

Effects of Laser Glazed Surface on Pitting Corrosion of Nickel Alloy 718 in Acidic and Seawater Environments

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Abstract: Studies on the effects of laser glazed and unglazed sample surfaces on the pitting corrosion resistance of nickel alloy 718 have been carried out. Both sample surfaces of nickel alloy 718 were cut to different dimensions for pitting corrosion tests using potentiostatic polarization process. The alloy samples used for electrochemical testing were connected to a flexible wire joined by spot weld process. The alloy samples were coated with low viscous polymeric wax leaving the surface areas to be tested exposed to seawater and one mole concentration of hydrochloric acid environments. These samples which are working electrodes have electrical connection between reference electrode and counter electrode and the entire system were connected to computer with PSTrace software that stands as potentiostat. Pre and post morphological examination of the sample surfaces were done using confocal laser scanning microscopy and scanning electron microscopy respectively. The results of pitting corrosion tests showed that the glazed and unglazed alloy sample surfaces immersed in seawater environment suffered from pitting corrosion as a result of the presence of pit initiation sites developed during surface laser treatment and also the presence of some aggressive anions like Cl^- , SO_4^{2-} etc in the environment which migrated into the pits due to electrostatic balance and escalated pitting corrosion; while the samples of both surfaces immersed in 1M HCl suffered more from general corrosion. Post pitting corrosion examinations revealed that corrosion oxide films formed on the sample surfaces in acidic and alkaline environments were not protective as they flaked and exposed the sample surfaces to more corrosion attack.

Keywords: Corrosion, Pitting, Potentiostat, Laser, Glazed, Nickel, Environment, Morphological

1. Introduction

Nickel alloy 718 is a corrosion-resistant Ni-Cr-Fe alloy developed for use where high strength and corrosion resistant applications are highly required. These properties have seen the wide usage of this alloy in oil and gas sectors. Other areas considered to be of potential material use of this alloy are in nuclear power plants, gas turbines, aircraft engines and generally where strength and corrosion resistance are considered most in engineering applications. [1, 3] This alloy is used in the low strength (non-aged) or high strength (precipitation-hardened) with high creep stress rupture strength condition and it possess good weld ability without post welding crack [2]. Amongst the super alloys, Ni-based

super alloy is normally regarded as the king or workhorse of super alloys because 50% of the weight of an aero-engine turbine are made of the alloy [4]. Study carried out by Lv et al on super alloys indicated that super alloys constitute (22%) of failed materials, steel (42%) and corrosion accounts for (17%) of failure mode next to fatigue (52%) in aviation industry [5]. In general, corrosion is defined as the natural tendency at which material's compositional elements especially metals return to their most thermodynamically stable state [6]. Corrosion can also be defined as an electrochemical reaction constituting of two half-cell reactions: an anodic reaction releasing electrons and a

cathodic reaction consuming electrons. The sum of the electrode potentials of these two reactions is called the Cell Potential (E), and the electrochemical reaction occurs spontaneously if E is positive [7]. Corrosion resistance of stainless steels has made their wide applications in different areas of industries and households. Many researchers have studied the corrosion behaviour of these materials and came out with different findings that show high corrosion resistance of these materials in many environments [8]. Therefore, it is essential to study the corrosion properties of the Nickel alloy 718 fabricated by laser melted surfaces. Ni-based super alloys are used in different parts of gas turbine engines, namely, discs, high-pressure compressor blades, and combustion chambers due to their ability to operate at high temperature (close to 80% of the melting point) as well as resist creep, corrosion, and oxidation [9]. The additive manufacturing of these parts offers advantages such as weight reduction, adaptability to complex design Blade integrated disk (BLISK), improved build-to-fly ratio, and the elimination of unwanted joints, which helps in reducing corrosion [10, 11].

Austenitic stainless steel was found to have the ability to resist corrosion in acidic and sea water environments. This happens by its formation of protective oxide film of chromium oxide (Cr_2O_3) with a combination of (Fe, Cr) $_2\text{O}_3$ on the surface of the work as a protective layer against corrosion due to its low diffusion constants for oxygen and metal ions [12]. Nickel alloy 718 exhibits good pitting corrosion resistance in carbon dioxide, acetic acid and hydrogen sulphide environment. At relatively high temperature and pressure, alloy 718 corrosion rates are normally very low. At high percentage of acid, oxygen and sulphur concentrations, its corrosion rates become significant. However, the pitting resistance is considered only in the most severe environment encountered in the industry. Alloy 718 has pitting corrosion resistance equivalent to duplex stainless steels [13].

Figure 1 shows an example of nickel alloy 718 undergoing pitting corrosion in an aggressive environment with several pit sites on the surfaces of the alloy. Pitting corrosion is a localized form of corrosion that forms as a result of development of cavities on the surfaces of material experiencing this form of corrosion [14]. It is a very dangerous form of corrosion because it is very difficult to detect. The material under this form of corrosion might look strong on visual inspection but inside of the material could have been eaten up by this localised form of corrosion. A minor pit if not detected on time can lead to material failure. It is always very difficult to know the extent of damage by visual inspection; rather corrosion scientist uses special microscopic instruments to detect the extent of damage. Normally when this defect is noticed in engineering component, the affected part is usually replaced on time to avoid loss of human life and the entire engineering system. Pitting corrosion may assume different forms; sometimes the mouth of the pit may have a little open with large cavity within it or mouth open with semi-permeable membrane of corrosion products cover. This form of corrosion can assume

different shapes of either cup shaped or hemispherical shape [14]. In material that is prone to this form of corrosion, the point of initiation is usually at point of defect on the material. This area acts as anodic point while the surrounding areas act as cathodic points. With high chloride content in the environment and deficiency of oxygen, pits initiation and propagations trigger at very high rate. Cases of pitting corrosion are caused by localized surface variations arising from normal anode to localized cathode or normal cathode to localized anode. The aim of this work is to study the corrosion behaviour of laser glazed and unglazed surfaces using pitting corrosion polarization test in acidic and seawater environments where this alloy are normally exposed during engineering applications.



Figure 1. Nickel alloy 718 under pitting corrosion attack in an aggressive environment [3].

2. Methodology

The glazed and unglazed sample surfaces of alloy 718 were cleaned from dirt and contaminations before use for the experiment. The alloy sample used for electrochemical testing was connected to a flexible wire through spot welding process. The sample and the wire were coated with low viscous polymeric wax leaving an area to be exposed in seawater and one mole concentration of hydrochloric acid environments uncovered. This sample which stands as a working electrode was connected to computer with PSTrace software that acts as a potentiostat. A potentiodynamic corrosion polarization test is an electrochemical analyzer used to keep a set of electrode potential (ie the material we are investigating constant) as it delivers the current which is instantaneously needed to hold the potential constant. The potentiostat has three electrodes. (1) The working electrode, (W) ie alloys 718 to be investigated. (2) the counter electrode (C) made of platinum (3) the reference electrode (R) made of Ag/AgCl saturated calomel electrode. The reference electrode usually has an electrolytic connection to the working electrode through a salt bridge with a narrow tube near the working electrode.[15] Open circuit potential against time of the material and the pH of the solution were measured before polarization. Scan rate was 0.002m/s and polarization started at 2V against open circuit potential. Thereafter, cyclic voltammeter generated was exported using excel which is log of current density against log of electrode potential to determine the pitting corrosion behaviour of the

sample surface exposed in these environments of interest. Tests on the samples were done on the laser glazed and unglazed surfaces to determine corrosion susceptibility of the samples in the selected environments. The diagrams shown in figure 2 and figure 3 below are the potentiodynamic set up of the entire experiment.

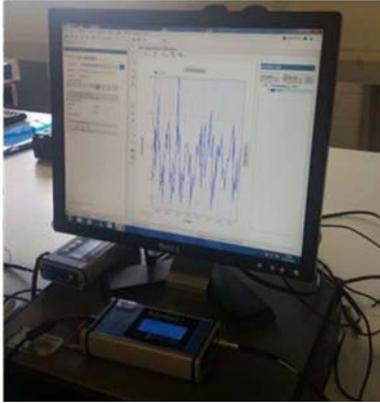


Figure 2. Experimental set-up using potentiostat [16].

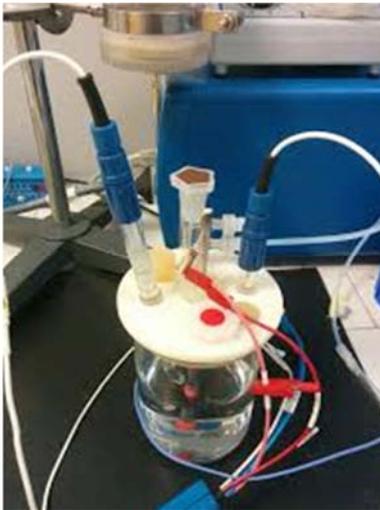


Figure 3. Experimental set-up using potentiostat [16].

3. Results and Discussions

The results of pitting corrosion tests for glazed and unglazed samples surfaces carried out in simulated one mole concentration of hydrochloric acid solution and seawater environments are presented in figures 4, 6, 7 and 8.

Figure 4 is the cyclic voltammetry results of pitting corrosion of alloy 718 surface glazed samples in seawater environment. The pitting corrosion behaviour of the sample showed a good Tafel extrapolation fitting at both anodic and cathodic lines during the initial stage of the corrosion process.

Further down the anodic region, there was an abrupt increase in corrosion current density with a near constant electrode potential. At about 2.00 current density value, the corrosion current became constant while electrode potential increased abruptly before a decrease in current density was observed. Down the line of the current density, a pronounced

initiation and development of metastable pits were observed by the formation of wavelike lines. Thereafter, stable pits began to form at an electrode potential value of about 0.66V. When compared with an unglazed sample which has stable pitting potential of about 1.00V; it shows that glazed sample is more susceptible to pitting corrosion than unglazed sample in seawater environment. This behaviour is attributed to the presence of some pit initiation sites on the surfaces of the glazed sample as shown in photomicrograph of laser confocal in figure 5 below. The surfaces have several scars and flaws that act as potential anodic initiation sites for development and propagation of pitting corrosion. Consequent upon the developments of these pits, the presence of some aggressive anions in seawater environment like Cl^- , SO_4^- etc migrated into the pits due to electrostatic balance and escalated pitting corrosion.

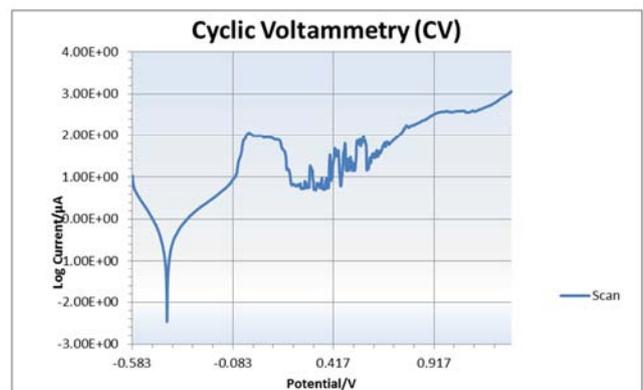


Figure 4. Pitting corrosion curves of glazed alloy 718 sample in seawater environment.

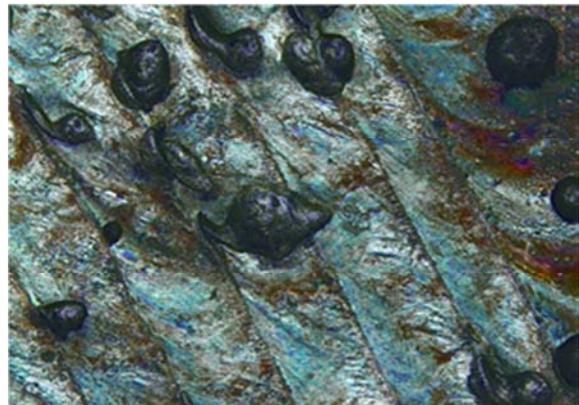


Figure 5. Photomicrograph of laser confocal of laser glazed surface of nickel alloy 718.

Figure 6 is the pitting corrosion polarisation curve of an unglazed surface used in seawater. Tafel extrapolation fitting for calculation of i_{corr} is possible. The current density value used in the corrosion process before metastable pits began to form was lower than the value used in sample with glazed surface in figure 4. More so, the anodic curve showed gradual increase in both corrosion current density and the electrode potential. Development of metastable pits started at an electrode potential value of about 0.304V to

1.00V before stable pits were established. This phenomenon is a clear indication that unglazed sample showed less susceptibility to pitting corrosion than glazed sample in seawater environment. It can also be established from anodic corrosion curve that metastable pits were not as pronounced as they are in figure 4.

What this means is that fewer number of pits were formed on the sample surface.

Figures 7 and 8 represent pitting corrosion curves of glazed and unglazed alloy 718 sample surfaces immersed in one molar concentration of hydrochloric acid solution respectively. In this environment, both samples suffered more to general corrosion than pitting corrosion. Unglazed sample suffered more corrosion attack than glazed sample as can be seen in anodic curves of the alloy. In the anodic curves of glazed and unglazed samples, initiation and development of metastable pits were not obvious when compared with anodic curves of alloy 718 in seawater environment. Post corrosion examination of sample surfaces revealed that samples immersed in this environment suffered more of general corrosion than pitting corrosion as the grain boundaries were attacked more than the grains in figure 9. Another important corrosion feature shown by these two samples is that their Tafel extrapolation fittings for the determination of i_{corr} cannot be performed on any of the polarisation curves and this makes it difficult to calculate the corrosion rate using linear fitting.

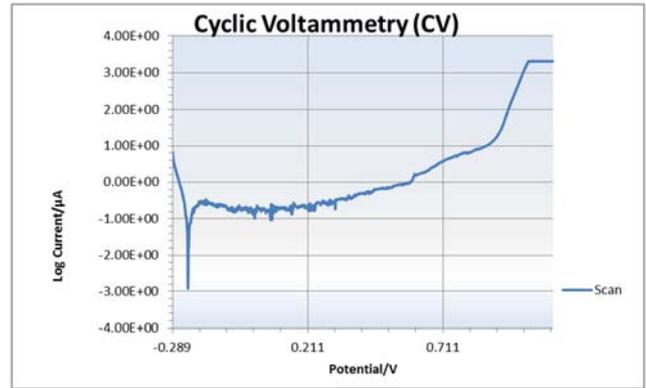


Figure 8. Pitting corrosion curves of unglazed alloy 718 samples in seawater environment.

The post corrosion examination of sample surfaces immersed in hydrochloric and seawater environments are presented in figures 9, 10 and 11 respectively. In figure 9, the surface revealed severe corrosion attack on the sample surfaces especially at the grain boundaries. Pitting corrosion was not pronounced on the sample surfaces; rather the sample was more prone to general corrosion. Consequent upon this, grain boundaries which are regions of inhomogeneity with high energy level acted as anodic regions in preference to grain regions that were cathodic when subjected to corrosion process. This behaviour is in agreement with potentiodynamic polarization curves of samples immersed in hydrochloric acid environment earlier discussed. Results of samples immersed in seawater environment in figure 10 revealed that the sample suffered from pitting corrosion attack with presence of pit initiation sites on surfaces of the laser confocal photomicrograph of the samples. Another important feature that was found from post corrosion examination of sample surfaces from scanning electron microscope is that the corrosion oxide films formed were not protective. The oxides are in fragments and partly covered some areas on the surface while bulks of the surfaces were not covered indicating that the oxides had flaked off from the surface as shown in figures 9 and 11 below. Figure 11 are the oxide films at a relatively high magnification. The oxides are in fragments and do not form protective oxide films on the surfaces of the sample.

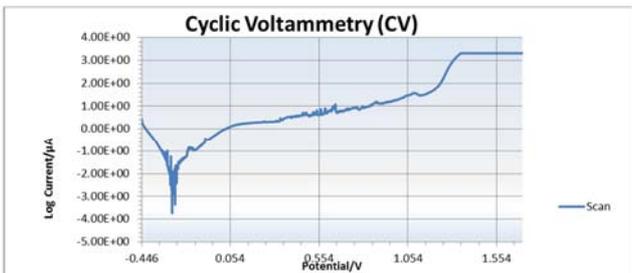


Figure 6. Pitting corrosion curves of unglazed alloy 718 sample in seawater environment.

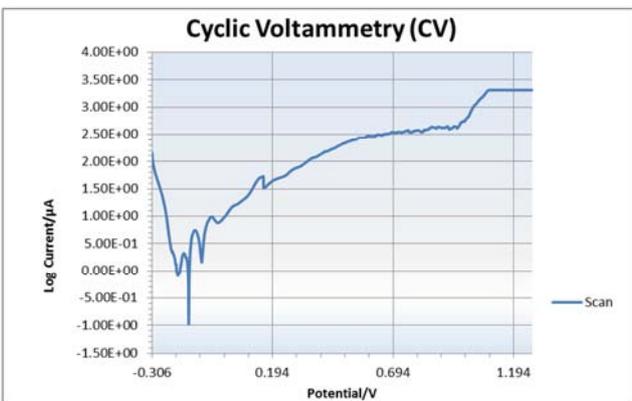


Figure 7 Pitting corrosion curves of glazed alloy 718 sample in 1M HCl environment.

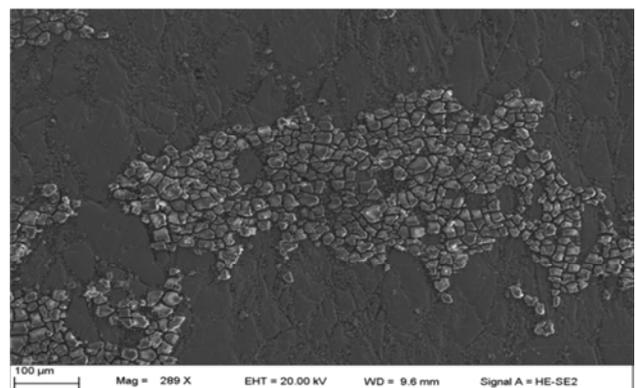


Figure 9. Post corrosion SEM of alloy 718 immersed in 1M HCl environment.

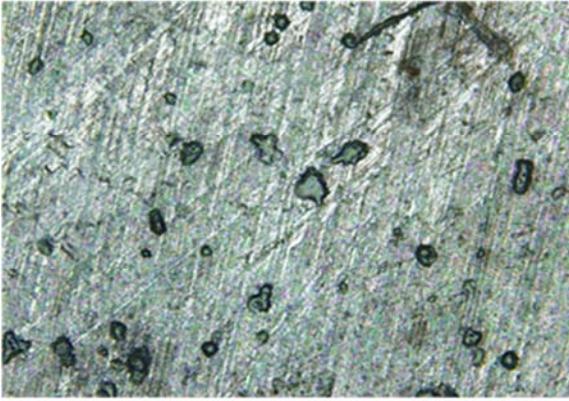


Figure 10. Post corrosion SEM of alloy 718 immersed in seawater environment.

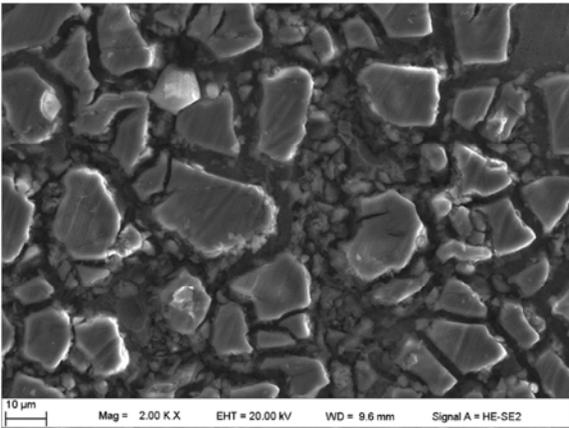


Figure 11. Scanning electron microscopy of post corrosion oxide films on the surface of alloy 718 at highmagnification.

4. Conclusion

Corrosion behaviour of nickel alloy 718 sample immersed in seawater environment suffered from pitting corrosion while the same sample immersed in 1M HCl environment suffered from severe general corrosion. Furthermore, it was observed that glazed sample has high susceptibility to pitting corrosion than unglazed sample in seawater environment. In 1M HCl environment, glazed sample showed less susceptibility to general corrosion than unglazed sample. The corrosion oxide films formed in these environments were found to be un-protective.

References

- [1] Julien Deleume, Jean-Marc Cloué, Eric Andrieu: Influence of δ phase precipitation on the stress corrosion cracking resistance of alloy 718 in PWR primary water. *Journal of Nuclear Materials* 382 (1) November 2008.
- [2] W. L. Kimmerl et al: Stress corrosion cracking of alloy 718 in pressurized-water-reactor primary water, 1562 Beeson St., Alliance, OH 44601 EPRI, 3412 Hill view Ave., Palo Alto, CA 94303, 2014.
- [3] A. Devaux et al: Gamma double prime precipitation kinetic in Alloy 718, *Journal of Materials Science and Engineering A486* (2008) 117–122.
- [4] <https://www.farinia.com/additive-manufacturing/3d-materials/inconel-718-aerospaceadditive-manufacturing> (accessed on 8 April 2020).
- [5] Lv, J. H.; Wang, W. Z.; Liu, S. W. Statistical Analysis of Failure Cases in Aerospace. *Int. Sch. Sci. Res. Innov.* 2018, 12, 497–501.
- [6] S. E. Ede, A text book on theory of corrosion & protection 1st edition, Obi press, Enugu Nigeria, 2012, 1, Pp 1-2.
- [7] El-Meligi, A.; Palatino, L. I. Effect of nanostructure on corrosion and corrosion resistance of materials. *Curr. Chem. Res.* 2012, 2, 47–56.
- [8] Ede, S. E, Effects of laser glazed surface on corrosion resistance of nickel alloy 718. A dissertation submitted to the University of Manchester for the award of MSc. in corrosion control Engineering, Faculty of Engineering and physical sciences September 2019.
- [9] Akca, E.; Gursel, A. A Review on Super alloys and IN718 Nickel-Based Inconel Super alloy. *Period. Eng. Nat. Sci.* 2015, 3, 15–27.
- [10] Thompson, M. K.; Moroni, G.; Vaneker, T.; Fadel, G.; Campbell, R. I.; Gibson, I.; Bernard, A.; Schulz, J.; Graf, P.; Ahuja, B.; et al. Design for Additive Manufacturing: Trends, opportunities, considerations, and constraints. *CIRP Ann.* 2016, 65, 737–760.
- [11] Gibson, I.; Rosen, D.; Stucker, B. Directed Energy Deposition Processes BT--Additive Manufacturing Technologies: 3D Printing, Rapid Prototyping, and Direct Digital Manufacturing. *Johns. Matthey Technol. Rev.* 2015, 59, 245–268.
- [12] CrtomirDonik and Aleksandra Kocijan: Comparison of the corrosion behaviour of austenitic stainless steel in seawater and in a 3.5%NaCl solution, 48 (6) 937 (2014).
- [13] JuriKolts: Alloy 718 for the oil and gas industry; Super alloy 718-metallurgy and applications. The minerals, metals & materials society, Conoco Inc. P. O. Box 1267 Ponca City, OK 74603, 1989. International NACE annual conference on pitting corrosion 2008.
- [14] Yuan Tian et al: International conference and ASM of The Minerals, Metals & Materials Society on rationalization of microstructure heterogeneity in INCONEL 718 builds made by the direct Laser additive manufacturing process 2014.
- [15] www.palmsens.com.
- [16] Scully J. C, The fundamentals of corrosion, 3rd edition, oxford pergamon press 1990.