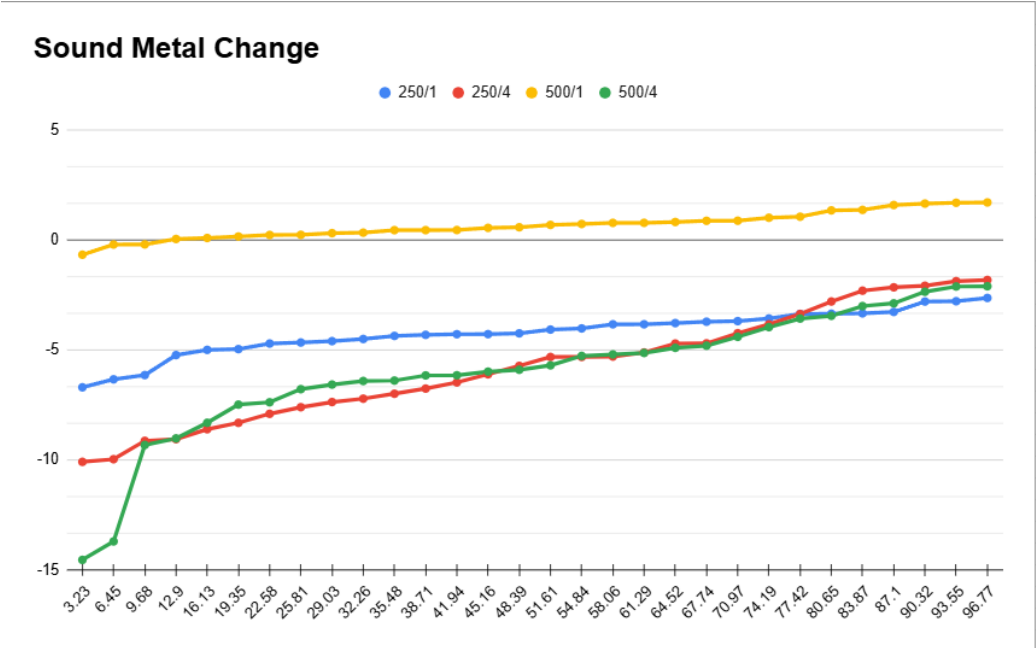


Figure 4-4 Sound Metal Change

4.4 SEM and EDS

Sample 250-1 exhibited a corrosion morphology dominated by extensive oxidation. The surface showed a high average oxygen concentration (23.34 wt.%), indicating the formation of a thick, non-protective oxide scale. This oxidation-driven process resulted in the significant depletion of surface chromium (8.04 wt.%), the alloy's primary passivating element. The thick oxide scale appeared to limit direct interaction with the molten salt, as evidenced by minimal surface concentrations of chlorine (0.33 wt.%) and potassium (0.96 wt.%). The degradation pathway for this sample is consistent with high-temperature oxidation leading to breakaway corrosion kinetics due to the consumption of the protective chromium as shown in Figure 4-5.

Conversely, Sample 250-4 demonstrated a fundamentally different response, characteristic of a hot corrosion mechanism. The surface had a much lower oxygen content (6.96 wt.%) but showed massive infiltration of salt species, with high average concentrations of potassium (25.03 wt.%) and chlorine (4.82 wt.%). This chemical signature indicates that the molten salt acted as a fluxing agent, actively dissolving any nascent protective oxide layer and preventing the formation of a stable scale. This direct chemical attack by the salt resulted in higher retained concentrations of surface iron (58.77 wt.%) and chromium (11.53 wt.%), not due to superior performance, but because the surface was in a continuous state of flux, exposing the substrate directly to the aggressive environment as shown in figure 4-6.

Sample 500-1 displayed a complex corrosion morphology characterized by both significant oxidation and localized interaction with salt species. The surface exhibited a high average oxygen content of 18.66 wt.%, indicating substantial oxide scale formation. Alongside this oxidation, there was evidence of localized salt adherence, with an average potassium content of 0.81 wt.% and chlorine at 0.31 wt.%. Critically, the EDS data shows a severely depleted average surface chromium concentration of 10.56 wt.%. This suggests a persistent high-temperature oxidation mechanism, where the protective chromium element is continuously consumed to form an oxide scale, which is then locally fluxed or

disrupted by salt components, preventing the establishment of a stable, passive layer. The presence of sulfur (averaging 8.57 wt.%) in one area suggests potential sulfidation, a highly damaging corrosion mechanism as shown in Figure 4-7.

Sample 500-4, conversely, showed signs of catastrophic oxidation. The average surface oxygen concentration was exceptionally high at 27.41 wt.%, with some regions reaching up to 34.09 wt.%. This indicates the formation of a very thick, non-protective, and likely porous oxide scale. Unlike the 250-hour test, this sample also showed significant ingress of salt constituents within the oxide layer, with an average sodium content of 6.56 wt.% and potassium of 2.05 wt.%. The interaction with salt appears to have accelerated the oxidation process. The average surface chromium content was 15.80 wt.%, but this value is deceptive due to extreme variations, with some points showing almost complete depletion (0.48 wt.%) and others an unusually high concentration (58.91 wt.%), the latter likely to represent a chromium-rich oxide phase rather than the base alloy as shown in Figure 4-8.

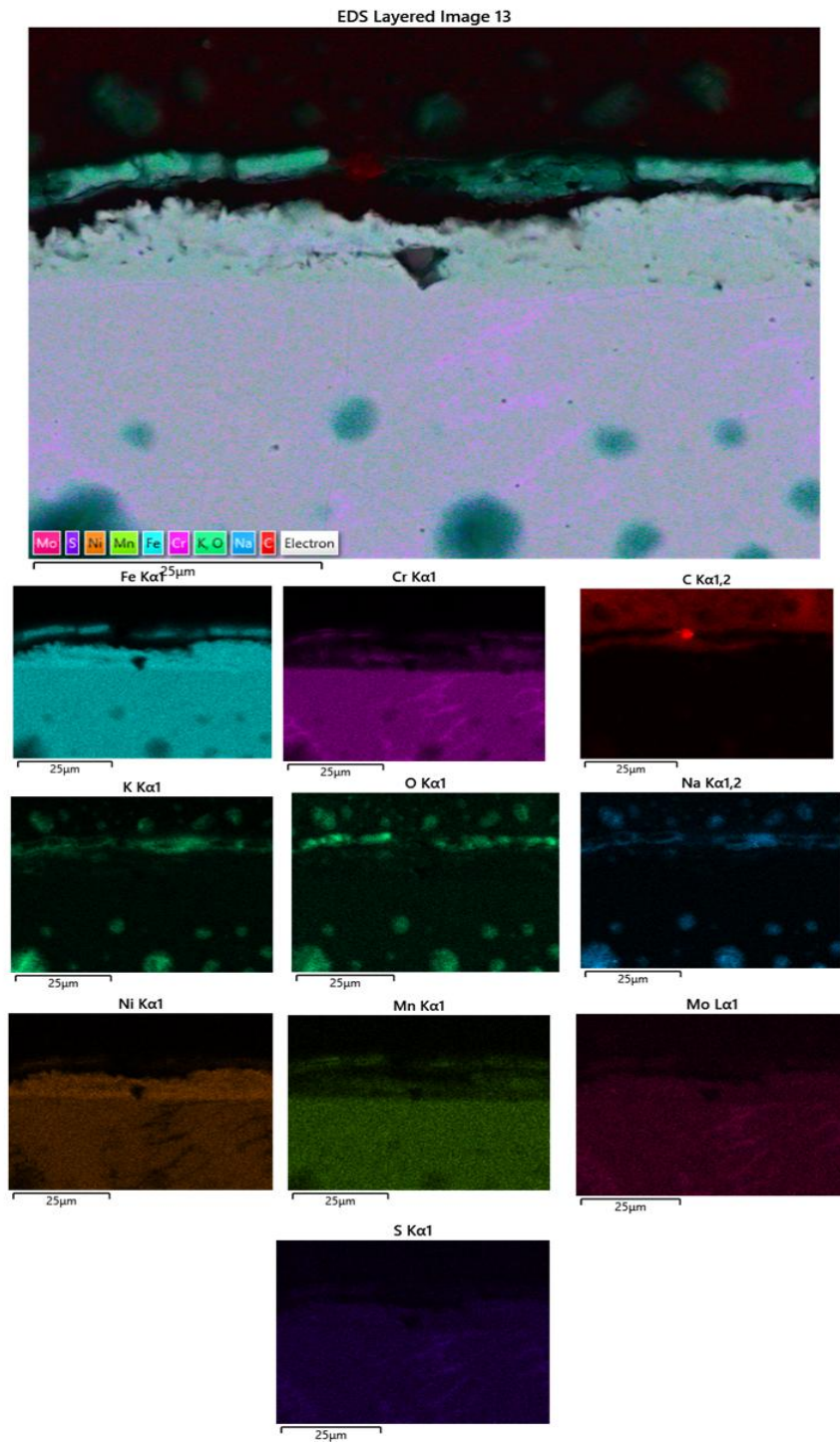


Figure 4-5: 250/1 EDS Results

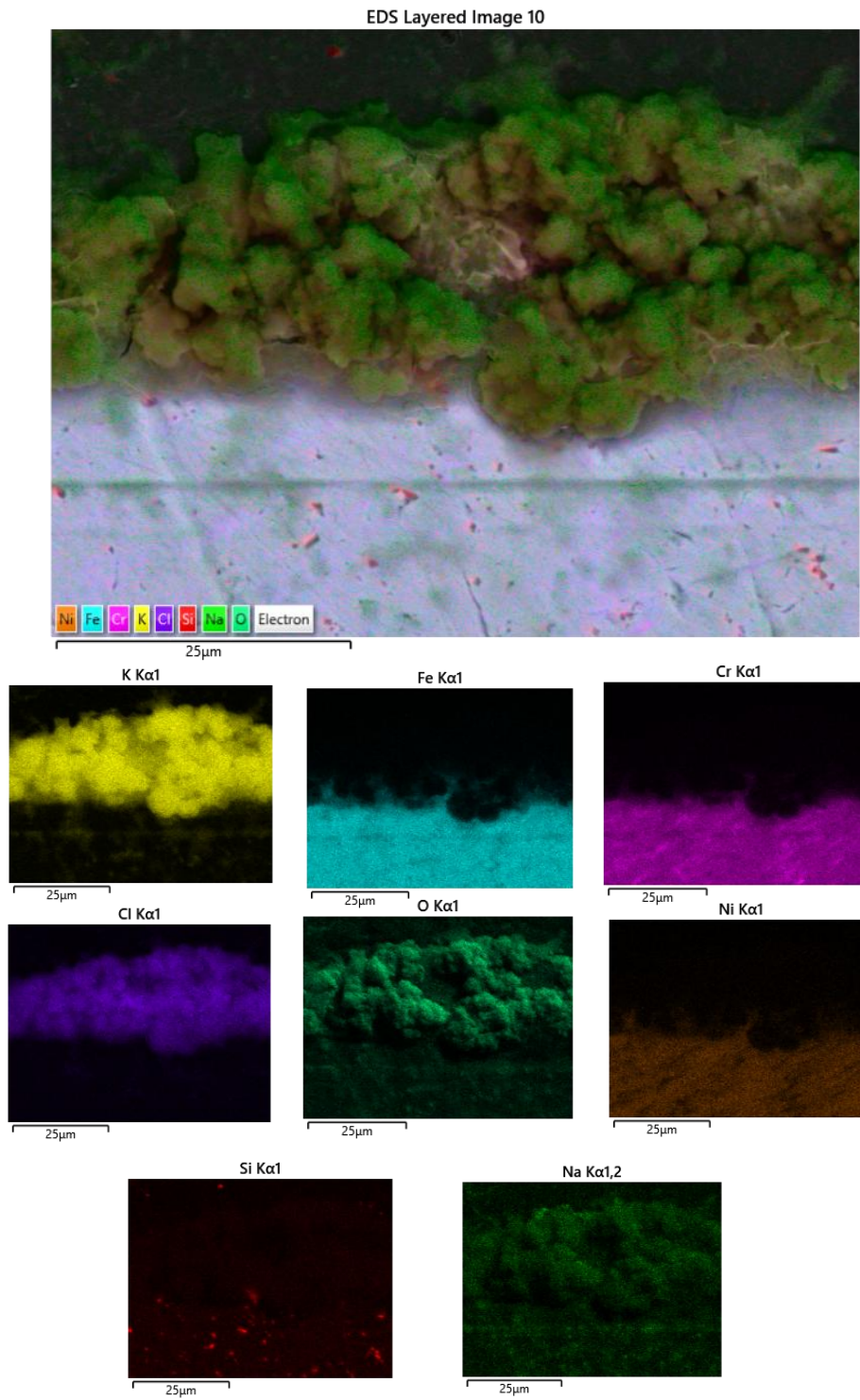


Figure 4-6: 250/4 EDS Results

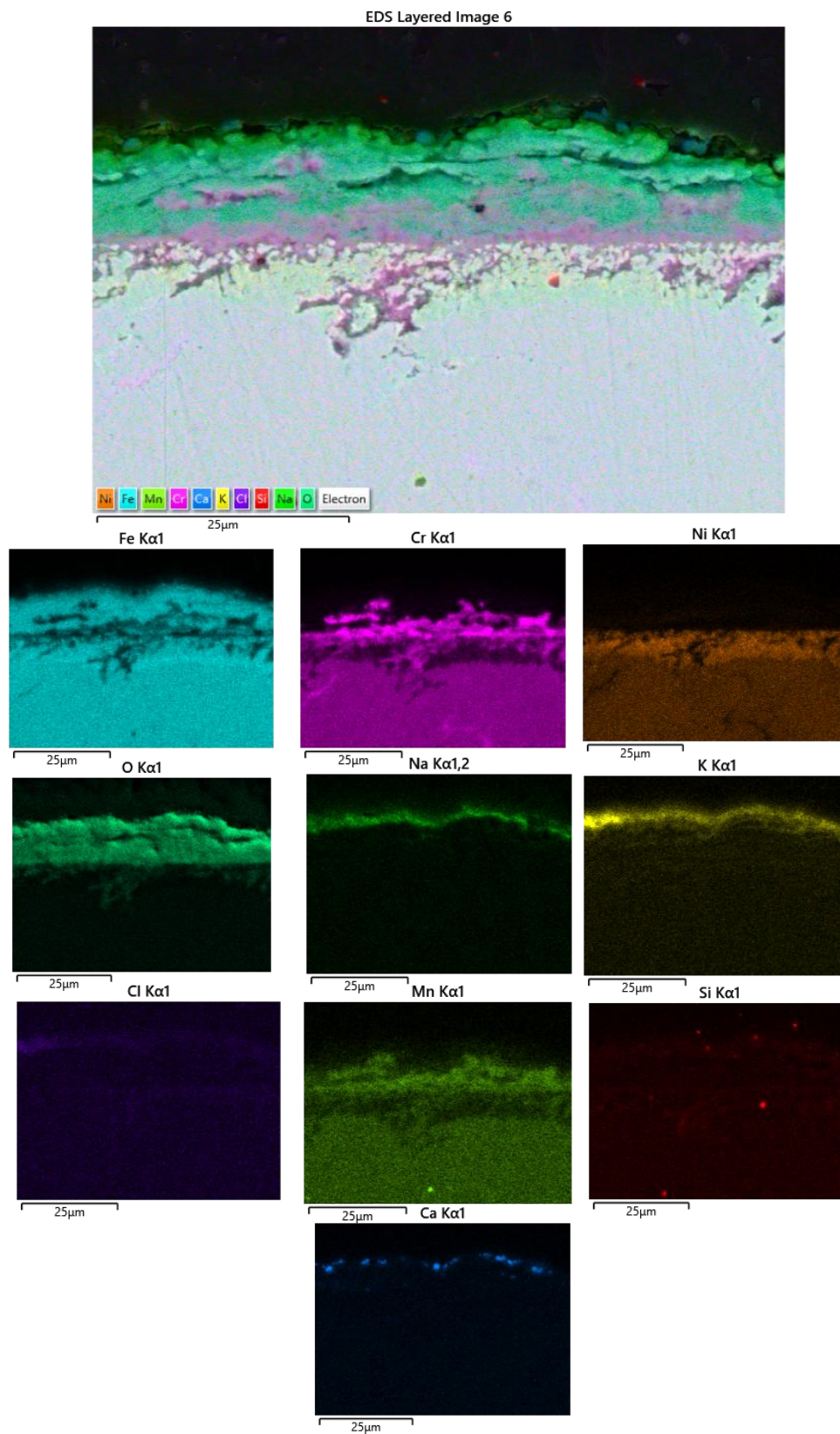


Figure 4-7 : 500/1 EDS Results

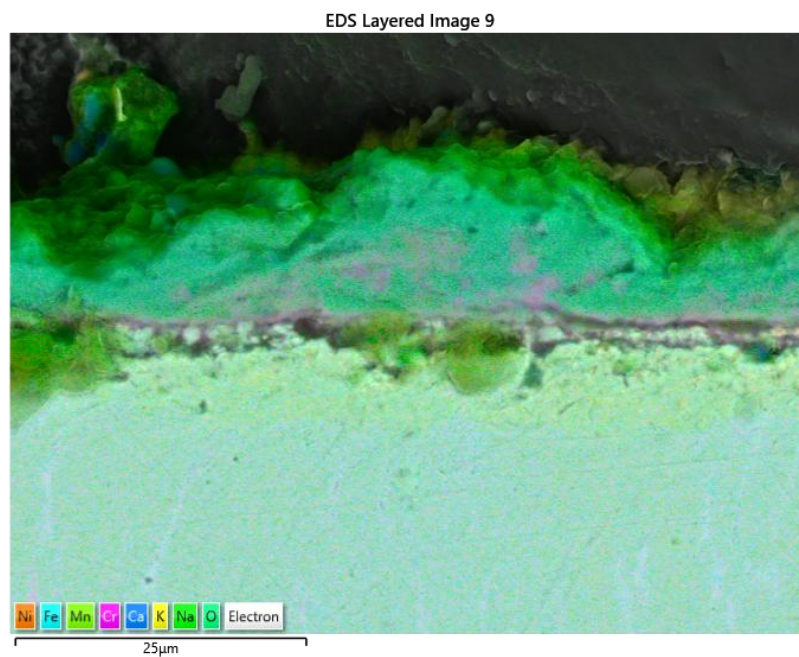
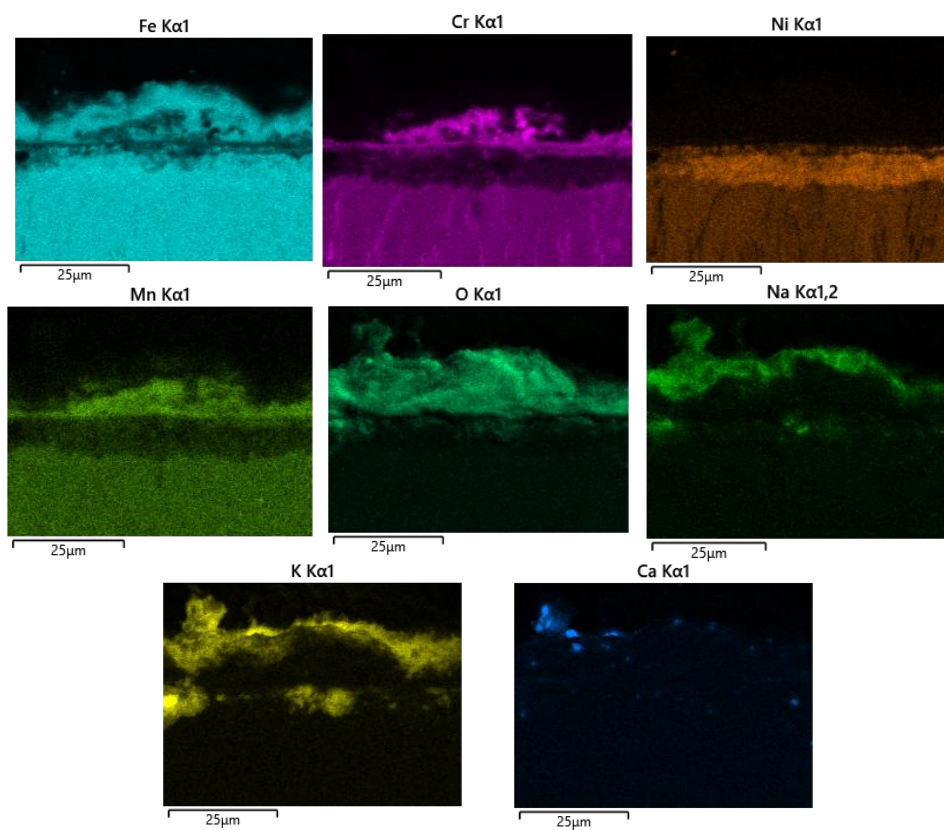


Figure 4-8 : 500/4 EDS Results

4.5 Salt evaporation test

This test was conducted to observe the trend of the evaporation rate and to determine if and how the position of the crucible inside the furnace affects the evaporation rate of salt as shown in Figure 4-9. A test was conducted 24 hours under the same furnace conditions. Here we can observe the samples being placed in this manner for the test. Each sample has weighed and has approximately 5 grams of salt in the crucible. It can be observed that the first sample lost 731.63 mg during the 24-hour test. In contrast, crucible 4 lost nearly twice the mass of crucible 1, which was 307.12mg as shown in the Table 5. From this, it can be observed that the position of the crucible in the furnace plays a role in the salt evaporation test. In the Table 5, the total weight loss of the samples after the test can be observed in Figure 4-10

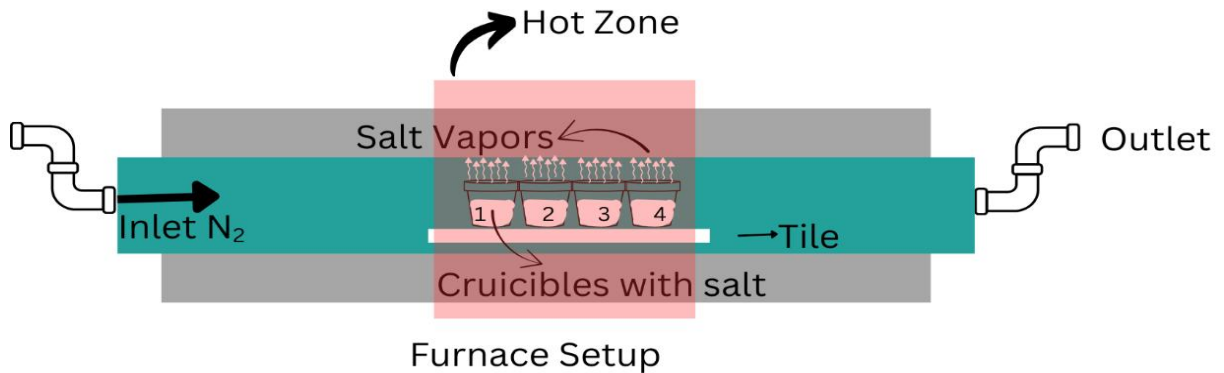


Figure 4-9: Furnace Setup for salt Evaporation test

Position	Crucible weight (g)	Salt weight (g)	Salt + crucible weight before experiment (g)	Salt + crucible weight after 24 hrs. (g)	Mass Lost (mg)	Salt evaporated (mg/hr)
1	26.01154	4.9994	31.01094	30.27931	731.63	30.4845833
2	19.4419	4.99994	24.44184	23.8268	615.04	25.6266667
3	22.37734	5.00659	27.38393	26.98441	399.52	16.6466667
4	20.69054	4.99688	25.68742	25.3803	307.12	12.7966667

Table 5 : Salt Evaporation Test Calculations

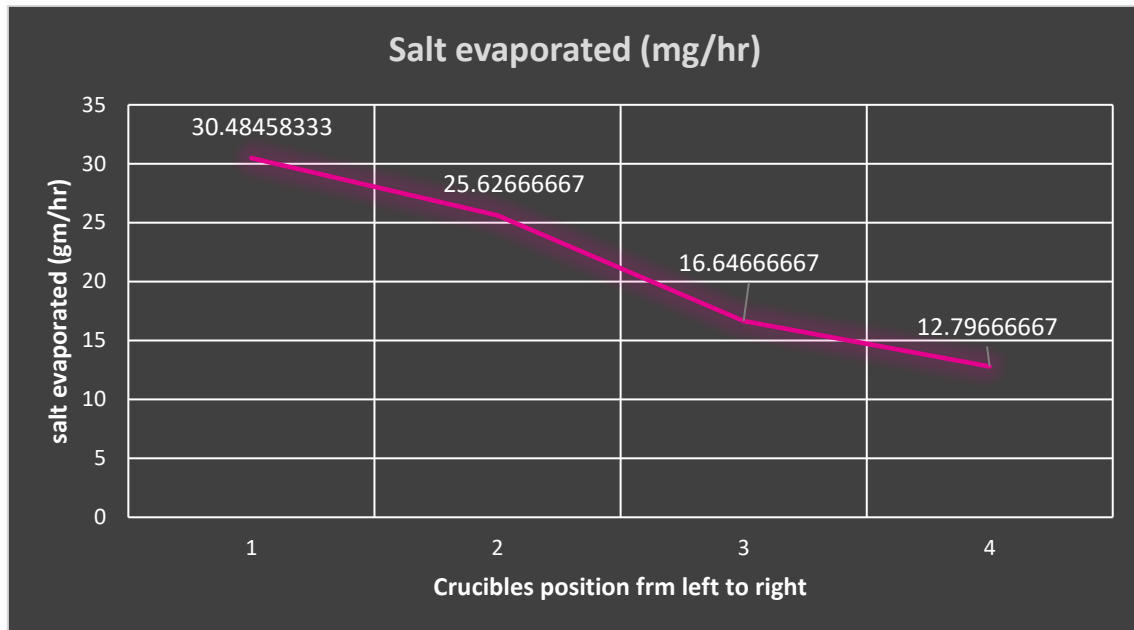


Figure 4-10 : Graph of the trend of salt evaporation

5 Discussions

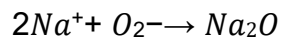
5.1 Comparison between 250/1 and 250/4

As can be observed from the mass change (figure), there was a greater mass gain by 250/4 than by 250/1, approximately 25 mg/cm² greater than 250/1. This is due to extra salt deposition on the walls of the samples, as the position of the crucibles in the hot zone. However, since they were placed at a distance, their evaporation rate was lower. An attempt was made to remove the salts from the sample walls. however, if it were tried harder, the corrosion scales from the walls would be removed, making it difficult to understand the corrosion rate, oxide rates, and metal loss rates. Due to this, it was decided to mount the samples as is to understand the important factor of corrosion. this caused uncertainty regarding the surety of the sample values. Moving to dimensional metrology reports that the 250/1 sample increased in size and did not lose any weight, whereas the 250/4 sample lost metal significantly, by as much as 93.857 μ m. Here, it is evident that metal loss is occurring in the 250/4 sample. However, since salt was present on the circumference of the sample, mixed with the corrosion residues, the exact amount of metal loss is uncertain. Whereas with the data of sound metal loss, 250/1 had a sound metal loss of -126.547 μ m, and a sound

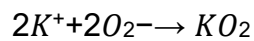
metal loss of -172.357 μm for the 250/4 sample, from this we can denote that there is good metal loss from 250/1 which is adding weight to the sample and keeping the same circumference but 250/4 is showing signs of having weak outer layer and greater sound metal loss than 250/1. This indicates that both samples exhibit penetrative damage, but sample 250/4 experiences more internal metal damage.

After analysing the SEM and EDS images, it was observed that oxide layers were deposited on the circumference of the sample, regardless of the rolling direction, which can be clearly seen in both samples. Regardless of whether salt is present in the sample, it can be observed that metal oxide formation still occurs in both samples. Under the 4000x zoom of both images, we can observe some penetrative salt infusion on the metal surfaces in 250/1, where salt deposition of elements such as Na, K, and O can be observed, which may be due to salt infusion. This is caused by the oxides and the peroxides, which are present in the nitrate salt, can sustain the formation of Na_2O and KO_2 , depending on the affinity of the Na^+ and K^+ ions, which may decrease the formation of metal oxides or corrosive ability of the salt by using the movement of electrons. The equation which governs that types of change is given below: -

Equation 2



Equation 3



In the map of 250/1, it can be observed that the ferrous oxide layer is not attached to the metal sample. It can be observed that Ni is attempting to migrate to the top layer of the sample in 250/1, and Ni oxides are forming in both samples, particularly towards the circumference of the sample. Based on the experiment's findings, it can be concluded that the 250-hour sample is more corrosion-prone and is actively protecting itself by forming a chromium protective layer. The

findings are not conclusive regarding the rate of corrosion or the extent of degradation that occurred due to exposure to molten solar salt for 250 hours.

5.2 500/1 Vs 500/4

Here are the samples that have undergone two cycles of 250 hours each, totaling 500 hours of processing. Starting the discussions with the mass change data, there was a mass increase for both samples. The first 250 hours of cycling, both samples (500/1 and 500/4) had gained 0.832mg and 0.864 mg, respectively. This shows a similar increase in both samples, with a good trend; however, the next cycle does not exhibit the same trend. The next 250-hour cycle shows that 500/1 has gained approximately 0.499 mg/cm², and 500/4 has gained 1.433 mg/cm², which is nearly three times the value of 500/1. Cumulatively, 500/1 has gained 1.331 mg/cm², and 500/4 has gained 2.296 mg/cm². Observing the trend, a small observation was made, suggesting that 500/4 is undergoing more corrosion than 500/1, or it may be that there is more uniform corrosion in 500/4 than in 500/1. Mass change is not a completely reliable indicator of corrosion understanding.

In dimensional metrology analysis, 500/1 has a total metal loss of 75.03 µm, and 500/4 has a total metal loss of 179.1 µm. This indicates that there is more surface loss in 500/4 than in 500/1, which is approximately twice that of 500/1. It's a good trend observing the 250-hour samples and comparing them with the trend 500/1 has metal loss, whereas 250/1 had metal gain, so it can be explained as the first 250 hours the sample has an expansion in the circumference, and after completing 500 hours, there is a loss of metal and creation of metal oxides. When 500/4 and 250/4 are analysed, a linear growth of metal loss change is observed. It can be said that there is uniform growth of corrosion byproducts due to the grain refinement of the 500/4 and 250/4 samples. They have undergone 120KN cold rolling, which affects the grain structure and material properties, such as layer thickness and metal electron arrangement. Comparing the sound metal changes in both samples, it can be observed that 500/1 had a total sound metal gain or negative metal loss of 19.463 µm, and 500/4 had a total sound metal loss of 179.109 µm. Comparing the results with the 250-hour sample, 250/1 and 500/1 showed some discrepancies, as evidenced by negative sound metal loss. This

may be due to thermal expansion or some corrosion byproducts, which could have environmental effects and potentially add mass to the sample.

By examining the SEM and EDS data, we can observe that although dimensional metrology reveals damage, it also indicates the formation of metal oxides and the extent of the damage. Observing the sample 500/1, metal oxides are formed on the circumference of the surface and the top layer of the sample. Here, it can be observed that a thick, dense Ni layer has been formed under the oxide layer. There is a mild salt infusion, which has happened due to electron exchange. It can also be observed that there are pitting, which is localized corrosion that causes internal material damage in 500/1, and which will affect the sample in different ways, such as a reduction in structural integrity and strength of the material, stress concentration on the material may be increased, and it may reduce the durability of the material. In contrast, for 500/4, since the grain size is smaller and the layer thickness is thin, localized corrosion is not observed; instead, uniform corrosion is observed. As observed in 500/1, there is also a thick layer of Ni being formed below the layer of oxides, and it can be observed that Fe, Cr, and Mn oxides are being formed in the same way as in sample 500/1. It is evident that 500/1 has corrosion, but with localized corrosion, it becomes more corrosive than 500/4, as the rate of corrosion cannot be accurately measured due to the unpredictability of pitting. Advanced testing can be made to determine the true composition of oxides by performing X-ray diffraction. By testing for more hours, we can determine the rate of corrosion and get more conclusive results regarding the effect of cold rolling on SS316L. Cold rolling on SS316L has an effect on the material by having lesser layer thickness and a smaller grain structure, which helps in better and uniform corrosion where as in 500/1 we can see the sample was produced without rolling on it so the layer thickness on the sample is more which didn't reduce the grain arrangement and structure which allowed the metal to have localised corrosion.

5.3 Sources of error

This subsection lists multiple sources of error which can be inherited during the methodology that was carried out during the course for the experiment.

- Instrumental errors: it may be due to micrometer readings or the temperature probe while measuring the temperature or malfunctioning or other machines.
- Human Error: mistakes made due to incorrect reading, improper handling of the sample, improper handling of the equipment, or not following the procedure properly.
- Environmental Errors: humidity, temperature, and fluctuations can affect the chemical reactions of the materials.
- Contamination errors: contamination during the manufacturing of the samples or cross-contamination of the samples.
- The lack of a gasket has led to the improvisation of applying silicone grease to seal the face of the furnace. Due to high temperatures, noxious gases will be produced.
- Salt contamination due to humidity or airborne contaminants.

6 Conclusion and Future Work

From this thesis, we can conclude that as-built SS316L from WAAM technology can exhibit localised corrosion, whereas the in-site cold-rolled samples showed uniform corrosion across the sample, indicating that the grain boundaries, grain size, and layer thickness matter and affect the corrosion. In in-site collected rolled samples, which are undergoing uniform corrosion, the rate of corrosion can be predicted and measured. However, the as-built sample undergoes localized corrosion, which is difficult to measure and unpredictable. Due to this nature of material behaviour, it is preferred to have sample 4, which is in-site cold-rolled materials. Further studies can be conducted on different weights and layer thicknesses of cold-rolled samples, ranging from 0 to 120 KN, to observe the trend of the samples. Long exposure of samples may reveal better data and help understand the trend line, particularly if the corrosion is gradually increasing or unpredictable.

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Appendices

A.1 Cures Approval Form



3 June 2025

Dear Mr Shankar ,

Reference: CURES/25460/2025

Project ID: 28818

Title: High temperature corrosion behaviour of additively manufactured stainless steels in molten salts

Thank you for your application to the Cranfield University Research Ethics System (CURES).

We are pleased to inform you your CURES application, reference CURES/25460/2025 has been reviewed. You may now proceed with the research activities you have sought approval for.

If you have any queries, please contact CURES Support.

We wish you every success with your project.

Regards,

CURES Team