Total hemispherical emissivity of Inconel 718

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ABSTRACT

Total hemispherical emissivity for Inconel 718 was measured in anticipation of its application in Very High Temperature Gas Reactors (VHTRs). A majority of current emissivity data for Inconel 718 is in the form of spectral measurements. The data presented here were obtained with an experimental apparatus based on the standard ASTM C835-06 for total hemispherical emittance. Measurements of Inconel 718 were made for four different surface types including: (i) ‘as-received’ from the manufacturer (ii) oxidized in air and humidified helium, (iii) sandblasted with aluminum oxide powder, and (iv) with a thin coating of nuclear grade graphite powder (grade NGB-18). The emissivity for the ‘as-received’ sample ranged from 0.21 to 0.28 in the temperature interval from 760 K to 1275 K. Oxidation in air at 1073 K resulted in an increase in emissivity into the range from 0.2 at 650 K to 0.52 at 1200 K. There was no dependence on the oxidation times studied here. Oxidation with humidified helium at 1073 K produced less of an increase in emissivity than the oxidation in air but there was an increase up to the range from 0.2 at 600 K to 0.35 at 1200 K. Sandblasting of Inconel 718 was also observed to increase the emissivity up to the range from 0.43 at 780 K to 0.53 at 1270 K when 60 grit sized powder was used and up to the range from 0.45 at 683 K to 0.57 at 1267 K when 120 and 220 grit sized powders were used. Coating of graphite powder onto the ‘as-received’ Inconel 718 showed no increase in the emissivity whereas the coating of graphite powder onto the 220 grit sandblasted Inconel 718 did show an increase in emissivity up to the range from 0.60 at 650 K to 0.70 at 1200 K. This was apparently due to better adhesion of graphite on the roughened surface.

1. Introduction

Inconel 718 is used in nuclear reactor vessel and component fabrication. Hence, data on its physical and thermal properties are of interest. We report here our measurements of its emissivity under a range of temperatures and surface conditions.

We note that there have been several studies of the emissivity of Inconel 718 by spectral and calorimetric methods. Green et al. (2000) and Tanda and Misale (2006) reported total hemispherical emissivity. Green et al. used sheets of Inconel 718 similar to this study and performed measurements up to 1273 K. Tanda and Misale cut their samples from bar stock using electrodischarge machining (EDM). Due to the EDM, Tanda and Misale effectively polished their samples to a mirror finish for unoxidized emissivity data. Moreover, Tanda and Misale took lower temperature data (350 to 600 K). Rogers (2009) used an ASTM C835 standard for emissivity measurements on polished Inconel 718 along with Tanda and Misale's results to validate emissivity results on the same polished sample from their spectral emissivity apparatus using a Fourier Transform Infrared (FTIR) spectrometer. Extensive spectral emissivity data from del Campo et al. (2010), using an FTIR spectrometer, measured normal and directional emissivity of Inconel 718 and a few other alloys for a variety of surface conditions and levels of oxidation. Researchers from this work extended their data to yttria stabilized zirconia coated samples of Inconel 718 (Gonzalez-Fernandez et al. 2012). Alaruri et al. (1998) and Leshock et al. (2001) obtained emissivity data using a single-wavelength pyrometer. Raj and Prabhu (2013) extended two-color pyrometry by using a CCD camera to acquire 2D spatial distributions of temperature and emissivity for plates of Inconel 718. Pottlacher et al. (2002) and Cagran et al. (2009) measured normal spectral emissivity of solid and liquid Inconel 718 using pulse heating

and a μ s-division-of-amplitude photopolarimeter. We will use the data of Green et al. for comparison with the data reported here. A summary of the previous work that has been described is given in Table 1.

Table 1

A summary of previous measurements of the emissivity of Inconel 718.

Work (year)	Data Reported	Method	Temperature (K)	Emissivity	Surface(s) Measured
Alaruri et al. (1998)	Spectral Effective	Pyrometer (1.6 μ m)	923-1323	0.8-0.95	‘as-received’
Greene et al. (2000)	Total Hemispheric	Calorimetric	473-1273	0.25-0.91	‘as-received’ Pre-Oxidized
Leshock et al. (2001)	Spectral Normal	Pyrometer (1.6 μ m)	723-1023	0.45-1.0	‘as-received’
Pottlacher et al. (2002)	Spectral Normal	μ s-DOAP (0.684 μ m)	1500-3000	0.35-0.55	‘as-received’
Tanda & Misale (2006)	Total Hemispheric	Calorimetric	623-853	0.15-0.65	EDM Machined Mirror Polished Pre-Oxidized
Cagran et al. (2009)	Spectral Normal	μ s-DOAP (0.684 μ m)	900-3000	0.37-0.55	‘as-received’
Rogers & Crandall (2009)	Total Hemispheric	FTIR (0.4-25 μ m)	873-1383	0.16-0.63	Mirror Polished
		Calorimetric [†]	629-1300	0.17-0.20	
del Campo et al. (2010)	Spectral Normal	FTIR (2-22 μ m)	456-912	0.1 - 0.9	EDM Wire Cut Brushed Sandblasted In-Situ Oxidized Pre-Oxidized
	Spectral Directional	FTIR (0-85 deg)	728	0.22-0.53	Sandblasted
Gonzalez- Fernandez et al. (2012)	Spectral Normal	FTIR (2.5-22 μ m)	793	0.63	Sandblasted
Raj & Prabhu (2013)	Spectral Normal	CDD Camera (Two-Color Pyrometer)	773-1073	0.4-0.8	‘as-received’
Skubisz & Micek (2013)	Spectral Normal	Pyrometer	673-1223	0.86-0.92	‘as-received’
This Study	Total Hemispheric	Calorimetric [†]	650-1300	0.2-0.7	‘as-received’ Sandblasted Pre-Oxidized Graphite Coated

[†] Based on ASTM C835.

2. Methods, materials, and results

Since the details of our experimental apparatus and methods are published elsewhere (Maynard et al. 2010) and are based on the readily available ASTM standard C835-06 (ASTM 2006), we refer the reader to our earlier work and to the standard for more detailed descriptions of the method and of the apparatus. We describe here in some detail, however, the preparation of the Inconel 718 samples studied in this work. The nominal composition for Inconel 718 ‘as-received’ from the manufacturer is given in Table 2. Inconel 718 sheets with a nominal thickness of 0.0409 cm were cut into strips 25.4 cm long and 1.27 cm wide required for the apparatus. Sample test strips were washed in acetone and rinsed with DI water following the spot welding of K-type thermocouples onto the test strips in the manner specified in the ASTM standard. To examine the effects of oxidation and surface roughness on emissivity, separate strips were oxidized in air and humidified helium, or were sandblasted with aluminum oxide powders. For oxidation, four samples were oxidized. Three of these were oxidized in air at ~1073 K for 5, 10, and 15 minutes and one was oxidized in humidified helium at ~1073 K for 15 minutes. Three different grit sizes of aluminum oxide powder (60, 120, and 220) were used to roughen the surface of Inconel 718 test strips by sandblasting. Two additional samples of Inconel 718, including one ‘as-received’ sample strip, and one 220 grit sandblasted sample strip, had reactor grade graphite powder (NGB-18) applied. Scanning Electron Microscopy (SEM) with an Energy Dispersive Spectrometer (EDS) was used for x-ray analysis of surface oxygenation of samples, and an optical profilometer was used to characterize the surface roughness of the samples.

Table 2Composition of Inconel 718.[†]

Element	Weight %
Ni+Co	50.00-55.00
Cr	17.00-21.00
Fe	Balance (11.134-24.60)
Nb+Ta	4.75-5.50
Mo	2.80-3.30
Ti	0.65-1.15
Al	0.20-0.80
Co	1.00 max
Mn	0.35 max
Si	0.35 max
Cu	0.30 max
P	0.015 max
S	0.015 max
C	0.08 max
B	0.006 max
UNS Number	N07718
Density	8.19 g cm ⁻³
Melting point	1483-1617 K

[†] <http://www.specialmetals.com/documents/Inconel%20alloy%20718.pdf>

The oxidation of Inconel 718 in air at ~1073 K did not result in significant differences in oxidation among the various test strips for oxidation durations of 5, 10, and 15 minutes.

However, oxidation in humidified helium did produce a surface noticeably less oxidized than those sample surfaces oxidized in air. Table 3 shows a qualitative analysis of oxygen on the surface of the various oxidized Inconel 718 samples obtained using SEM-EDS. The intensity of the 524.9 eV oxygen K α_1 -line is assumed to correlate to the amount of oxide on the surface.

‘As-received’ Inconel 718 showed roughly half the intensity of the oxygen K α_1 -line compared to the air oxidized samples at a SEM beam voltage of 15 keV. There is little variation of oxygen intensity among the samples oxidized in air when the EDS electron beam energy is 15 keV. For

oxidation in humidified helium at ~ 1073 K for 15 minutes, the intensity of the oxygen $K\alpha_1$ -line is noticeably lower than that observed even for the sample oxidized in air for 5 minutes. EDS was repeated at 10 keV to better excite the surface oxygen on the air oxidized samples since at the lower energy one expects less electron penetration into the sample and hence a higher fractional energy loss in the surface oxide layer. While the 10 keV data appears to show a slight increase in the oxygen $K\alpha_1$ -line intensity between the 5 minute and 10 minute oxidation treatments and then a slight decrease for the 15 minute oxidation, it is most likely that these differences are primarily representative of the fact that each sample was different and, hence, that the sampling points were different. The trend for the oxidation with humidified helium also appears at this lower beam voltage. Thus, it appears that for all practical purposes the oxidation of the Inconel 718 in air at ~ 1073 K reached a plateau within the first five minutes of treatment. It is not clear from the limited data that has been acquired here that the oxidation of Inconel 718 in humidified helium at ~ 1073 K for 15 minutes has reached a plateau, although it does seem clear that some oxidation beyond that of the 'as-received' sample has occurred. It should be noted that SEM-EDS is of limited use in analyzing thin film compositions. Our use of the technique here was primarily to show that we were studying samples that were oxidized to a level representative of what might be encountered in a VHTR accident scenario. The air oxidized samples would seem to adequately reflect this. A more surface-sensitive technique like x-ray photoelectron spectroscopy (XPS) or secondary ion mass spectrometry (SIMS) would be needed to get more accurate measurements of surface oxygen content. A collage of SEM secondary electron images are given in Fig. 1 for the 'as-received' and various oxidized samples. In Fig. 1, surface artifacts from the manufacturing process can clearly be seen. For the oxidized surfaces, the formation of growths on the surface occurred but the number and size of these

growths did not vary drastically between the samples. SEM-EDS revealed the growths are Nb-Ti rich. Since the EDS results of the growths are similar for the oxidized surfaces, EDS spectra, for two points on Fig. 2(a) (the 15 minute air-oxidized sample) are shown in Figs. 2(b) and 2(c). Fig. 2(b) is the EDS x-ray spectrum of one of the growths which clearly shows it to be rich in Nb-Ti, whereas Fig. 2(c) is the EDS x-ray spectrum of what appears to be normal oxidized alloy.

Table 3

The intensity of the 524.9 eV oxygen $K\alpha_1$ -line observed for EDS electron beam of voltages of 10 keV and 15 keV for oxidized and ‘as-received’ sample strips. The net counts can be used to infer the degree of surface oxidation of the samples.

Strip condition	Net counts	
	15 keV	10 keV
‘As-received’	3549±130	---
Oxidized for 5 minutes	6856±155	11417±198
Oxidized for 10 minutes	6828±154	12714±204
Oxidized for 15 minutes	6924±156	12142±202
Oxidized in humidified-He	5897±149	10034±189

Fig. 1. SEM images for Inconel 718 samples in conditions corresponding to: (a) ‘as-received,’ (b) air oxidation for 5 minutes, (c) air oxidation for 10 minutes, (d) air oxidation for 15 minutes, and (e) humidified He oxidation for 15 minutes. All oxidized samples were oxidized at ~1073 K.

Fig. 2. SEM-EDS data for two selected points on the surface of the Inconel 718 sample strip that was oxidized for 15 minutes in air at ~ 1073 K. Included are: (a) an SEM image of the area on the oxidized sample strip from which points were selected for compositional analysis, (b) the EDS spectrum for the point labeled '1' (in orange) which corresponds to one of the Nb-Ti rich growths, and (c) the EDS spectrum for the point labeled '2' (in blue) which appears to correspond to a normal (non-growth) area of the oxidized Inconel.

The first measurement made in this study was of the total hemispherical emissivity of Inconel 718 in ‘as-received’ condition. The resulting emissivity values as a function of temperature are shown in Fig. 3 where they are compared to values from Greene et al. (2000). The emissivity values in this study ranged from 0.21 to 0.28 for the temperature range from 760 K to 1275 K. Greene et al. (2000) reported values about 10% higher than in the present study over the same temperature range. Yet, the slope between the two different data sets is very similar. Since the samples were different and the sample histories prior to receipt are unknown, this may be due to nothing more than slightly different degrees of oxidation or surface contamination.

Fig. 3. Total hemispherical emissivity of ‘as-received’ Inconel 718 obtained in this study and compared with data from Green et al. (2000).

Next we measured the emissivities of the four oxidized samples. Results for the oxidized samples are shown in Fig. 4 where they are compared to the results for the ‘as-received’ sample.

Consistent with the SEM-EDS analysis of the oxidized surfaces, the emissivities are virtually the same for all three air oxidized samples. Also, the sample oxidized in humidified helium, which seemed to have less oxidation, had an emissivity slightly lower than the air oxidized samples but above that of the 'as-received' sample. Unlike the 'as-received' sample, where the emissivity as a function of temperature appears to have a relatively constant slope, the emissivities of the oxidized samples rapidly increase from around 0.35 at 1100 K to around 0.52 at 1200 K. Greene et al. (2000) also looked at the effect of oxidation on the emissivity of Inconel 718. Their oxidations were done in air at temperatures of 1273, 1373, and 1415 K with durations of 15, 30, and 60 minutes at each temperature. Emissivities from Green et al. (2000) ranged from 0.575 to 0.875 for samples of Inconel 718 oxidized at 1273 K and 0.8 to 0.9 for samples oxidized at 1373 K and 1415 K. The short times and relatively lower temperature for the air oxidation can explain the emissivities reported here. For the Inconel 718 oxidized in humidified helium, the emissivity goes from 0.2 at 600 K to 0.25 at ~925 K. The emissivity starts a rapid rise at around 1000 K, but then slowly increases between 1100 K and 1200 K to a value of 0.36. Also, the oxidation of the Inconel 718 in water vapor resulted in a mild discoloration. Previous measurements by this group on lightly oxidized (in air) Haynes 230 showed a similar plateau behavior (Maynard et al. 2011). Here the emissivity for Inconel 718 oxidized with water vapor in helium is compared to Haynes 230 oxidized in air at ~1153 K in Fig. 5.

Fig. 4. The emissivity of oxidized Inconel 718 compared to the emissivity of 'as-received' Inconel 718. The oxidized samples consist of three samples oxidized in air at a temperature of ~ 1073 K for 5, 10, and 15 minutes and one sample oxidized in humidified helium at a temperature of ~ 1073 K for 15 minutes. As expected from the EDS data which indicated approximately the same degree of oxidation for all three air-oxidized samples, the results for the three air-oxidized samples are virtually identical. The sample oxidized in humidified helium which is believed to not be as fully oxidized as the other oxidized samples lies, as expected, between their values and those for the 'as-received' sample. It is interesting to note that, as the temperature increases above ~ 1200 K, the emissivity values begin to decline. It seems most likely that this behavior corresponds to outgassing of oxygen from the samples either directly or as the result of some phase change(s) in the oxide layer.

Fig. 5: The emissivity of pre-oxidized Inconel 718 in humidified helium compared to Haynes 230 oxidized in air at ~ 1153 K (Maynard et al. 2011).

In Fig. 4, the emissivity for the oxidized data starts to drop past 1200 K. The reason for this is not completely understood. Greene et al. (2000) also reported issues of measuring emissivity above 1273 K, due to the welded thermocouples (S Type) causing erroneous readings around 1273 K. Greene et al. (2000) determined this using a piece of Inconel 718 with a welded thermocouple in contact with a sheathed thermocouple probe and compared their readings in a tube furnace. Thus, Greene et al. (2000) reported emissivity data for oxidized Inconel 718 up to 1273 K. This test has not been done for the thermocouples used in this study. Yet, the K Type thermocouples used in these measurements have an upper working limit around 1645 K, unlike the S Type Green et al. (2000) used whose upper limit is 2041 K. The working temperatures will be lower with fine gauge wires; 0.07 mm (0.003 in) diameter wires were used in this study.

Thermocouple readings could be affecting the emissivity, yet in both Green et al.'s (2000) work and the current study this behavior is seen in the oxidized measurements. Greene et al.'s (2000) thermocouple test shows deviations among the welded and reference thermocouples before 1273 K and their data for 'as-received' was reported past 1273 K. Also, in both studies the thermocouples are attached prior to oxidation. Though K Type and S Type can be used in oxidizing environments, there could be some interaction between the welded thermocouples and oxidized surface.

To see any differences in the emissivity from changes in the Inconel 718 samples, additional runs for the air oxidation for 10 minutes were repeated and terminated at select temperatures around the peak in the original data. Results of these runs are given in Fig. 6. SEM-EDS of the additional runs did not see any differences among the samples terminated early.

Fig. 6: The emissivity of four separate samples of Inconel 718 oxidized in air at 1073 K for 10 minutes terminated at select temperatures around emissivity peak.

Surfaces areas and roughness of ‘as-received’ and sandblasted samples are given in Fig. 7 (a-d). In the figures, a 3D profile of an area is in the upper left and a profile of a line scan is given on the right at the corresponding location on the scan on the lower left. Roughness parameters for the scans are given in the table on the lower right of the figure. The arithmetic average of the roughness profile, R_a , is used to determine the amount of roughening of the sample as the averaging tends to be insensitive to extreme features (peaks and valleys) in the profile. The R_a for the 60 grit, 120 grit, and 220 grit sandblasted samples are 2.13 μm , 2.11 μm , and 1.36 μm respectively. These are consistent with the abrasive grit sizes used as smaller beads size tend to produce smaller surface features. The R_a for the ‘as-received’ sample has a value for 0.51 μm . Surface area progressively increased from 15.19 mm^2 for ‘as-received’ sample to 17.36 mm^2 for the 120 grit sandblasted sample, whereas the surface area decreased to 16.50 mm^2 for the 220 grit sandblasted sample. Lam et al. (2005) studied the surface area on metals abraded by different grits sizes of SiC paper. They determined the surface area could be understood from a combination the overall size of the surface features from the abrasive and the density of such features on the geometric area of surface. Thus, an intermediate grit size provided a balance of the two factors for maximum surface area. The coarsest and finest grit sizes favor one factor over the other and does not provide additional gains in surface area. Due to the issues of SEM-EDS of rough surfaces, we only report point scans for the identification of aluminum oxide and graphite particles on Inconel 718 sandblasted with 220 grit beads. Figures 8(b) and 8(c) are the EDS spectra for selected points on the SEM micrograph in Fig. 8(a).

The emissivities for the sandblasted samples are provided in Fig. 9. Compared to the ‘as-received’ samples, the sandblasted surfaces exhibit larger emissivities ranging from 0.45 to 0.57. Consistent with the surface area, the 60 grit sandblasted sample has the lowest emissivities from 0.43 to 0.53 over the temperatures of 780 to 1270 K. Yet there is little difference in the emissivities of the samples roughened with 120 grit and 220 grit aluminum oxidize particles, despite the differences in the R_a and surface areas. Over the temperature interval of 682 to 1270 K, the emissivity among the 120 and 220 grit sandblasted surfaces ranges from 0.45 to 0.57.

Similar behavior has been seen from emissivity measurements of Hastelloy X and Haynes 230 from this group (Maynard et al. 2010 and 2011). In our studies of Hastelloy X and Haynes 230, the surfaces were roughened with sandpaper with grit sizes 100, 240, and 600. The emissivities for Haynes 230 and Hastelloy X at the two highest grits (240 and 600) were very close to one another. In the data among Inconel 718, Haynes 230 and Hastelloy X, there is a temperature where the emissivity of the sample roughened with the highest grit is slightly higher than the sample roughened with the next to highest grit. In Fig. 9, the emissivity for the 220 grit sandblasted surface is higher than that of the 120 grit sandblasted surface above ~850 K. This temperature is ~1200K for Hastelloy X and ~1140 K for Haynes 230 (Maynard et al. 2010 and 2011). Emissivity data for Hastelloy N from this group was also treated with sandblasting using aluminum oxide beads of 60, 120, and 220 grit sizes. The emissivities for the sandblasted Hastelloy N show little dependence of the grit size used (Gordon et al. 2012).

Other studies on Inconel 718 also found an increase of emissivity with surface roughness, yet these roughness measurements are associated with a particular surface treatment. Campo et al. (2010) measured the spectral emissivities of Inconel 718, Rene 41, and Haynes 25. Inconel 718 discs were cut by wire-cut electrical discharge machining (EDM). Some samples were

brushed to clean the machined surface, while other samples were brushed followed by a sandblasting. The R_a values in their study for Inconel 718 as brushed, sandblasted, and EDM cut are 1.3, 1.6, and 2.4 μm respectively. The emissivities measured by Del Campo et al. (2010) increased with increasing R_a . Tanda and Misale (2006) examined EDM cut and polished (mirror finish) Inconel 718. These surfaces are quite distinct such that other mechanisms can come into play. EDM cut surfaces have a layer solidified molten metal called the recast, or white, layer followed by a heat-affected zone on top of the base metal. The type of power source used, parameters of the discharge, and the addition of skim cuts on the surface determine the thickness of the recast layer and heat-affect zones (Sommer 2005). Del Campo et al. (2010) noted the brushing removed the recast layer from the EDM process.

(a) Inconel 718 sandblasted with 60 grit beads, measurement was taken at center.

(b) Inconel 718 sandblasted with 120 grit beads, measurement was taken at center.

(c) Inconel 718 sandblasted with 220 grit beads, measurement was taken at center.

(d) Inconel 718 'as-received', measurement was taken at center.

Fig. 7: Surface area and roughness from optical profilometry for (a) 60 Grit Sandblasted, (b) 120 Grit Sandblasted, (c) 220 Grit Sandblasted, and (d) 'as-received' samples.

(a)

(b)

(c)

Fig. 8: EDS spectra of selected points (a) on an SEM image of Inconel 718 sandblasted with 220 grit beads and a graphite coating for (b) the aluminum oxide particle and (c) the graphite particle.

Fig. 9: The emissivity of roughened Inconel 718 from sandblasting (SB) with aluminum oxide at the selected grit sizes of 60, 120, and 220.

The effect of emissivity from a coating of graphite particles was examined for Inconel 718. In High Temperature Gas Cooled Reactors, graphite dust forms in the coolant and can deposit on structural materials within the primary cooling loop. The emissivity from such a graphite coating for Hastelloy X and Haynes 230, and Hastelloy N has been reported by this group (Maynard et al. 2010 and 2011 and Gordon et al. 2012). Fig. 8(c) shows EDS of a NGB-18 grade graphite particle as indicated in the corresponding SEM micrograph in Fig. 8(a). Elements from the underlying metal and possible contamination (powders were applied with a Q-tip) are seen in the spectrum. Graphite particles can be clearly seen in an SEM micrographic utilizing the backscattered electrons (BSE) from the sample (Fig. 10). The intensity of BSE into the detector is proportional to the average atomic number. Thus, in the figure, graphite particles

appear black against the gray color. The emissivities of the graphite coated samples compared to their uncoated counterparts are given in Fig. 11. The emissivity of the 'as-received' surface does not change with the addition of graphite particles. However for the sandblasted surface, the emissivity increases with the graphite particles. The emissivity ranges from 0.6 to 0.7 over a temperature interval of 650 to 1200 K for the sample sandblasted with 220 grit followed with a coating of graphite powder. The increase could be from the fact that the roughened surface can contain more graphite. An alternative explanation (as suggested to us by one of the referees of the paper) is that the increased surface area also increases the microcrystalline structures on the alloy. These crystalline features allow the graphite to couple more closely to the alloy enhancing the phonon, and perhaps also plasmon, transport through the graphite-metal interface. Thus, more heat is transferred to the graphite particles, which has a much higher emissivity than the metal. This phenomenon needs to be investigated more in its own right because of its general importance.

Fig. 10: Backscattered electron image of Inconel 718 sandblasted with 220 Grit and coated with graphite.

Fig. 11: The emissivity of Inconel 718 coated with particulate graphite for the ‘as-received’ and Sandblasted (SB) 220 Grit surface finishes.

3. Conclusions

The total hemispherical emissivity for Inconel 718 has been evaluated in an ASTM C835-06 apparatus used in emissivity measurements for other alloys for interest in HTGR applications. A summary of this work is compared to previous studies on the emissivity of Inconel 718 in Table 1. The emissivity of Inconel 718 for the oxidation conditions examined here increased the emissivity compared to the un-oxidized sample, but there were no differences among the oxidized samples except the sample oxidized with humidified helium. For the oxidized samples, the decrease in the emissivity at higher temperatures will need more study to determine if either temperature readings, materials changes, or both attribute to this decrease.

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