GEOSMART

Project acronym:	GeoSmart		
Project title:	Technologies for geothermal to enhance competitiveness in smart and flexible operation		
Activity:	LC-SC3-RES-12-2018		
Call:	H2020-LC-SC3-2018-RES-SingleStage		
Funding Scheme:	IA	Grant Agreement No:	818576
WP2	Development of Thermal Energy Storage System		

D2.7 Final material choices documented for demo sites

Due date:	M43	
Actual Submission Date:	01/08/2023	
Lead Beneficiary:	TWI	
Main authors/contributors:	TWI	
Dissemination Level[1]:	PU	
Nature:	Report	
Status of this version:		Draft under Development
		For Review by Coordinator
	X	Submitted
Version:	1.0	
Abstract	The deliverable is an update of D2.1 that reports on the screening of material options for GeoSmart application	

REVISION HISTORY

Version	Date	Main Authors/Contributors	Description of changes

This project has received funding from the *European Union's Horizon 2020 research and innovation programme* under grant agreement No 818576

[1] Dissemination level security:

PU – Public (e.g. on website, for publication etc.) / **PP** – Restricted to other programme participants (incl. Commission services) /

RE – Restricted to a group specified by the consortium (incl. Commission services) / **CO** – confidential, only for members of the consortium (incl. Commission services)

This project has received funding from the European Union's Horizon 2020 program Grant Agreement No 818576. This publication reflects the views only of the author(s), and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Document: D2.7Final material choices documented for demo sites

Version: 1.0

Date: 1 August 2023

CONTENTS

Summary

The deliverable is an update of D2.1Correct material choices documented for demo sites and reports on the evaluation of performance of selected carbon and stainless steel grades in the phase change material (PCM) environment.

Objectives Met

The deliverable contributes towards the following WP objectives:

- Selection of the most appropriate storage media for each of the case study examples. Development and validation of the storage and heat exchange systems around this, based on the storage requirements specified. Production of large scale demonstrator equipment ready for the case studies. The results of this work package will be utilised by both case studies and will be used up until the end of project.

1. INTRODUCTION

Within the GeoSmart project thermal energy storage systems are developed and designed for geothermal power plants Insheim, Germany and Kızıldere-2, Turkey. For Insheim a water thermocline storage is considered. For Kızıldere-2 a steam storage as well as a latent thermal energy storage are planned. This deliverable contributes to the development of the phase change materials (PCM) module, considering the increasing use of water thermocline and steam storages as commonly utilized technologies.

On the Kızıldere-2 site belonging to Zorlu, the separation of steam from the liquid brine occurs at various pressure levels through flashing, and it is subsequently directed towards high, medium, and low pressure turbines to generate electricity. One of the objectives of the project is to store a part of the steam and the heat of the brine after the first separation to adapt the production of electricity to the demand. The steam will be stored in a steam accumulator.

For storing the brine heat, a latent thermal energy storage will be developed.

In these latent heat storage systems, phase change materials (PCM) are utilised to store heat at a nearly constant temperature level. Hence, in the subsequent sections of the document, this storage is referred to as a PCM module. During periods of low demand, steam and heat are accumulated within the system. Conversely, during high-demand periods, steam is released from the steam accumulator and directed towards the low-pressure turbine. The PCM module is employed to warm up the brine that comes from the outlet of the low-pressure separator. After the PCM module, steam is generated by flashing for the low-pressure turbine. The PCM module will operate between 107 and 165°C.

The objective of this deliverable was to extend the assessment of materials carried out in Deliverable 2.1, evaluating the performance of selected carbon and stainless steel grades in the PCM environment. Evaluating the comparative performance can facilitate the choice of more cost-effective materials, thereby enhancing the business viability of the GeoSmart technology.

2. MATERIALS

Samples were prepared from the following materials for corrosion testing:

- SA516
- SA105
- SA179
- 304L
- 316L

Samples were tested in the as-received condition and following a surface preparation with a 600 grit abrasive paper. Due to availability of material, number of samples and sample size/shape varied between the different grades assessed. A samples list in included in Table 1.

Table 1 Sample ID table.

Material	Surface Condition	No. of Samples	Sample ID
SA516	As-received	3	SA516-AR-(2-4)
	600 Grit	3	SA516-600-(2-4)
SA105	As-received	4	SA105-AR-(2-5)
	600 Grit	3	SA105-600-(2-4)
SA179	As-received	1	SA179-AR-1
	600 Grit	4	SA179-600-(2-5)
304L	As-received	4	304L-AR-(2-5)
	600 Grit	4	304L-600-(2-5)

Material	Surface Condition	No. of Samples	Sample ID
316L	As-received	4	316L-AR-(2-5)
	600 Grit	4	316L-600-(2-5)

3. METHODS

Following D2.1, HiTec salt (40wt.% sodium nitrite, 7wt.% sodium nitrate and 53 wt.% potassium nitrate) was selected as the PCM. Hitec was heated in a glass vessel to 165°C at a rate of 50°C/hour. High purity air was bubbled through the molten salt (2Lmin^{-1}) for the duration of testing to remove any trapped moisture. Samples were submerged in the molten salt for a period of 168 hours. Following testing, samples were removed from the molten salt and allowed to cool. Once at room temperature, residual salt was removed by rinsing with de-ionised water and the samples were dried.

Following corrosion testing, one sample in each condition was cross-sectioned and assessed by scanning electron microscopy (SEM) with energy dispersive x-ray spectroscopy (EDX).

To assess mass loss as a result of corrosion testing, selected samples underwent a series of cleaning cycles in accordance with ASTM G1-03 [1]. Mass change was recorded after each cycle until a constant mass was achieved.

Photographs of example samples were taken following testing and cleaning.

4. RESULTS AND DISCUSSION

4.1 SA516

4.1.1 As-received samples

Visual assessment of the SA516 samples in the as-received condition showed the surface to be covered with dark brown deposits, likely oxides, from mill scale and/or atmospheric corrosion (Figure 1). Following corrosion testing, the samples appeared largely unchanged. A limited quantity of the surface deposits had been removed, making the dull grey steel substrate more visible. Following cleaning, the brown surface deposits were removed and the dull grey steel was fully visible.

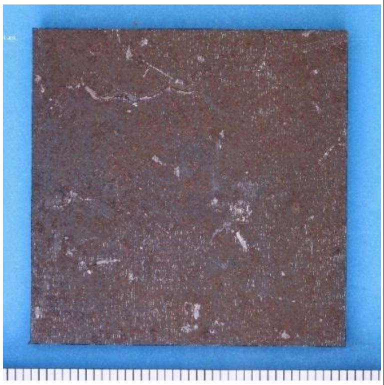
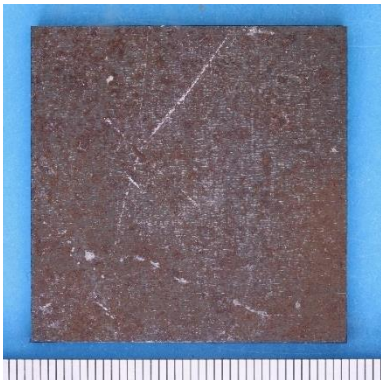
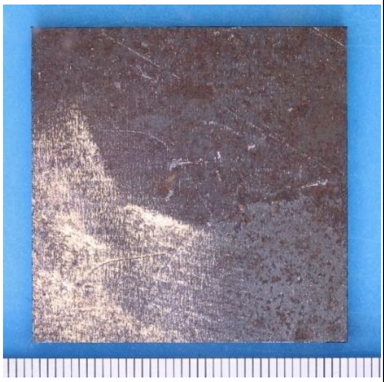
	SA516-AR-2	SA516-AR-3	SA516-AR-4
Pre-Test			
Post-Test			
Post Cleaning			

Figure 1 Photographs showing samples composed of SA516 in the as-received condition before testing, after testing and post-cleaning.

Cross-sectioning of the samples following corrosion testing showed the surface to be covered with an intermittent layer of deposits (Figure 2). These deposits were composed of largely Fe and O. No extensive pitting or other signs of corrosion were observed.

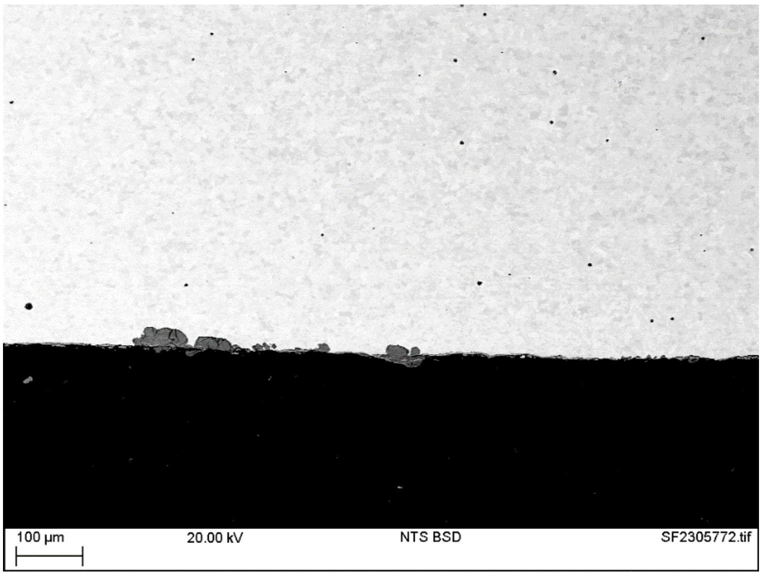


Figure 2 SEM image of a cross-section of sample SA516-AR-4 following testing.

Mass loss assessments indicated the loss of 0.0745-0.0827g per specimen (Table 2) following cleaning, corresponding to a corrosion rate of 0.1235mm.year^{-1} (Table 3). However, from a visual assessment it is clear that iron oxide material present on the surface of the sample prior to corrosion testing was removed in the cleaning process. Results should therefore be compared with samples in a prepared conditions.

Table 2 Mass loss for all samples following ASTM G1 cleaning cycles. *Rates impacted by cleaning cycles.

Material	Surface Condition	No. of Samples	Sample ID	Mass loss / g
SA516	As-received	2	SA516-AR-2	0.0827
			SA516-AR-3	0.0745
	600 Grit	2	SA516-600-2	0
			SA516-600-3	0
SA105	As-received	3	SA105-AR-2	0.0567*
			SA105-AR-3	0.0584*
			SA105-AR-4	0.0561*
	600 Grit	2	SA105-600-2	0.0011*

Material	Surface Condition	No. of Samples	Sample ID	Mass loss / g
			SA105-600-3	0.0009*
SA179	As-received	1	SA179-AR-1	0.0042
	600 Grit	4	SA179-600-1	0.0019
			SA179-600-2	0.0020
			SA179-600-3	0.0023
			SA179-600-4	0.0024
304L	As-received	3	304L-AR-2	0.0009
			304L-AR-3	0.0016
			304L-AR-4	0.0008
	600 Grit	3	304L-600-2	0
			304L-600-3	0
			304L-600-4	0
316L	As-received	3	316L-AR-2	0.0017
			316L-AR-2	0.0037
			316L-AR-2	0.0027
	600 Grit	3	316L-600-2	0
			316L-600-3	0

Material	Surface Condition	No. of Samples	Sample ID	Mass loss / g
			316L-600-4	0

Table 3 Corrosion rates for all materials assessed. *Rates impacted by cleaning cycles.

Material	Surface Finish	Corrosion Rate (mm/year)
SA516 Grade 70	As-received	0.1235
	600 grit	0
SA105	As-received	1.0034*
	600 grit	0.0179*
SA179	As-received	0.0152
	600 grit	0.0077
316L	As-received	0.0073
	600 grit	0
304L	As-received	0.0030
	600 grit	0

4.1.2 Examination of samples prepared to 600 grit

Visual assessment of the samples prior to testing showed a bright metallic finish (Figure 3). Following testing the surface had turned a slight pink colour, however, no obvious surface deposits were observed. Following cleaning the samples were returned to their metallic finish with some black staining on the surface.

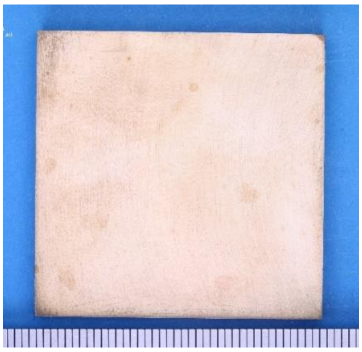
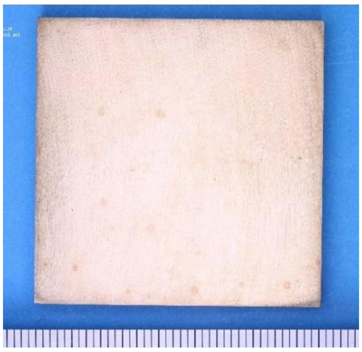
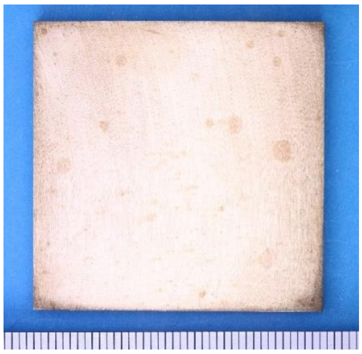
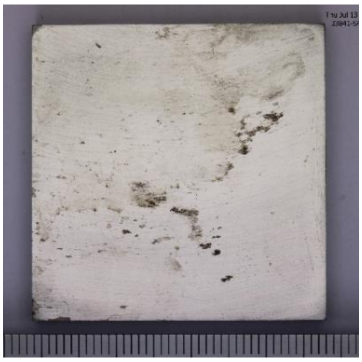
	SA516-600-2	SA516-600-3	SA516-600-4
Pre-Test			
Post-Test			
Post Cleaning			

Figure 3 Photographs showing samples composed of SA516 prepared to a 600 grit finish before testing (pre-test), after testing (post-test) and post-cleaning.

Cross-sectioning of the samples following testing showed no surface deposits or significant signs of pitting and other types of corrosion (Figure 4).

Mass loss following cleaning was 'zero' indicating no measurable corrosion rate.

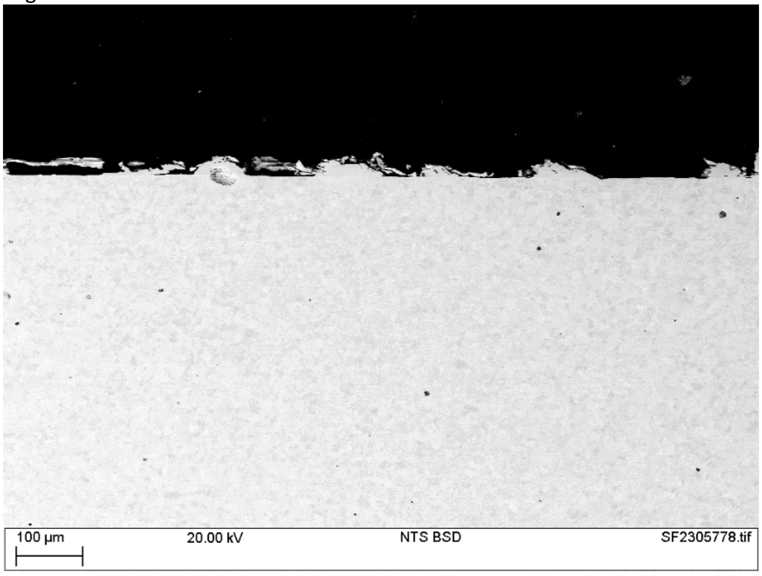


Figure 4 SEM image of a cross-section of sample SA516-600-4 following exposure testing.

These results suggest that SA516 does not undergo significant corrosion in Hitec at these temperatures and durations. It is likely that this is the case from both the as-received and ground conditions. However, results in the as-received condition may have been effected by the presence of oxides prior to testing.

4.2 SA105

4.2.1 As-received

Visual assessment of the samples prior to testing showed a bright metallic surface with rough surface finish (Figure 5). Following testing the surface had a consistent pink/orange colour but no deposits were observed. Following testing the original colour of the samples was visible, however, a number of black areas were noted and possible loss of base material.

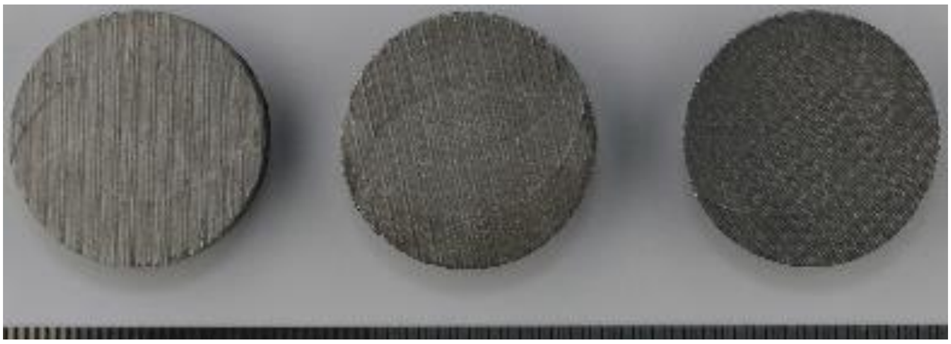
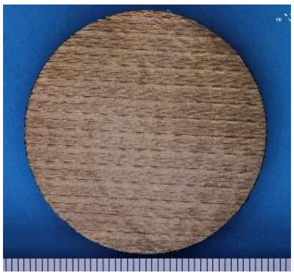
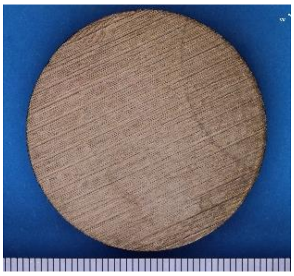
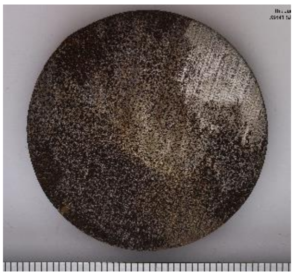
	SA105-AR-2	SA105-AR-3	SA105-AR-5
Pre-Test			
Post-Test			
Post Cleaning			

Figure 5 Photographs showing samples composed of SA105 in the as-received condition before testing, after testing and post-cleaning.

Cross-sectioning of the samples following testing showed no surface deposits or significant signs of pitting and other corrosion (Figure 6).

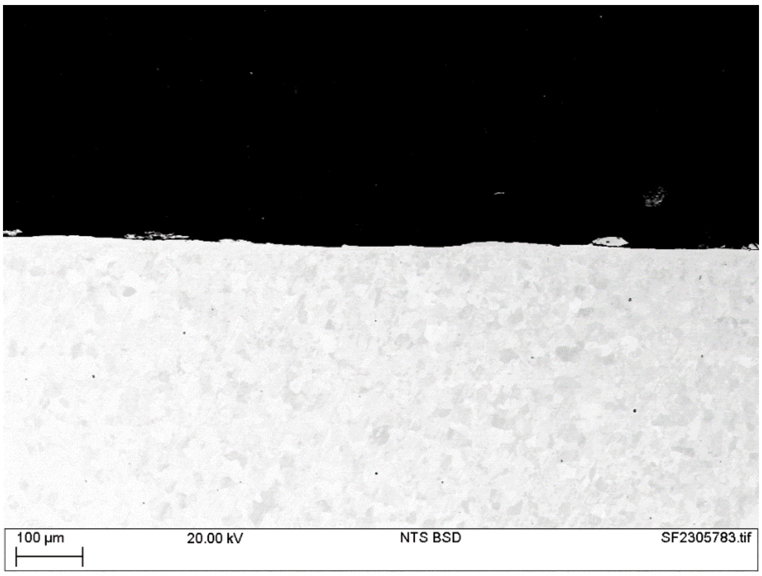


Figure 6 SEM image of a cross-section of sample SA105-AR-5 following exposure testing.

Mass loss following cleaning was 0.0561-0.0584g (Table 2), indicative of an extrapolated corrosion rate of 1mm.year^{-1} (Table 3). However, while cleaning was performed in accordance with ASTM G1 some loss of material following cleaning was visually apparent. Additionally, high mass loss was not consistent with SEM assessment of sample cross-sections following testing. As such a cleaning of untested material was also performed. Mass loss result of this cleaning was consistent with post-test samples (0.0572g, 1.00mm.year^{1}) suggesting that material loss was as a result of the cleaning process.

These results suggest that SA105 in the as-received condition does not undergo significant corrosion in Hitec at these temperatures and durations.

4.2.2 600 grit

Visual assessment of the samples was consistent with the as-received samples in all conditions, though the post-cleaning samples appeared less effected by the cleaning process (Figure 7).

	SA105-600-2	SA105-600-3	SA105-600-4
Pre-test			
Post-Test			
Post Cleaning			

Figure 7 Photographs showing samples composed of SA105 prepared to a 600 grit finish before testing, after testing and post-cleaning.

Cross-sectioning of the samples following testing showed no surface deposits or significant signs of pitting and other types of corrosion (Figure 8).

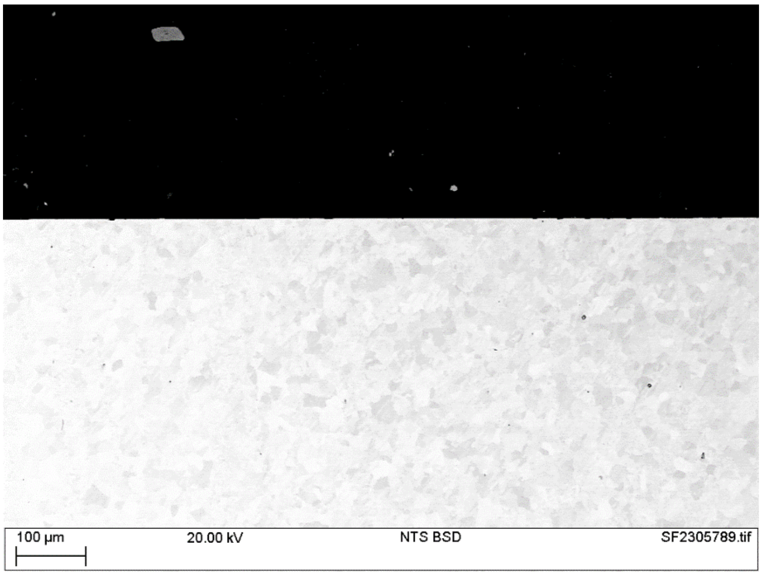


Figure 8 SEM image of a cross-section of sample SA105-600-4 following exposure testing.

Mass loss following 0.0009-0.0011g (Table 2), is indicative of an extrapolated corrosion rate of 0.0179mm.year^{-1} (Table 3). However, this mass is attributed to the cleaning process as cleaning of an untested sample with the same preparation gave a comparable mass loss.

These results suggest that SA105 prepared with a 600 grit finish undergoes limited or no measurable corrosion in Hitec at these temperatures and durations.

4.3 SA179

4.3.1 As-received

Prior to testing the samples had a grey metallic finish with a number of brown spots across the surface (Figure 9). Following corrosion testing, the sample has a gold colour but no surface deposits were observed. Following cleaning the original grey metallic colour was observed.

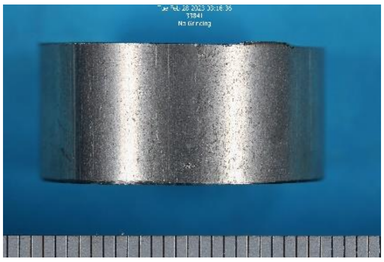
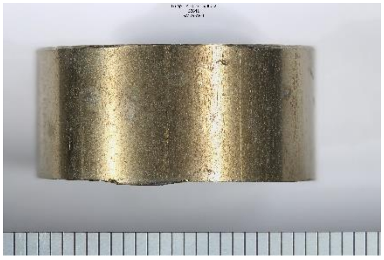
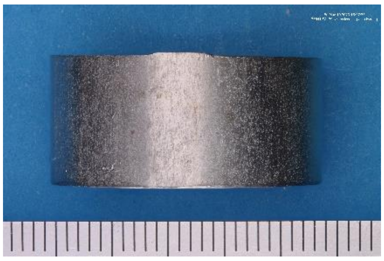
	SA179-AR-1
Pre-Test	
Post-Test	
Post Cleaning	

Figure 9 Photographs showing samples composed of SA179 in the as-received condition before testing, after testing and post-cleaning.

Cross-sectioning of the sample following cleaning showed areas of isolated corrosion products (Figure 10), composed of Fe and O, across the surface. No extensive pitting or other signs of corrosion were observed.

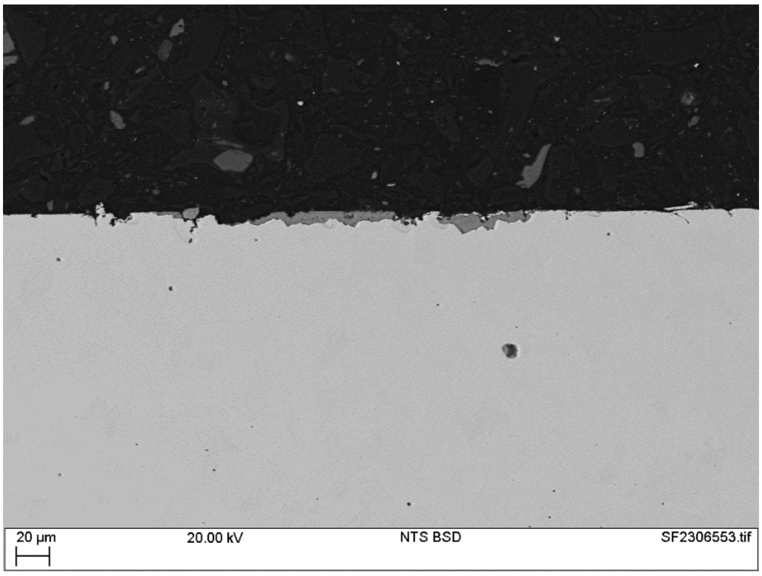


Figure 10 SEM image of a cross-section of sample SA179-AR-1 following exposure testing.

Mass loss following ASTM G1 cleaning was 0.0042g (Table 2), indicative of an extrapolated corrosion rate of 0.0152mm.year^{-1} (Table 3).

These results suggest that SA179 in the as-received condition undergoes limited or no measurable corrosion in Hitec at these temperatures and durations, though this is based on limited data.

4.3.2 600 grit

Samples were visually consistent with the as-received sample before testing, after testing and following cleaning (Figure 11). The only significant visual difference was that the small brown spots present on the as-received sample had been removed during the grinding process.

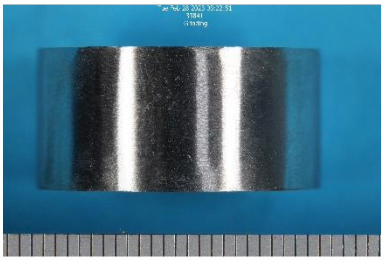
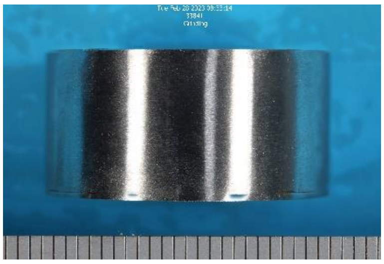
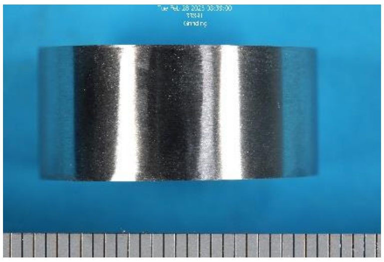
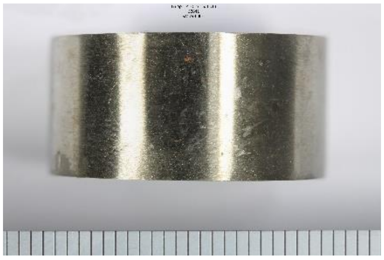
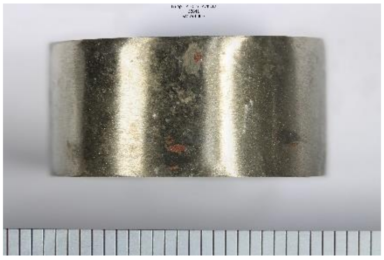
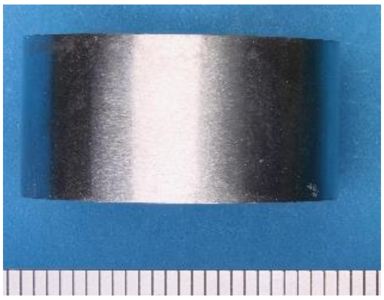
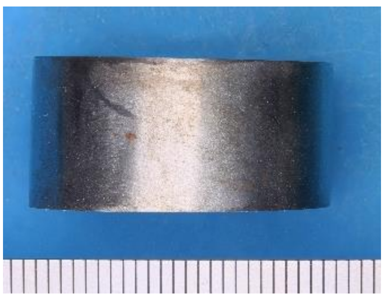
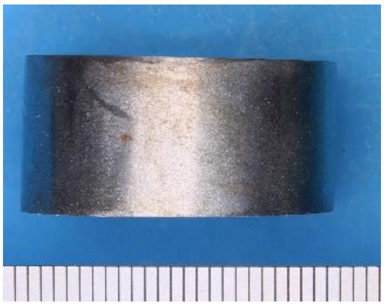
	SA179-600-2	SA179-600-3	SA179-600-4
Pre-Test			
Post-Test			
Post Cleaning			

Figure 11 Photographs showing samples composed of SA179 prepared to a 600 grit finish before testing, after testing and post-cleaning.

Cross-sectioning of the samples following testing showed no surface deposits or significant signs of pitting and other corrosion (Figure 12).

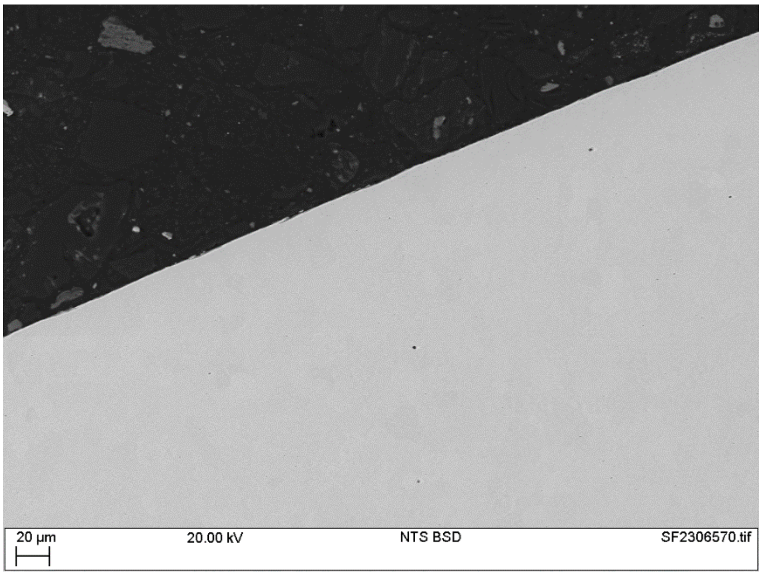


Figure 12 SEM image of a cross-section of sample SA179-600-3 following exposure testing.

Mass loss following ASTM G1 cleaning was 0.0019-0.0024g (Table 2), indicative of an extrapolated corrosion rate of 0.0077mm.year^{-1} (Table 3).

These results suggest that SA179 prepared to a 600 grit finish undergoes limited corrosion in Hitec at these temperatures and durations. Additionally, the lack of corrosion product present on the samples prepared to 600 grit (versus the as-received material) suggests that the corrosion rate of the as-received material may be artificially high, due to the impact of corrosion products present of the samples prior to testing.

4.4 304L

4.4.1 As-received

The samples prior to testing had a dull grey finish with a rough surface texture. The visual appearance of the samples appeared unchanged following testing or cleaning (Figure 13).

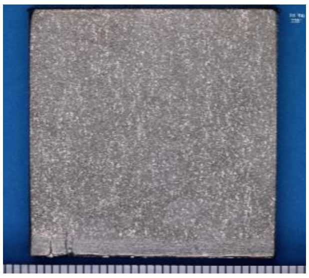
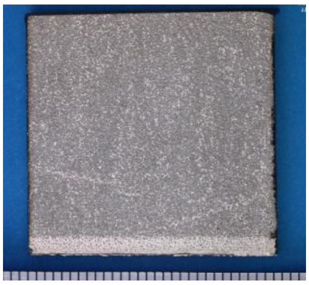
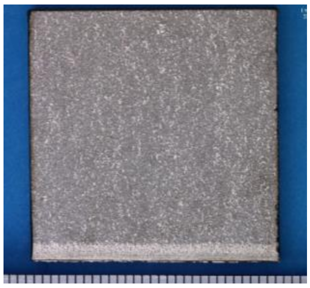
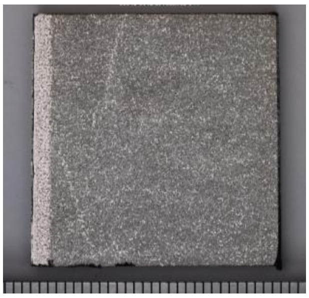
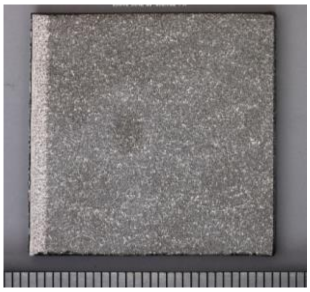
	304L-AR-2	304L-AR-3	304L-AR-4
Pre-Test			
Post-Test			
Post Cleaning			

Figure 13 Photographs showing samples composed of 304L in the as-received condition before testing, after testing and post-cleaning.

Cross-sectioning of the samples following testing showed no surface deposits or significant signs of pitting and other corrosion (Figure 14).

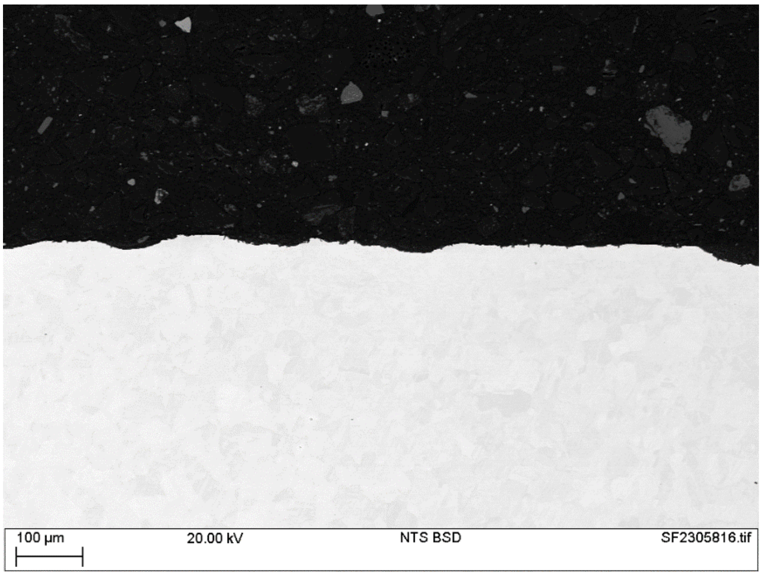


Figure 14 SEM image of a cross-section of sample 304L-AR-5 following exposure testing.

Mass loss following testing was between 0.008-0.0016g (Table 2), indicative of an extrapolated corrosion rate of 0.0030mm.year^{-1} (Table 3).

These results suggest that 304L in the as-received condition does not undergo significant corrosion in Hitec at these temperatures and durations.

4.4.2 600 grit

The samples prior to testing had a bright grey metallic finish. The visual appearance of the samples appeared largely unchanged following testing or cleaning though were less bright after each step (Figure 15).

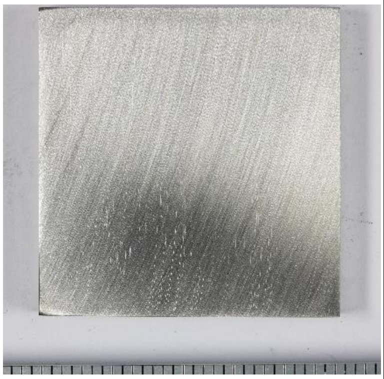
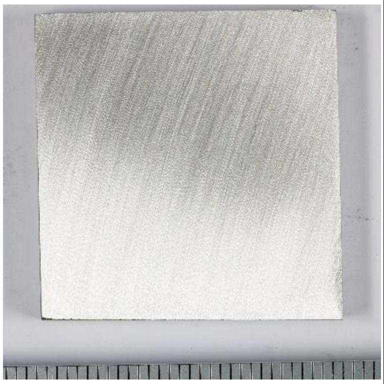
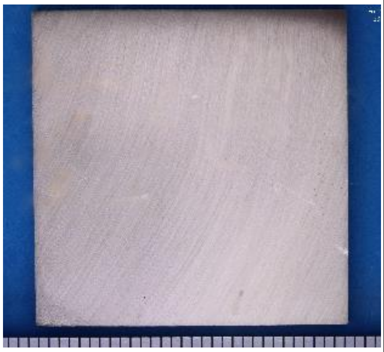
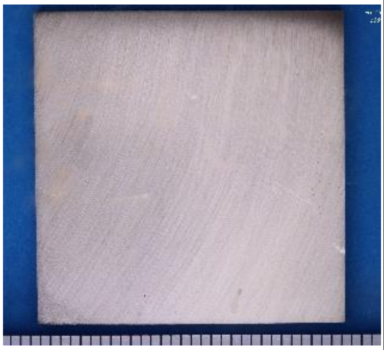
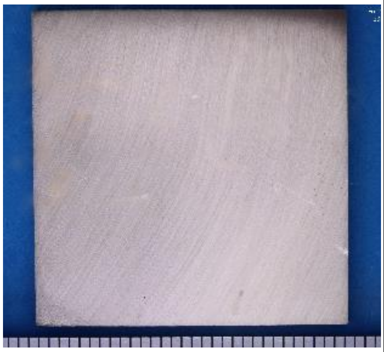
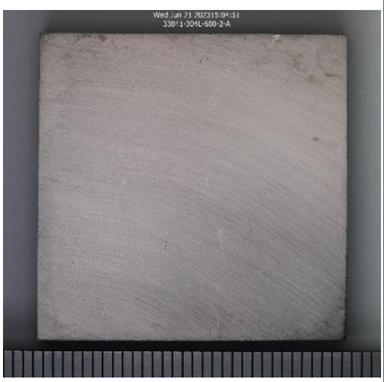
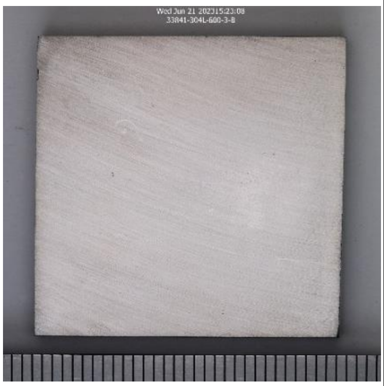
	304L-600-2	304L-600-3	304L-600-4
Pre-Test			
Post-Test			
Post Cleaning			

Figure 15 Photographs showing samples composed of 304L prepared to a 600 grit finish before testing, after testing and post-cleaning.

Cross-sectioning of the samples following testing showed no surface deposits or significant signs of pitting and other types of corrosion (Figure 16).

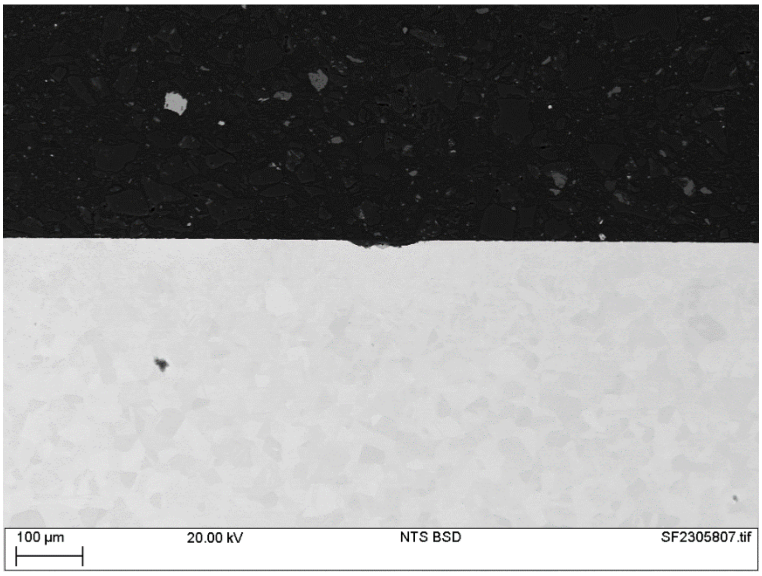


Figure 16 SEM image of a cross-section of sample 304L-600-5 following exposure testing.

Mass loss following cleaning was zero indicating no measurable corrosion rate.

These results suggest that 304L prepared to a 600 grit finish does not undergo significant corrosion in Hitec at these temperatures and durations.

4.5 316L

4.5.1 As-received

The samples prior to testing had a dull grey finish with a rough surface texture (Figure 17). The visual appearance of the samples appeared largely unchanged following testing or cleaning.

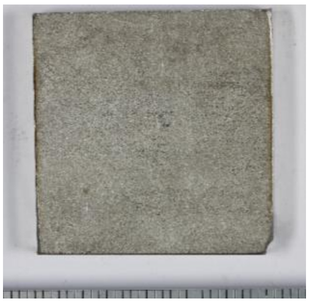
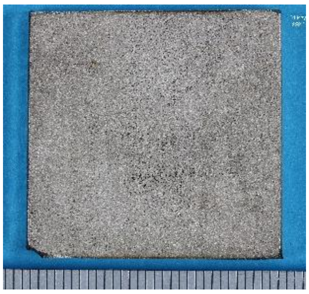
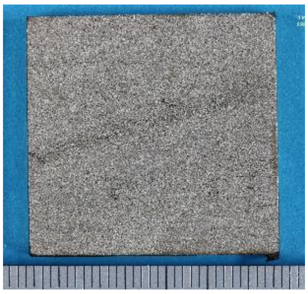
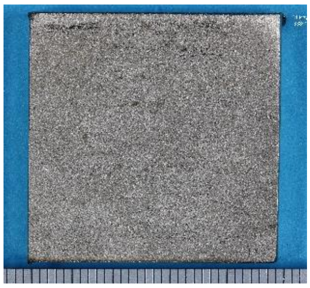
	316L-AR-2	316L-AR-3	316L-AR-4
Pre-Test			
Post-Test			
Post Cleaning			

Figure 17 Photographs showing samples composed of 316L in the as-received condition before testing, after testing and post-cleaning.

Cross-sectioning of the samples following testing showed no surface deposits or significant signs of pitting and other types of corrosion (Figure 18).

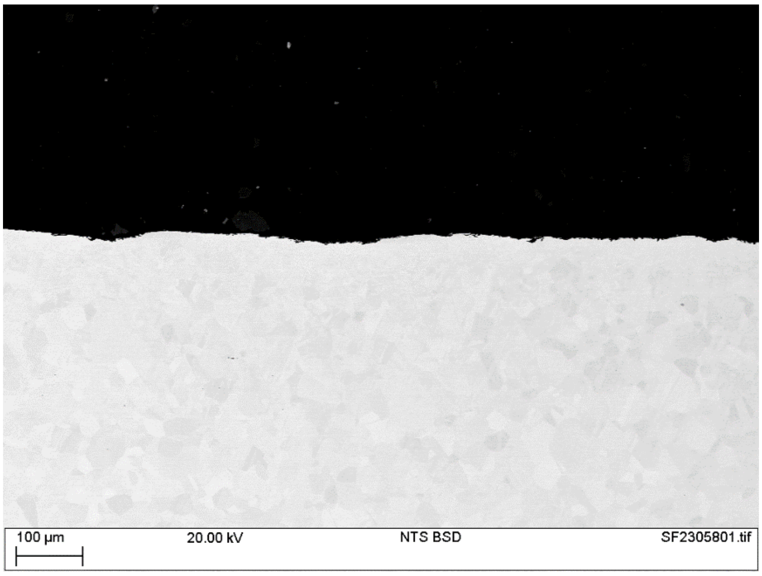


Figure 18 An SEM image of a cross-section of sample 316L-AR-5 following exposure testing.

Mass loss following testing was between 0.0017-0.0037g (Table 2), indicative of an extrapolated corrosion rate of 0.0073mm.year^{-1} (Table 3).

These results suggest that 316L in the as-received condition does not undergo significant corrosion in Hitec at these temperatures and durations.

4.5.2 600 grit

The samples prior to testing had a bright grey metallic finish (Figure 19). The visual appearance of the samples appeared largely unchanged following testing or cleaning though were less bright after each step.

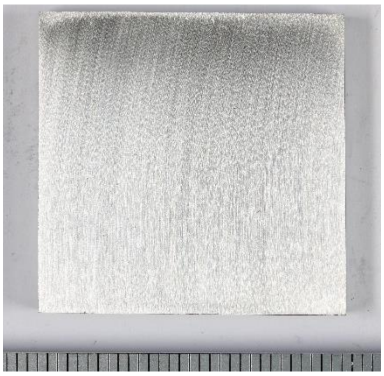
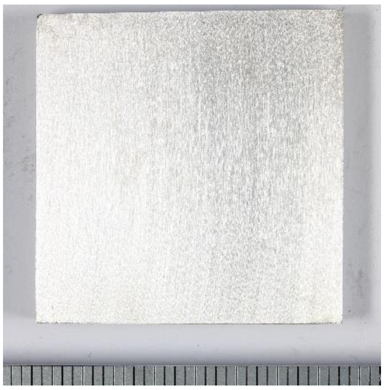
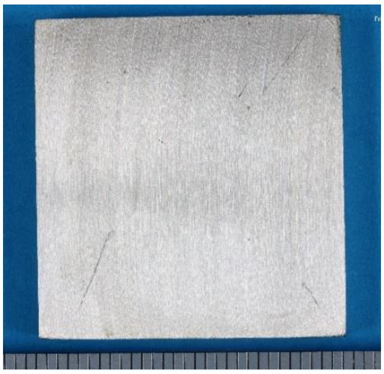
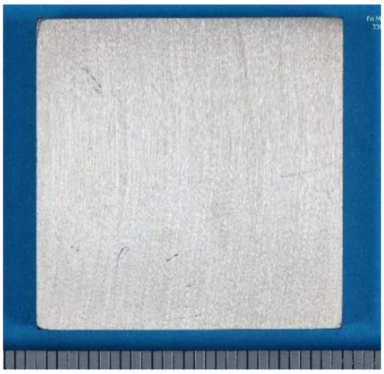
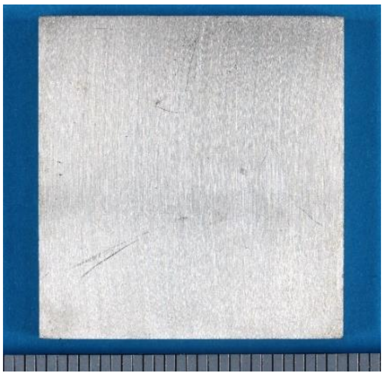
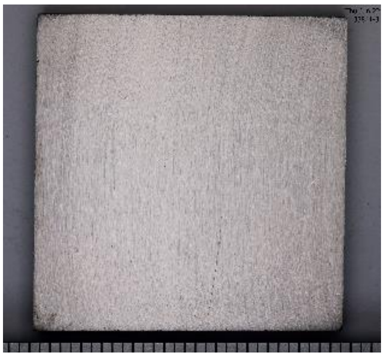
	316L-600-2	316L-600-3	316L-600-4
Pre-Test			
Post-Test			
Post Cleaning			

Figure 19 Photographs showing samples composed of 316L prepared to a 600 grit finish before testing, after testing and post-cleaning.

Cross-sectioning of the samples following testing showed no surface deposits or significant signs of pitting and other corrosion (Figure 20).

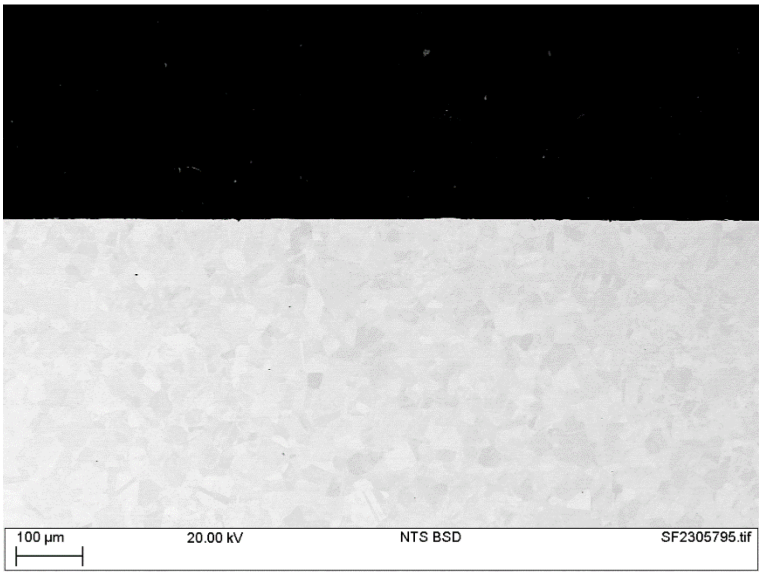


Figure 20 SEM image of a cross-section of sample 316L-600-5 following exposure testing.

Mass loss following cleaning was zero indicating no measurable corrosion rate.

These results suggest that 316L prepared to a 600 grit finish does not undergo significant corrosion in Hitec at these temperatures and durations.

4.6 Summary

Results of the corrosion testing performed show that all carbon and stainless steel grades assessed undergo limited or no significant corrosion over the duration of the testing under the conditions listed. Additionally, projected corrosion rates suggest that these materials would be suitable for long-term service in these environments. Where high corrosion rates were observed this was attributed to either removal of surface oxide present prior to testing or base material consumption during the ASTM G1 cleaning process.

These results confirm that the use of certain carbon steel grades for service with Hitec at selected temperatures can be appropriate and can allow for reduced capital cost relative to stainless steels. This is particularly advantageous to less established technologies, such as the GeoSmart developments, which often have higher initial costs.

5. CONCLUSIONS

The main conclusions of this work were:

- The carbon steel grades assessed are appropriate for service with HiTec exposure at the temperature specified.
- The stainless steel grades assessed are appropriate for service with HiTec exposure at the temperature specified.
- The use of the stainless steel grades assessed does not provide any obvious corrosion performance benefit relative to the carbon steel grades.

REFERENCES

[1] ASTM G1-03(2017)e1, Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens.