

Determination of corrosion rate under various corrosive environments using image analysis.

Alexis Tejedor De León

Department of Materials and Metallurgy, Centro Regional de Veraguas, Universidad Tecnológica de Panamá,
Panamá

Alexis.tejedor@utp.ac.pa

Abstract In a humid tropical atmosphere, different corrosive media, to which a metal is exposed in working conditions and given the chemical, the rate of corrosion of the metal is not the same. In this sense, the objective of this study was to analyse the corrosion rate by analysing photographic images from welded metal-exposed to eight (8) different liquids environments with potential corrosive. The paper shows some numerical calculations based on changes in shades of grey or darkened images. This photograph was taken through a camera of 12.1 MP (Lumix Panasonic model FP1) of the metal samples surfaces immersed in various media for certain periods of time. Subsequently, each of the images obtained were edited to standard size 2000x2000 pixels (Microsoft® Office 2010) and brought into a grid (Scale 1:1 cm) in AutoCAD® 2008 wherein the surface was interpreted as a dark area of corrosion and its value determined. Finally it is concluded that the analysis of photographic images constitutes a basic tool for determining corrosion rate. In this study, the metals in contact with tap water from the public network presented a corrosion rate of $83.09 \pm 20.57 \text{mm}^2 \cdot \text{h}^{-1}$.

Key words: Corrosion rate, corrosive environments, image analysis, metallic corrosion.

Introduction

There are many structures that are buried in the ground, such as water pipes, gas, oil and oil products, electrical cables, anchors, poles, tanks, among others. In all, most of these structures are constructed of metallic materials, so that corrosion is a problem which is faced regularly (Calderón *et al*, 2005).

Therefore maintaining an industrial metallic installation costs can be reduced when using corrosion resistant metals (Carvalho *et al*, 2006). However, industrial systems, metals often have to be welded before there are being put into operation, which at times involves contact of metallic materials with gases, solids and liquids within operating system. Depending on the environment where the metals are exposed, thin films on the metal welded surface arise, this circumstance generates a highly corrosive condition, which is maximized in many cases in tropical humid environment (Marulanda, 2007).

For example, in certain occasions the corrosive attack is accelerated when system components reach the melting temperature of the film formed salts, which exerts a flux on the protective oxide layer, deteriorating by dissolution and transport of oxidizing species to the metal surface and the metal ion salt into the reservoir, thereby triggering the step of propagating or accelerated attack (Tristancho *et al*, 2007).

That is why appropriate inspection and monitoring activities, to detect and characterize the degradation of metals. Once degradation characterized by corrosion of a metal component, structural integrity and/or function may be evaluated and decisions may be taken, for the purposes of repairing or replacing the damaged component (Mendoza *et al*, 2009).

In Panama, do not have the expertise to analyse the progress of corrosion of metal parts exposed to different liquid media, as there are no publications that indicate the degree of metal's weldability and the resulting levels of corrosivity. Theory indicates that care must be taken to weld these steels, where the selection of the welding process and to use consumable part of performing a defect-free welds (Cortés *et al*, 2004).

The corrosion rate of a metal in a corrosive environment is usually assessed by performing weight loss trials. This technique is time consuming and does not allow obtaining an instantaneous corrosion rate (Valcare *et al*, 2004). This is why the aim of this project is to determine the feed rate of corrosion of metal welded surfaces in abutting

contact with various liquids in tropical environments, by images analysing. The corrosion feed rate was determined by analysing photographic images

Materials and Method.

Welding: The materials used in this research were those common to the metalworking industry in the region. Two metal parts (hypoeutectoid steel SAE 60xx) of dimensions 64x70x6.4mm were jointed by electric welding (220V and 125A) using commercial coated electrodes AWS E6011.

In total 8 samples of welded metals were used in this study. The weld beads have a width of 7 ± 0.1 mm and a length of 8.25 ± 1.09 mm is brought to an energy welding system was about $1.55 \text{KJ} \cdot \text{mm}^{-1}$. Each welded piece was sectioned transversely, manually, and the welded surface was subsequently sanded progressively until specular surface sanding. Each of the eight samples sanded was identified with consecutive Roman numerals (I to VIII).

Corrosive Liquid Environments: In the present research eight liquid solutions was used, namely: (i) caustic soda, (ii) hydrochloric acid, (iii) sea water, (iv) glucose, (v) mineral, (vi) tap water, (vii) river water and (viii) ethyl alcohol.

The initial volume of each corrosive liquid was placed into 100mL glass containers. Once metal samples were submerged into each eight liquid, the containers were sealed during the reaction time studied. Each of the eight metal containers containing the samples was placed in controlled conditions of temperature and humidity. $23.5 \pm 1^\circ\text{C}$ and $45 \pm 2\%$, respectively.

The cross section of the weld beads in each sample were photographed every two day, for seven consecutive days. To remove samples from the solutions was used a forceps devices. The sample was cleaned with a soft cloth before photographing.

Image Analysis: After the contact time the welded sample with the respective corrosive liquid, polished surface of each sample was placed on a microscope mark Zeiss model, KF2-ICS using the 10X objective. We used a 12.1-megapixel Panasonic Lumix camera, model FP1. The lens remained in 1X.

The welded joints were photographed before being submerged in the solutions, and subsequently every two days. Each of the images obtained were edited to standard size 2000x2000 pixels (Microsoft® Office 2010) and brought into a grid (Scale 1:1 cm) in AutoCAD® 2008. Any dark surfaces images were interpreted as corrosion surfaces. To each sample was determined by the increase in the dark surface photographed. The feed rate of corrosion ($\text{mm}^2 \cdot \text{h}^{-1}$) at the welded joint was calculated by dividing the area of the darkness area between the time of submerged in corrosive solution.

Results

As mentioned above, we used as liquid solutions, eight corrosive environments. The table below shows the results in the change in pH of the solutions during development of the research.

Table 1. Measurements of pH variability (initial, final) of each eight liquid solutions used in the corrosion studies.

<i>Sample</i>	<i>Solution</i>	<i>Conc.(v/v)</i>	<i>Initial pH</i>	<i>Final pH</i>
I	Caustic soda (CS)	75	12	13
II	Hydrochloric acid (HC)	75	4	4.5
III	Sea water (SW)	75	8.3	6
IV	Glucosa (GL)	75	5.4	4.5
V	Mineral water (MW)	100	7	5
VI	Tap water (TW)	100	6.7	4.5
VII	River water (RW)	100	7.1	6
VIII	Ethyl alcohol (EA)	96	6.2	5.5

Given the differences of the various behaviours observed in images obtained, the analysis of surface states obtained by manual photography was not simple, being therefore necessary to obtain a greater amount of information to determine the size of the surface "tainted" by effect of impairment and correlate the measured wear variables, and possibly corrosion parameters of the corresponding immersion tests.

For this purpose the images in "jpg" were inserted into a template at 1:1 cm square in Autocad®, for subsequent determination of darkened surface size in area units (mm²). In the figure below shows one of the images transported.

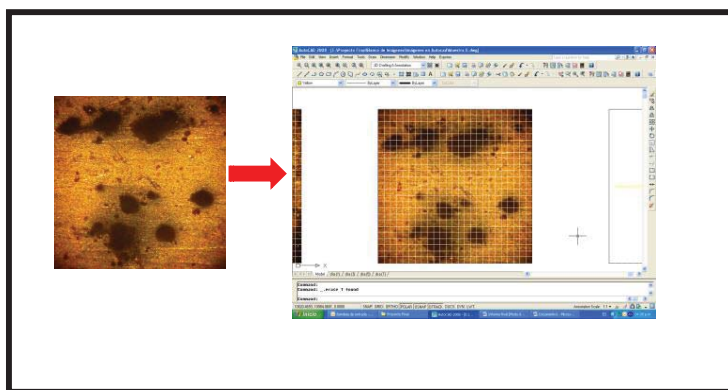


Figure 1. Image "jpg" transported to Autocad® for determining the size of the darkened surfaces.

Every 24 hours, the samples were removed from the respective solutions and their surfaces were photographed.

For each of the images captured and transported to Autocad®, we proceeded to determine the size of the darkened surfaces and the calculation of the corrosion rate, since their immersion times were recorded for each of the samples.

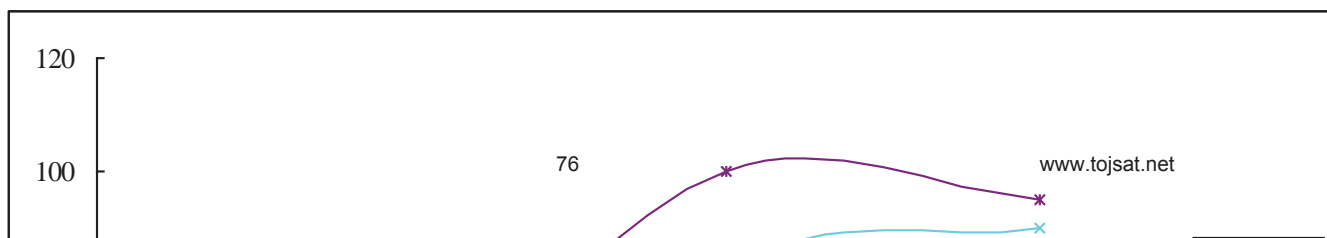
In the table below shows the average values such as the corroded surface and the corrosion rate of metal for each eight solutions studied.

Table 2. Values of the corroded surface and corrosion rate in welded metal surfaces for different liquids studied.

<i>Solution</i>	<i>Corroded surface (mm²)</i>	<i>Corrosion rate (mm²/h)</i>
CS	0	0
HC	1533±694	16.20±2.68
SW	7600±1202	23.08±2.24
GL	1233±613	11.460±1.04
MW	7033±5213	59.26±37.66
TW	8633±4582	83.10±20.57
RW	900±756	7.87±3.86
EA	133±125	1.04±0.85

To understand the behaviour of the corrosion rate of metal parts, the calculated data were plotted and the results are presented in Figure 2

As seen in the above table so as in the figure in question, the corrosion on metal surfaces welded differ significantly from one liquid environment to the other.



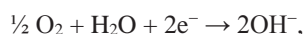
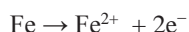
Corrosion rate, mm²*h⁻¹

Figure 2. Variation of the corrosion rate depending on the corrosive medium.

In our case, in particular, the corrosion rate seems to behave by the following pattern of aggressive corrosive (from high to low):



In the case of tap water it contains some salts; certain amount of dissolved oxygen and the presence of chloride ions, by the effect of its treatment sterilization as potable water, which results in the appearance of greater corroded surface by the effect of the oxidation reactions. Specifically, the half-reactions which occur are the oxidation of the iron is:



The relative importance of these two half-reactions of reduction is determined by the concentration of oxygen in solution and the pH [12], which as can be seen in Table 1, to this solution was studied in a reduction of the pH thereof.

Discussion

As seen in the table 1, it is verified that there were significant changes in the pH of the etching solutions. The medium pH variability appears to be associated with the corrosion products, due to a particular process. In this regard, in the caustic soda solution and the hydrochloric acid was an increase in the pH of the medium, unlike the other six solutions wherein the pH decreased.

In these latter substances, the fact that the pH has been decreased, this means in a more severe corrosion conditions, because the instability of the protective passive film on the metal surface as a results in the risk of

disappearing (Duffó *et al*, 2010)

Several studies have found that the main parameter that is taken as a criterion of corrosive aggressiveness of the solutions is the pH (Escoda *et al*, 2003). For acidic media, such as HCl our case, take into consideration possible oxidizing character. In this regard, studies on the behaviour of steel in the presence of acid pH solutions have shown that the steel undergoes a greater and more rapid deterioration due to the formation of soluble salts.

In this case, the action will depend on the acid concentration and the total amount thereof acting on the metal, since in some circumstances the weakening that is produced can end the total disintegration of the material (Vera *et al*, 2005)]

In terms of variability of pH corrosive environments, it has been shown that passive loses iron ions generating compounds and becoming extremely complex and it has been found that the iron oxidation rate depends on the composition and stability of the intermediary species, the pH and temperature, all these factors determine the type of species to be formed (Villaruel *et al*, 2007).

Given the features found on the aggressive behaviour of the tap water in the corrosion rate, it is necessary to recommend detailed studies to determine qualitatively and qualitatively the trend corrosive or scale (Trujillo *et al*, 2008) of this water

In the case of mineral water and sea water, the presence of dissolved salts increases the conductivity of the liquid medium, favouring also the charge transport in the solution.

This cargo is necessary for the process of corrosion is evidenced, for example, if the solution is slightly conductive accumulates excess positive charge, which would oppose to the formation of new positive ions Fe^{2+} and the corrosion is slowed (Heredia, 2011)], as was evident in the experiment carried out.

Although the literature refers to acidic solutions (HCl) are highly corrosive by nature, in our experience was not possible to determine, via photography image analysis.

This was due to the fact that the surface oxides formed were quickly dissolved by the acid solution in preventing their attachment to the metal surface.

However if it was verified that the corrosion was much more aggressive by the decrease in the metal section and by the change in the colour of the final solution.

Unlike what was observed in the other corrosive media employed in the case of hydrochloric acid solution and as mentioned earlier, there was no occurrence of hydrated ferric oxide brown on the metal surface. This is because in acid iron oxides are soluble, so that the Fe^{3+} cation is in solution form complexes with water and / or chloride ions, which provide an intense yellow colour in the solution after a couple of days.

In the solution containing sodium hydroxide is not observed significant corrosion of the metal. The decrease of the oxidizing ability of the dissolution due to the increased concentration of OH^- ions, since it implies a decrease in the oxygen reduction potential and / or water.

However, the literature refers to the need for a concentrated sodium hydroxide hot solution to the iron corrosion is observed more quickly (Marulanda *et al*, 2009).

Like any chemical reaction, the iron corrosion reaction depends on thermodynamic and kinetic factors, and due to the latter there is an increase of the reaction rate associated with increased temperature (García & Salinas, 1993).

Conclusions

Importantly, in this study were not characterized neither the corrosion products on the metallic surface nor the oxide volume formed, instead we determined the level of progress of the surface oxidation of welded metal pieces and immersed in different solutions liquid.

The photographic image analysis by determining the darkened surface area is a useful and acceptable accuracy tool to determine the corrosion rate of metal parts.

The rate of corrosion of steel hypoeutectoid surfaces joined via arc welding and submerged in different liquid media was evaluated according to the photographic images taken at a certain time interval.

A very good agreement was found between the results of the corrosion rate for the different media studied, yielding behaviour that conforms to the following pattern:

TW>MW>SW>HC>GL>RW>EA<CS

Acknowledgements

The UTP (Universidad Tecnológica de Panamá) for the financial support.

References

- Calderón, J.A.; Delgado, J.; Peñaranda, S. & Restrepo, A. (2005) Análisis estadístico de los factores que intervienen en la corrosión de tuberías enterradas. *Revista Facultad de Ingeniería*, no. 34, (pp. 23-34).
- Carvalho Silva, C.; Eufrásio Machado, J.P.S; Pereira Farias, J.; Cabral Sabral, A.V.; Batista Sant'Ana, H. & Lima Rodríguez, C.E.A (2006). Avaliação da corrosão do metal de solda de eletrodos revestidos AWS E309MoL-16 em meio contendo petróleo pesado. *Tecnologia em Metalurgia e Materiais*, vol. 2, no. 3, (pp. 37-42).
- Marulanda, J.L (2007). Evaluación de la corrosión por sales fundidas mediante técnicas electroquímicas del acero 2¼ Cr-1 Mo usado en calderas. *Scientia et Técnica*, vol. 13, no. 34, (pp. 451-456).
- Tristancho, J.; Vásquez, C. & Peña, D. (2007) Estudio de la corrosión en caliente de la aleación AISI-SAE 304H, mediante la técnica de espectroscopia de impedancia electroquímica (EIS). *Dyna, Rev. Fac. Nac. Minas*, vol. 74, no. 153, (pp. 119-124).
- Mendoza Schwartzman, M.M. de; Dutra Quinan, M.A.; Costa Campos, W.R. da & Lorenço Lima, L.I. (2009). Avaliação da suscetibilidade à corrosão sob tensão da ZAC do aço inoxidável AISI 316L em ambiente de reator nuclear PWR. *Soldagem & Inspeção*, vol. 14, no. 3, (pp. 228-237).
- Cortés, R.; Villanueva, J.; Ponce, E.; Rojas, M. & Rojas, E.(2004). Estudio de la soldabilidad y corrosión del acero inoxidable AISI 904L con los agentes utilizados en la lixiviación del cobre. *Revista Facultad de Ingeniería*, vol. 12, no. 2, (pp. 43-56).
- Valcarce, M.B.; Vásquez, M. & Sánchez, S.R. de (2004). Determinación de la velocidad de corrosión de latón de aluminio en agua potable, In: Congreso CONAMET/SAM, Viña del Mar, *Proceedings*, (pp. 1-6).
- Duffó, G.S.; Farina, S.B. & Schulz, F.M. (2010) Corrosión de materiales metálicos embebidos en hormigón., In: Congreso IBEROMET XI y X CONAMET/SAM, Viña del Mar, *Proceedings* (pp. 1-8).
- Escoda, L.; Lledó, M.; Suñol, J.J.; Roura, P. & Carda, J. (2003) Estudio sobre la resistencia química de baldosas cerámicas no-esmaltadas para pavimentos industriales. *Boletín de la Sociedad Española de Cerámica y Vidrio*, vol. 42, no. 2, (pp. 85-88).
- Vera, R.; Aplabaza, J. & Carvajal, A.M.(2005) Evaluación de recubrimientos superficiales en la corrosión del hormigón armado en ambientes industriales. *Revista de la Construcción*, vol. 4, no. 1; (pp. 13-18).
- Villarroel, M.; Vera, R.; Carvajal, A.M.; Vera, E. & Ortiz, C. (2007) Estudios de los productos de corrosión de acero embebido em hormigón en ambiente marino e industrial”, In: Congreso SAM/CONAMET 2007, San Nicolás, *Proceedings*, (pp. 646-651).
- Heredia Avalos, S. (2011) Experiencia sobre corrosión en metales de uso cotidiano, *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias*, vol. 8, (pp. 466-475).
- Trujillo, E. Martínez, V. & Flores, N.S. (2008) Auste del equilibrio químico del agua potable con tendencia corrosiva por dióxido de carbono. *Información Tecnológica*, vol.19, no. 6, (pp. 89-102).
- Marulanda, J.L.; Tristancho, J.L. & Cañas A. (2009) Protección contra la corrosión en sales fundidas de un acero Hot Rolled, en el Arango de temperaturas de 400°C -600°C, recubierto por rociado térmico con acero inoxidable 312. *Dyna, Rev. Fac. Nac. Minas*, vol. 76, no. 160, (pp. 229-235).
- Garcia, S. & Salinas, D. (1993) Conceptos teórico-prácticos de corrosión y protección catódica. *Química Nova*, vol. 16, no. 5, (pp. 463-469).