# Corrosion Behaviours of Aged Haynes 282 and Inconel 718 in Acidic and Alkaline Environments

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**Abstract**-Haynes 282 and Inconel 718 are super-alloy materials originally designed and used in aero- and land-based gas turbine engines. However, they are being considered and used in challenging environments such as nuclear power plants, chemical, and petrochemical plants due largely to their high creep strength and corrosion resistance at low and high temperatures. Recently, there is quest for their uses in the oil and gas refineries. This work examines the corrosion behaviour of these two materials in acidic and alkaline environments; similar to that in the petroleum refinery. The samples were cut, aged, and electrochemically characterized using VersaSTAT 3 model potentiostat with graphite counter electrode and Ag-AgCl SCE. The Linear polarization corrosion test conducted revealed that the corrosion rate, break down potential(Ecorr) and the corrosion current(Icorr) of the aged Haynes 218 are 0.05mmpy, 0.198V, 5.032µA in dilute HNO3 ; 0.145mmpy,16.23V,13.48 µA in dilute NaOH while those of aged Inconel 718 are 0.068mmpy,96.5V,63.56 µA in the dilute HNO3 and 0.026mmpy,0.41V,2.478 µA in the dilute NaOH respectively. These results showed that aged Haynes 282 has a higher corrosion resistance than aged Inconel 718 in the acidic medium ,but, the reverse in the alkaline medium .However better corrosion passivation was obtained in HNO3 for the two materials than in NaOH.

**Keywords**- Super-alloys, Haynes 282, Inconel 718, Tafel Extrapolation Method

## 1 INTRODUCTION

Supper-alloys, or high-performance alloys, are alloys that exhibit several key characteristics such as excellent mechanical strength, resistance to thermal creep deformation, good surface stability and resistance to corrosion or oxidation at very high temperature (Yang and Thomson, 2014). As a result of the materials challenges for high temperature applications, nickel based super-alloys emerged as the materials of choice for these applications. The properties of this nickel based super-alloys can be tailored to a certain extent through the addition of many other elements; both common and exotic, including not only metals, but also metalloids and non-metals (Pike, 2008). Chromium, Iron, Cobalt, Molybdenum, Tungsten, Tantalum, Aluminium, Titanium, Zirconium, Niobium, Rhenium, Yttrium, Carbon, Boron, or Hafnium are some examples of the alloying elements used.

Inconel 718 and Haynes 282 are nickel based super-alloys invented in the early 1960 at INCO Huntington Alloys and 2006 by Haynes Incorporation USA respectively. While Haynes 282 is recently developed, Inconel 718 had been in existence for quite some time. Inconel 718 alloy has become the most widely used nickel based super-alloy in the aircraft engine industry. It was used in many critical aircraft engine components, accounting for over 30% of the total finished component mass of a modern aircraft engine (Pollock and Tin, 2006). Hayne 282 is a more recent material and is still under testing. (Haynes 282 Data sheets, 2008). Nickel based super-alloys are solution/precipitation strengthened alloys containing many alloying elements. These are complex engineered materials because they involve precipitation of intermetallic phases, called the gamma prime (ɣ′) and gamma double prime (ɣ′′), and carbides such as MC (rich in Ti and Mo), M23C6 (rich in Cr) and other carbides like M6C (rich in Mo) and M7C3 (Zhao,2002; Kaufman,1961;Sabol,1969 and Kotval,1969).

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The superior strength, high resistance to oxidation and corrosion and creep properties of these alloys are essentially derived from the presence of these micro constituent phases ( Sims, 1966). The ɣ′ phase is coherent with gamma matrix (ɣ) and is an important constituent that contributes to the strength (Oblak et. al, 2010), while the carbides are incoherent to the matrix and are present at grain boundaries and intragranularly in nickel alloys (Roger, 2008). The alloying elements determine composition of the super-alloy while the heat treatment is important for optimizing the properties. Ageing is a heat treatment used to increase the yield strength of malleable materials, including most structural alloys of aluminium, magnesium, nickel, titanium and some stainless steels. Ageing basically involves the precipitation of extremely small, uniformly dispersed particles of a second phase within the original phase; which acts as the matrix. According to Poulonis and Schirra (2011), ageing is a two stages heat treatment generally used to heat treat super-alloys. It involves solution treatment and cooling either in the furnace, air or liquid medium such as water.

Haynes 282 super-alloy is a wrought gamma prime strengthened super-alloy; for potential applications in air and land based gas turbines and other high performance and high temperature environments. Haynes 282 is a unique Ni-Cr-Co-Mo-Al-Ti super-alloy which combines exceptionally high temperature properties with good weldability and fabricability. At high temperature, even as high as 900°C, the new alloy is stronger in creep strength than Haynes waspaloy and approaches the creep strength of Haynes R-41

The hot corrosion of some super-alloys was studied (Singh, 2011). The author conducted the study to compare the corrosion behaviour of nickel-, cobalt and iron-base super-alloys at temperatures above 600°C. It was discovered that super-alloys develop resistance to corrosion by forming either alumina or chromia scales upon their surfaces. The time to which such oxides reaction product barriers are stable upon the surface of super-alloys is discussed by first considering how these oxides scales are formed and how they were destroyed in use. It was observed that super-alloys although have numerous alloying element which could be used to suggest that they will have complex reactions with oxygen, hence a resistance to oxygen by utilizing the concept of Selective Oxidation. Selective oxidation occurs as a result of addition of alloying element of aluminium or chromium at concentrations sufficient to allow continuous scale of either $Al_2O_3$ or $Cr_2O_3$.

Also another researcher studied the Hot Corrosion Behaviour of super-alloys in different Corrosive Environments (Betteridge, 1956). This investigation was carried out as a result of hot corrosion problem in aircraft, marine, industrial and land-based gas turbines. Degradations by high temperature oxidation, hot corrosion and erosion are the main modes of material damage in the hot sections of gas turbines, boilers, industrial waste incinerators, etc. The specimens were exposed to two different molten salt environments $Na_2SO_4$ + 60% $V_2O_5$ and $Na_2SO_4$ +5% $V_2O_5$ + 5% NaCl at 900°C under cyclic conditions. Confirmation of the discoveries made (Silva, 2013). The author was of the opinion that formation of protective oxide scales such as $Cr_2O_3$, NiO and spinel $NiCr_2O_4$ contributes to the better corrosion resistance. Depletion of chromium occurs at scale- metal interfaces. Scale initially comprises of $Cr_2O_3$. During initial cycles nickel concentration was high at metal interface region, but as the number of cycles increase nickel concentration increases in the scale, scale has NiO and $Cr_2O_3$. Initial scale formed in $Na_2SO_4$ + 60% $V_2O_5$ environment was adherent to substrate, while in the case of chloride environment $Na_2SO_4$ +5% $V_2O_5$ + 5% NaCl the initial scale formed is less adherent to substrate and crack propagation path is visible in initial cycles. Crack propagated via formation of $Cr_2O_3$. Regions of crack propagation showed Chromium and Oxygen in relatively large quantity. El-Bagoury et. al (2011) discovered in their work that the microstructure, mechanical and corrosion properties of Ni base super-alloys could be optimized using various ageing parameters. These discoveries highlight the variation in corrosion behaviour of nickel based Super-alloys in different corrosive media.

The aim of this research work is to compare the corrosion properties of Inconel 718 and Haynes 282 at different ageing heat treatment schedules both in acidic and alkaline environment with a view to extending the areas of applications of Haynes 282.

## 2 METHODOLOGY

The chemical analysis of the Inconel 718 and Haynes 282 used was conducted with a Positive Metal Identifier (PMI). Samples of Haynes 282 and Inconel 718 were cut into 10mm length x 10mm width square shape and 2mm thickness. The specimens were aged using the heat treatment schedules in Table 1, which are recommended by the super-alloy manufacturers for optimal mechanical performance. The samples were then mounted in Bakelite which was drilled at one end to touch the metal for electrical contact during the corrosion test as prescribed by the equipment manufacturer.

Anodic and cathodic linear polarisation test was conducted using the open circuit option in the potentiostat.The corrosion media was poured into the flask while the samples as well as other electrodes held in their holders were dipped into the flask. The machine was set with appropriate sample surface area and density entered on the input device of the machine. The test was run for a period of about five hours each. Corroded samples were then removed and the results were generated and printed from the machine and analysed.

## 3 RESULTS AND DISCUSSIONS

Table 2 and Table 3 show the results of the chemical analyses of Inconel 718 and Haynes 282 respectively. From these two Tables, it could be observed that the two materials are nickel based with nickel composition being 50.80% in Inconel 718 and 57.38 % in Hayne 282 while Chromium is 19.14% in Inconel 718 and 19.16% in Haynes 282. The corrosion behaviours of the two materials with different heat treatment conditions in alkaline and acidic environments are shown in Figures 1 to 5 and 6 to 10 respectively while the analyses of the Figures are presented in Tables 5, & 6 and Tables 4,& 7 respectively.

All the graphs in Figures 1 to 10 show the active – passive electrochemical behaviours of the two super-alloys with variation in slopes which are indicators of corrosion rates and degree of passivation as presented in the Table 4. The least corrosion rate was obtained in Haynes 282 sample with schedule B heat treatment. The behaviour is further corroborated with the Ecorr for this sample because the Ecorr is negative indicating heavy passivation in the acidic medium for this sample more than the other two samples. In Table 5 Inconel 718 samples show very low corrosion rates with similar passivation. Table 6 shows the corrosion characteristics of Haynes 282 in alkaline medium. Also, from Table 6, sample with heat treatment schedule B demonstrated the least corrosion rate and better passivation than others. However this in comparison with Table 5 shows that Inconel 718 sample had lower corrosion rate and better passivation in the alkaline medium than its Haynes 282 counterpart. From Table 7, Inconel 718 again exhibited lower corrosion rates than those of Haynes 282 in Table 4 in HNO3 solution.

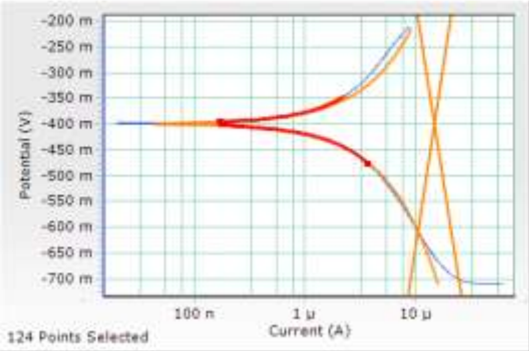


Fig.1:Electrochemical behaviour of control sample of Haynes 282 in 0.5M NaOH

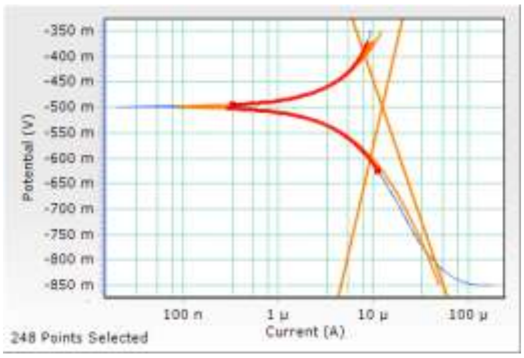


Fig. 2: Electrochemical behaviour of aged Haynes 282 A in 0.5M NaOH

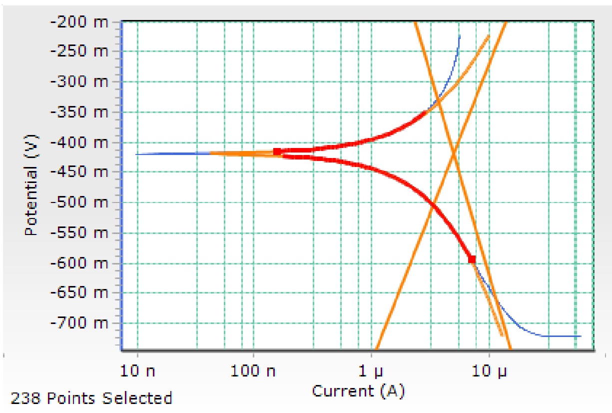


Fig. 3: Electrochemical behaviour of Haynes 282 B in 0.5M NaOH

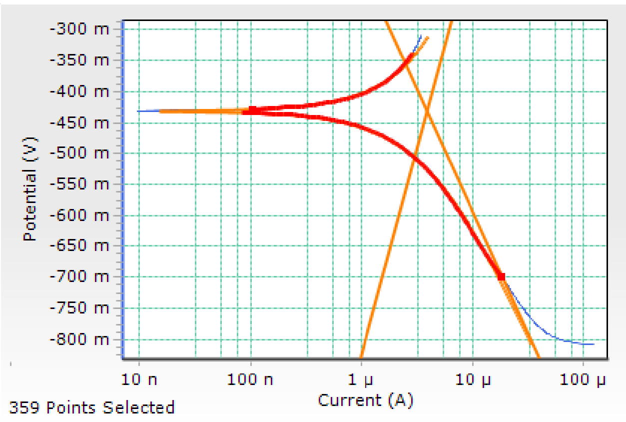


Fig.4:Electrochemical behaviour of Inconel 718 Control sample in 0.5M NaOH

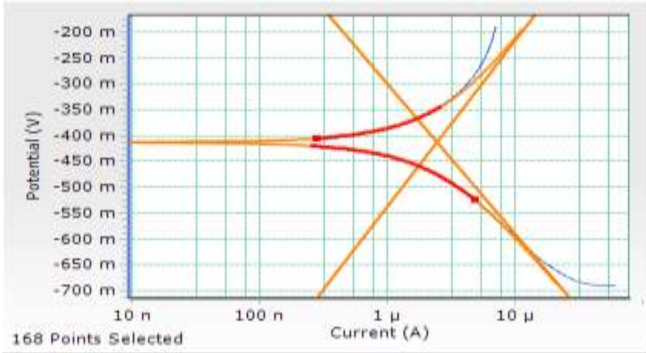


Fig.5: Electrochemical behaviour of Inconel 718 A in 0.5M.NaOH

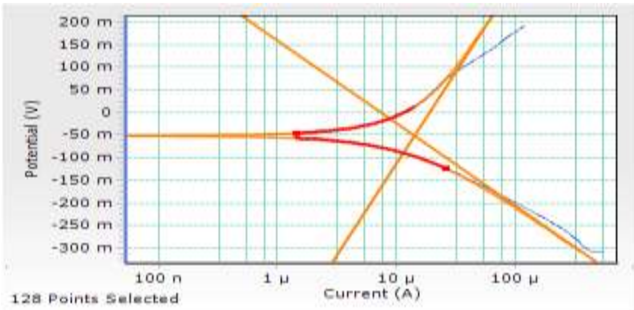


Fig.6: Electrochemical behaviour of Haynes 282 Control sample in 0.5M conc. Of HNO3

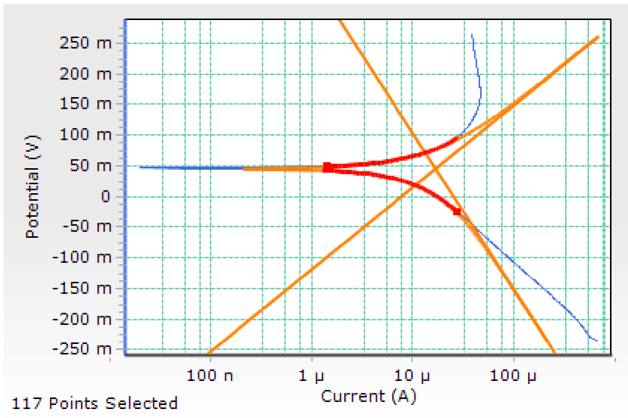


Fig.7: Corrosion rate of Haynes 282 A in 0.5M conc. Of HNO3

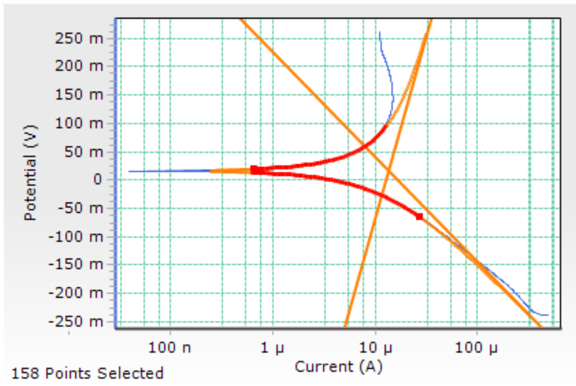


Fig.8: Electrochemical behaviour of Haynes 282 B in 0.5M conc. Of HNO3

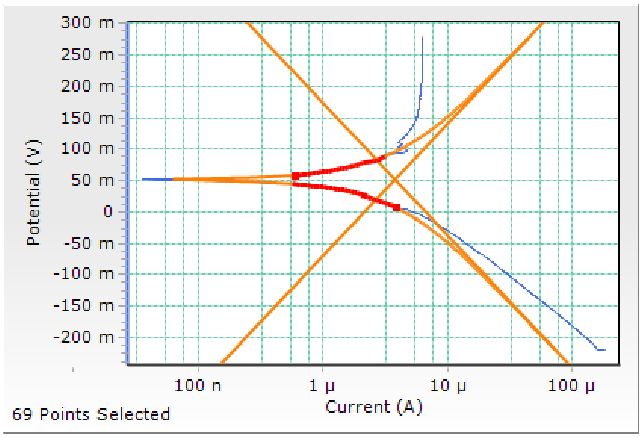


Fig.9: Electrochemical behaviour of Inconel 718 Control sample in 0.5M conc. of HNO3

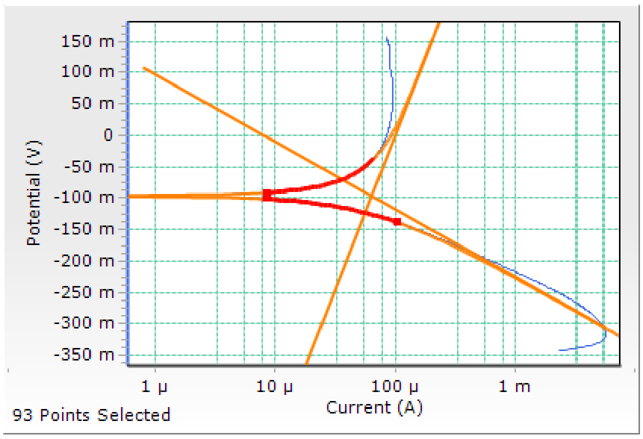


Fig.10: Electrochemical behaviour of Inconel 718 A in 0.5M conc. Of HNO3

Table 1. Heat Treatment Schedule used for Inconel 718 and Haynes 282 super-alloys

| S/N | Material coding | Solution treatment | Ageing Treatment 1 | Ageing Treatment 2 |
|---|---|---|---|---|
| 1 | Inconel 718 control | Nil | Nil | Nil |
| 2 | Inconel 718 A | 955°C/1Hour(HR)/Air cooled(AC) | 730°C/8Hours(HR)/Furnace cooled(FC) | 820°C/8Hour(sHR)/Air cooled(AC) |
| 3 | Haynes 282 control | Nil | Nil | Nil |
| 4 | Haynes 282 A | 1150°C/2H/AC | 1010°C/1HR/AC | 788°C/1HR/FC |
| 5 | Haynes 282 B | Nil | 1020°C/1HR/AC | 900°C/1HR/FC |

Table 2. Chemical analysis of Inconel 718

| Ti% | V% | V %+/_ | Cr% | Mn% | Mn% +/_ | Fe% +/- | Co% | Co% +/- |
|---|---|---|---|---|---|---|---|---|
| 0.0293 | 0.05905 | 0.01165 | 19.14 | 0.08135 | 0.0204 | 0.0498 | 0.2317 | 0.0204 |
| Ni% | Ni% +/- | Cu% | Cu% +/- | Zn% +/- | Nb% | Nb% +/- | Mo% | Mo% +/- |
| 50.80 | 0.06 | 1.2169 | 0.0193 | 0.0069 | 4.9463 | 0.0119 | 3.1018 | 0.0091 |

Table 3. Chemical Analysis of Haynes 282

| Ti% | V% | V% +/_ | Cr% | Mn% | Mn% +/_ | Fe% +/- | Co% | Co% +/- |
|---|---|---|---|---|---|---|---|---|
| 0.0558 | 0.0551 | 0.014 | 19.16 | 0.2594 | 0.0288 | 0.0158 | 29.7053 | 0.0523 |
| Ni% | Ni %+/- | Cu% | Cu% +/- | Zn% +/- | Nb% | Nb% +/- | Mo% | Mo% +/- |
| 57.38 | 0.09 | 2.7428 | 0.0413 | NIL | ND | NIL | 8.7457 | 0.0246 |

Table 4. Comparison of Corrosion Properties of Haynes 282 in Acidic medium

| Specimen | Corrosion rate (mmpy) | Ecorr (v) | E(I=0): (mmpy) | Icorr (µA) | Cathodic Beta | Anodic Beta (V) | Chi-Square | Fit Range(mV | Points in Fits |
|---|---|---|---|---|---|---|---|---|---|
| Haynes282 Control | 0.15998 | -0.39886 | -398.586 | -14.795 | 1.372 | 1.372 | 10.024 | -476 mV to -346.8 mV | 124 |
| Haynes282 A | 0.13461 | -0.49863 | -498.625 | -12.449 | 0.54599 | 0.811181 | 15.217 | -624.7 mV to -371.7 | 248 |
| Haynes 282 B | 0.05442 | -0.41877 | 665.644 | -5.032 | 0.665644 | 0.491925 | 0.84448 | -593.7 mV to -350.2 | 238 |

Table 5. Comparison of Corrosion Properties of Inconel 718 in Alkaline Environment

| Specimen | Corrosion rate (mmpy) | Ecorr (v) | E(I=0): (mmpy) | Icorr (µA) | Cathodic Beta (V) | Anodic Beta (V) | Chi-Square | Fit Range(mV) | Points in Fits |
|---|---|---|---|---|---|---|---|---|---|
| Inconel718 Control | 0.041657 | -0.43122 | -431.216 | -2.478 | 395.872 | 666.615 | 2.4923 | -699.2 mV to -337.6 | 359 |
| Inconel 718 A | 0.026799 | -0.41289 | -412.888 | -2.478 | 289.714 | 319.937 | 0.065047 | -523.2 mV to -343.5 | 168 |

Table 6. Comparison of Corrosion Properties of Haynes 282 in Alkaline Environment

| Specimen | Corrosion rate (mmpy) | Ecorr (mv) | E(I=0): (mmpy) | Icorr (µA) | Cathodic Beta | Anodic Beta (V) | Chi-Square | Fit Range(mV) | Points in Fits |
|---|---|---|---|---|---|---|---|---|---|
| Haynes282 Control | 0.15489 | -51.336 | -51.336 | -14.324 | 182.668 | 403.835 | 0.086908 | -123.6 to 13.1 | 128 |
| Haynes 282 A | 0.18196 | 45.181 | 45.181 | -16.828 | 254.339 | 133.59 | 2.6434 | -24.2 to 96.3 | 117 |
| Haynes282 B | 0.14577 | 16.234 | 16.234 | -13.481 | 184.625 | 641.662 | 0.54821 | -65.3 to 96.3 | 158 |

Table 7. Comparison of Corrosion Properties of Inconel 718 in Acidic Environment

| Specimen | Corrosion rate (mmpy) | Ecorr: (mv) | E(I=0): (mmpy) | Icorr (µA) | Cathodic Beta (V) | Anodic Beta (V) | Chi-Square | Fit Range(mV) | Points in Fits |
|---|---|---|---|---|---|---|---|---|---|
| Inconel718 Control | 0.041017 | 51.912 | 51.912 | -3.793 | 211.999 | 211.202 | 5.4492 | 7.6 to 88.6 | 69 |
| Inconel 718 A | 0.06873 | -96.577 | -96.577 | -63.566 | 107.906 | 491.258 | 0.15433 | -138 to -37.1 | 93 |

## 4 CONCLUSION

The chemical analyses of the two super-alloys used for this research work indicated that Haynes 282 contained 57.38% Nickel while Inconel had 50.80%.Also the chemical analyses showed that the chromium content of the two materials are nearly the same, 19.16% for Haynes 218 and 19.14% for Inconel 718. The corrosion test conducted revealed that the corrosion rate, break down potential(Ecorr) and the corrosion current(Icorr) of the aged Haynes 218 are 0.05mmpy, 0.198V, 5.032µA in 0.5 Molar HNO3 ; 0.145mmpy,16.23V,13.48 µA in 0;5 Molar NaOH while those of aged Inconel 718 are 0.068mmpy,96.5V,63.56 µA in the 0;5 Molar HNO3 and 0.026mmpy,0.41V,2.478 µA in the o.5 Molar NaOH respectively. These results showed that aged Haynes 218 has a higher corrosion resistance than aged Inconel 718 in the acidic medium, while the reverse was the case in the alkaline medium .However better corrosion passivation was obtained for the two super-alloys in HNO3 solution than in NaOH solution.

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