Microanalysis of new metallic surfaces to prevent the intergranular corrosion in stainless steels and improve the competitiveness in the metallic industry in the northwest of Mexico

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Abstract A microanalysis was made to evaluate the use of new metallic surfaces to prevent the presence of intergranular corrosion (IC) in stainless steels as SS304 steel. The SS304 steel was used by it low cost compared with other steels of 300 and 400 series, in an experimental process in clean and corrosive environments to compare in both atmospheres. This is to avoid the presence of IC in the metallic industry of the Mexicali city located in the northwest of Mexico, with the evaluated materials because this can generate galvanic cells that are part of the presence of intergranular corrosion, as usually occurs with the presence of chromium material in stainless steels. The analysis of the use of carbon materials mentioned, was made to the experimental development in the process of tempering steel SS304. The study was conducted from 2012 to 2013, comparing the summer and winter seasons for the manufacturing process mentioned and different levels of temperature, relative humidity and concentration of sulfides in addition to assessments of costs of using the materials proposed in the experimental operations. To make the new materials was used the chemical vapor deposition (CVD) and to evaluate the surface of the metals used in the experimentation, was utilized the Scanning Electron Microscopy (SEM).

Keywords. Microanalysis, Intergranular Corrosion, Competitiveness, Costs, Metallic industry.

1. INTRODUCTION

The occurrence of intergranular corrosion at grain boundaries in stainless steels as the SS304 steel, which was utilized for experimental testing of this investigation in the tempering processes that are widely used in the metallic industry, has generated a search for the application of materials not previously used in this type of stainless steels with experimental processes (Raymond C. et al, 2006). This is with the objective to reduce or eliminate kinetic process that generates this type of corrosion in these materials and some other. The evaluation of materials such as vanadium, titanium, tantalum and nobio mainly; are based on the costs of each material, and the integration process in stainless steels that is evaluated in this research and affinity with carbon to prevent chromium is attracted, to the grain boundaries and cause intergranular corrosion. We also conducted an analysis of the operation of the proposed materials associated with carbon in these type of steels. The binding of carbon with the proposed materials, it is helpful to avoid active zones generated in the grain boundaries that forms galvanic cells, due to the good diffusivity of carbon in steels of this type, which attracts the chrome to the grain boundaries, and appear as chromium depleted zones, and thereby reducing the corrosion resistance and toughness of these steels. For this reason was made this study, to look methods that can prevent the intergranular corrosion that are appropriate to save costs of materials as raw material and the manufactured products with materials evaluated as operating performance in construction activities where the SS304 steel are used. The main physicochemical property evaluated is the corrosion resistance in the summer and winter and in corrosive environments where this type of stainless steels where is applied in a metallic industry installed in the northwest of Mexico where is located the Mexicali city (López B. G., 2008).

1.1 The industry and the competitiveness

The industrial economy and competitiveness of businesses depend on sales of their products, value-added activities, from the reception activities of raw materials, manufacturing processes and operations shipment to customers. Currently by global competition, companies are forced to reduce their costs of fabrication of their products at a price lower than its competitors, with more efficient manufacturing processes and make experimental evaluations with different materials than the common materials used to save costs. The saving cost is the most important factor of the competitiveness. The competitiveness of an industry according to Porter, depends on the strategic choice and the ability of industry to innovate and improve (Porter, 1990). In another sense, the competitiveness is controllable, since this economic factor of companies also depends on developing their skills available and where to direct their resources. This is where the strategic management to the competitiveness plays a very important role for the organization. It is a dynamic term that should be understood in a systematic way. Their study suggests the need to ask about the determinants that generate their development in time and space, and their limits. The industrial plants are increasingly preparing for the manufacture of its products, but sometimes are not ready when additional costs are presented. Some variations in the economy of the industries such as the metallic industry, can occur. This causes a decrease in the levels of productivity and in
the economy of companies, also in reducing the reliability of the manufactured products and competitiveness. Sometimes, some industries reduce their number of employees or in a drastic situation may close. In the industrial sector we can find several investigations related to competitiveness and industry, such as the analysis of the effect of innovation on the relationship between new manufacturing methods and marketing strategies and competitiveness. Our main objective in the sense of competitiveness the manufacturing process in relation to costs and their components will approach (Sánchez C. 2010), to discuss their participation in the process of sustainable and competitive development in essence, allowing the company to improve the results of the competition, according to their own objectives. In the metal industry, the use of materials such as the stainless steel and in specially the SS304 steel, in its industrial operations, it is very important for good physicochemical properties such as malleability and ductility and high corrosion resistance.

1.2 Main operations in the metal industry
The metallurgy is the art of obtaining and processing of metal ores to produce metallic materials (Ramírez t. et al, 2002) to evaluate the fabrication of metallic alloys, quality control in manufacturing processes and sometimes the corrosion process are analyzed, which can occurs in these type of materials. The operations of the metallurgical industry may be simple or complex, according to the metallic minerals used or the type of production process. The metallurgical processes comprises the following two main stages: the first stage is the obtaining of metal containing natural mineral raw materials, and the second step is the use of manufacturing processes to separate these natural minerals. There are many companies in the metals industry, and in the Mexicali city are about 50% of the metallic industry or are associated with small industries which are suppliers of large companies of these industries (B. G. López et al, 2006). Another aspect is the process of refining and enrichment activities or purification to remove impurities that are running in the metal after some manufacturing operations, and also to prepare alloys. There are other treatments of metal to facilitate basic operations for the extraction of metals that are mentioned next:

a) Physical operations. This process is to make some activities with the crushing operation, grinding, filtration (pressure or vacuum), centrifugation, decantation, flotation, dissolution, distillation, drying and physical precipitation.
b) Chemical operations. These activities comprises operations as roasting, oxidation, reduction, hydrometallurgy and electrolysis, hydrolysis, leaching by acid-base reactions, precipitation chemistry, electrodeposition and cyanidation. May use different treatment methods depending on the manufactured product. One of the most common treatments is the process of metal ore, which is necessary to make the separation of waste materials (Jones A. et al, 2005). Typically, the metal of interest, mixed with other materials such as clay and silicate, and often is processed in order to obtain raw materials for the manufacturing processes of the metal industry. One of the most common methods is the float operation, which involves the crushing and mixed with water, oil and detergent. To make this process is necessary liquid soap foam generated with the help of different densities provided by the oil, and separate the required surface of the mineral particles. Also can be used, the flotation and the separation of ferromagnetic minerals, with the magnets for ore particles and leaving intact the manufacturing processes. Another method extracting metal ore, is formed with a mercury amalgam alloy with another metal or metals. This dissolve the silver and gold contained in the ore to form a liquid amalgam, which is easily separated from the rest. After the metal gold and silver are purified, mercury is removed by distillation processes (Fontana M. et al, 2008).

1.3 The atmospheric corrosion
Atmospheric corrosion (AC) occurs when levels of relative humidity and temperature are higher than 70% and 30 °C, and the concentrations of air pollutants such as sulfates exceed air quality standards (AQS) in Mexicali, regulated by the Environmental Protection Agency and US Secretariat of Environment and Natural Resources of Mexico. The SS304 steels used in the experimental process were affected by pollution agents principally the sulfurs, in indoors of the metallic industry where was made the investigation, generating the deterioration of surfaces of this type of steels by the presence of atmospheric corrosion. Variations of climatic factors of nature, added to the levels of air pollution resulting from sulfur contaminants, aggressive environments originated within this industry and caused atmospheric corrosion (Gustavo López Badilla et al, 2013).

1.4 The intergranular corrosion
Intergranular corrosion is a corrosive phenomenon that occurs in materials with high hardness as the SS304 steel, mainly. The IC consists of a steel decarburization due to carbon diffusion phenomenon where the deterioration in the grain boundary materials, is essentially in the carbon areas of the stainless steels evaluated, where this chemical element is found by the drag of chromium atoms process, generating losses in the property of the corrosion resistance (Raymond C. et al, 2006). This phenomenon is characteristic of the types of the SS, but can occur in other alloys of steels and other metallic materials used in the metallic industry in the Mexicali
city. In nickel alloys and austenitic stainless steels, where chromium is added to increase the corrosion resistance, the mechanism appears to be a type of IC with the formation of chromium carbide (Cr$_2$C$_2$). This is because chromium affinity for carbon, which is thermodynamically very high, and like carbon has good diffusivity through the steel, the chromium is drawn into the grain boundary at the edge, and this forms zones with low corrosion resistance in the stainless steels (Gerhardus et al, 2012). This process is usually associated with increased maintenance temperature of 450 °C to 850 °C in the production process, which is called sensitization and is usually the product of a poor heat treatment or welding. By creating chromium carbide and the process mentioned, small galvanic cells are created due to the potential difference between the edges and the rest of the grain, originating the localized galvanic corrosion in the grain boundaries as the IC (Husebv R. A. et al, 2007). Another effect related to IC is an attack like a knife cut, mainly when is used the niobium alloys with carbon steels such as the 347SS steels stabilized. Titanium and niobium and their carbides are dissolved in the stainless steel at high temperatures, and in some cooling cycles, no niobium carbide precipitates, and behaves as steel so as not stabilized chromium carbides are formed. However this usually only occurs in cycles of cooling and welding affecting only a thin zone of several millimeters wide at the weld zone itself, where steel structures can be attacked by this phenomenon and with the heat above 1060 °C can dissolve the chromium carbide and niobium and forms carbides with defects (Jones A. et al, 2005).

1.5 The H$_2$S as corrosive and toxic pollutant
The H$_2$S is an aggressive agent that promotes very fast the corrosion process in different types, including the IC, affecting to the quality and durability of the stainless steels. The H$_2$S acts as a contaminant in the inner zones of the plants of the metallic industry; and promotes the formation of sulfide thin films on surfaces of steel. Recent research (López B. G., 2008) show that two main sources generating H2S in the city of Mexicali, being the Cerro Prieto Geothermal industry and the traffic vehicle. This geothermic industry is located at 20 km south of the city of Mexicali, and is very important because it supplies electricity to the Mexicali city and their valley and cities of the southeastern of United States and San Luis Rio Colorado in Sonora. This chemical agent with variations of climatic factors, promotes the IC and causes the deterioration of the stainless steels evaluated in this study. The H$_2$S have a bad odor as rotten eggs and for this reason is easy to detect, even at low concentration of 10-30 ppb (parts per billion) in the atmosphere around the geothermal fields, but the government authorities can't make nothing to this, because this Cerro Prieto industry justify this pollution, when it supplies the electricity. The H$_2$S activity that generates the corrosion phenomena is evident in the following mathematical equation

$$\text{Fe} + \text{H}_2\text{S} \rightarrow \text{FeS} + \text{H}_2$$  \hspace{1cm} (1)

1.6 The chemical vapor deposition technique
This technique is a chemical process used to develop new solid metal materials, using it with the deposition of films on a metal surface to produce materials suitable for a specific activity. This is, such as a new material to prevent corrosion from exposure to this aggressive environments internal or external companies (Cai et al, 2005). The process is often used in the semiconductor industry to produce thin films, where a wafer (substrate) to one or more volatile precursors, which react and / or decompose on the substrate surface to produce the desired deposit is exposed. Frequently, volatile byproducts are also produced, or is removed by gas flow through the reaction chamber. The processes include steps monocrystalline material, polycrystalline, amorphous and epitaxial. For this investigation, was used the CVD technique to apply the materials hafnium, niobium, tantalum, tungsten, vanadium and zirconium; on the metal surface of the steels tested. With these experimental processes, was obtained a new material to avoid the IC in stainless steels (Kihira H et al, 2005).

2. MATERIALS AND METHODS
The presence of intergranular corrosion in the SS304 steel is a concern in those skilled in the metalworking industry in northwestern Mexico where is located the Mexicali city. This is because in the last 10 years the incidence of events were increased, and decrease the quality of the manufactured materials and reliability of products manufactured in this region of Mexico. The presence of air pollution as derivative of sulfurs, levels of climatic factors to 85% and 45 °C of relative humidity and temperature and the use of materials with carbon and chrome, generates very fast the IC. This is not detected in the manufactured processes in the metallic industry in Mexicali, until occur a mechanical failure in the use of the steels fabricated in this companies of Mexicali, in this city or others cities of Mexico. This steels are used in construction activities as buildings and bridges principally. This was made in accord to the ASTM (ASTM, 2008) and ISO 9223 (ISO 9223, 1992) standards.

2.1 Experimental process
The study was conducted in two stages:
1. Analysis of material costs. This was done to determine which of the new materials proposed for use in the
stainless steels analyzed, were the main material integrated to carbon to avoid the IC. In this step was made an investigation to determine costs of the chemical elements suggested above as metallic materials, to be experimented with the SS304 steel.

2. Microanalysis of kinetic generated in the intergranular corrosion process. This was made to determine the main material evaluating the costs too, can be integrated with carbon to avoid IC, as a new material. This was made with the SEM technique.

3. Operational Evaluation of new materials. It was developed based on the application of new materials on the metal surface of different steel samples with CVD technique.

3. RESULTS AND DISCUSSION

Cost analysis of various types of materials used, indicated to the vanadium as the main chemical element to be integrated with the carbon, for their low cost as shown in Table 1 and is the material that generated greater affinity to carbon as shown in Figure 1. In Table 1, the proposed material costs being related to carbon and prevent the transport of chromium to the grain boundaries that are observed in the figures of this study.

Table 1. Analysis of costs of materials proposed and affinity level with carbon in the SS304 steel

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Hafnium</td>
<td>500.35</td>
<td>635.50</td>
<td>890.43</td>
<td>30 %</td>
</tr>
<tr>
<td>Niobium</td>
<td>22.50</td>
<td>23.80</td>
<td>26.75</td>
<td>35 %</td>
</tr>
<tr>
<td>Tantalum</td>
<td>165.40</td>
<td>163.75</td>
<td>183.15</td>
<td>50 %</td>
</tr>
<tr>
<td>Titanium</td>
<td>2.90</td>
<td>3.15</td>
<td>3.50</td>
<td>80 %</td>
</tr>
<tr>
<td>Vanadium</td>
<td>13.20</td>
<td>14.20</td>
<td>15.90</td>
<td>85 %</td>
</tr>
<tr>
<td>Zirconium</td>
<td>8.95</td>
<td>9.15</td>
<td>10.10</td>
<td>50 %</td>
</tr>
</tbody>
</table>


The costs of materials and their affinity with the carbon influenced for testing and percentages affinity of each material to concentrate chromium in the central grain surfaces. As shown in Table 1, the material of lower cost was the titanium with an average of 3 dlls / lb (per pound) with an affinity of 80%, followed by zirconium 9 dlls / lb with an affinity of 50 % vanadium 14 dlls / lb with an affinity of 85%, with the Nobio 23dlls / lb with an affinity of 35%, the tantalum 180dlls / lb with an affinity of 50% and 650 hafnium dlls / lb 30% affinity. The concept of affinity materials with carbon indicated the pairing of each material with carbon and to show equal percentages at or below 50%, represented that should not alloyed such materials with steel SS304, because it does not get a profit on the physicochemical properties of SS 304. This was obtained, evaluations with analysis processes Density Functional Theory (PDT), as The program used for the simulation of binding observed in Table 2 with the carbon materials and the SS304 steel was used for the ADF program molecular modeling analyzes. Table 2 shows the analysis program and the ADF Density Functional Theory, which shows that the materials of tantalum, titanium and vanadium; monoclinic phases type are common in all materials and material change hafnium and zirconium Nobio presented; tetragonal phases are the following order of monoclinic, training materials were presented.

Table 2. Characterization of phases in the experimental processes of evaluated materials with the SS304 steel

<table>
<thead>
<tr>
<th>Material</th>
<th>Affinity percentages (%)</th>
<th>Change of phases</th>
<th>Physical parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hafnium</td>
<td>30 %</td>
<td>TPMP</td>
<td>a = 5.455, c = 5.145</td>
</tr>
<tr>
<td>Niobium</td>
<td>35 %</td>
<td>TPMP</td>
<td>a = 5.615, c = 5.325</td>
</tr>
<tr>
<td>Tantalum</td>
<td>50 %</td>
<td>MPTP</td>
<td>a = 5.785, b = 5.150, c = 5.360</td>
</tr>
<tr>
<td>Titanium</td>
<td>80 %</td>
<td>MPTP</td>
<td>a = 5.660, b = 5.235, c = 5.345</td>
</tr>
<tr>
<td>Vanadium</td>
<td>85%</td>
<td>MPTP</td>
<td>a = 5.365, b = 5.135, c = 5.275</td>
</tr>
<tr>
<td>Zirconium</td>
<td>50%</td>
<td>TPMP</td>
<td>a = 5.785, c = 5.565</td>
</tr>
</tbody>
</table>

Change of monoclinic phase (MP) to tetragonal phase (TP) = MPTP
Change of tetragonal phase (TP) to monoclinic phase (MP) = TPMP

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Microanalysis

3.1 intergranular corrosion

One of the ways to understand what happens in the process of intergranular corrosion is make the microanalysis with the SEM technique, with which it can be observed the developing of the corrosion kinetic of this phenomenon. In the research conducted, the manner shown in the materials deteriorate according to the seasons primarily evaluated in this study for summer and winter for being where the electrochemical corrosion is the type of corrosion that have the major damage affecting to the stainless steels as the SS304 steel evaluated.

![Figure 1](image)

Figure 1. SEM of the IC in SS surface of products manufactured in metal plant in Mexicali at: (a) one (b) three, (c) six and (d) twelve months.

3.2 Sensitization of steels by intergranular corrosion

This occurs by the precipitation of carbides in grain boundaries of a stainless steel or alloy, generating the steel or steel alloy that can be susceptible to intergranular corrosion and also to the intergranular stress corrosion and cracking. Certain alloys when exposed to a temperature characterized as a sensitizing temperature, may be susceptible to intergranular corrosion. In a corrosive atmosphere, the interfaces of sensitized grain of these alloys results become very reactive and occur very fast the intergranular corrosion. This is characterized by a localized in the grain boundaries with relatively a little corrosion attack in the grains but can appear in all of the surface of the stainless steels. This causes a decay of the alloy (the grains do not form properly) and are presented low corrosion resistance and hardness. Spoilage by this phenomenon is observed in figure 1, with a drastic fractures observed microanalysis a metal surface of a steel evaluated by the presence of intergranular corrosion. In Figure 1a, are presented small fractures, which deteriorate the material, whereas in Figure 1b, only appear certain cracks, but a large fracture appear of this section of the metallic surface area analyzed. In Figure 1c, are presented a larger fracture that is observed in the lower area of the metallic surface evaluated and finally Figure 1d shows a fracture, with an image represented by cracks in the deformed material. This is a small section of a piece of steel used to analyze in this study, which indicates that this situation must be addressed, otherwise, you cannot use these steels evaluated. With the SEM technique, fractures and cracks are not appreciated well and use these metal materials and disintegrated quickly and cause catastrophic events.
3.3 Process of transport of carbon and chromium

One factor of deteriorating steels evaluated is the occurrence of the transport process of carbon and chromium to the grain boundaries. This is one of the main aspects of intergranular corrosion generated in sometimes, with a drastic deterioration that causes loss in physicochemical properties of stainless steels. This can cause irreversible damage to the population and ecosystems when a catastrophic collapse of bridges or buildings accident is generated, due to loss of hardness of fabricated and analyzed in this research steels. This is shown in Figure 2, where the transport process of chromium carbide is directed to the grain boundary which generate very chromium depleted zones and thus a reduction in corrosion resistance can occur and being very prone to the phenomenon of corrosion quickly and easily in corrosive environments. Such environments are presented in industrial plants for the city of Mexicali, being an area where levels exceed air quality standards, mainly sulfates in the winter time by the greenhouse effect. This process of obtaining the micrograph was prepared in a period of 30 seconds per effected at a temperature of 450 °C, and adapting the MBE through a steel pipe directly to the area of measurement with a microscope at a magnification of 500X for I do not damage it. The microphotography is to detect the transport process and observed with the SEM technique.

![Figure 2. SEM analysis of Cr23C6 transport process to the grain boundary in Experimental evaluation of SS304 steel at 450 °C (2013).](image)

Figure 3 shows the adaptation for taking the photomicrographs of the transport process of Cr23C6 indicated in block form with an instrument of the company where the analysis was developed and not allowed the dissemination of their specialized measuring equipment:

![Figure 3. Block diagram of the measuring process of transport of chromium carbide in the oven at 450 °C (2013).](image)

In figure 3, was observed the furnace annealing process, where the SS304 was attached via SS310 tube, whose connection joins the oven is performed under the microscope indicated.
Figure 4. Microanalysis of the formation of galvanic cells in grain boundaries of SS304 steel with separation of (a) high level in the summer and (b) average in the winter of 2013.

Figure 4 shows the kinetics of the formation of galvanic cells in the grain boundaries, which shows that the greater the separation called high (a) level increased higher temperature to 1 °C was generated (up to 1.5 °C) additional the temperature generated in the annealing process and an average temperature level of up to 0.7 °C. In addition in the metallurgical process, was generated closer spacing and therefore less energy and the formation of a galvanic cell having a lesser effect on the generation of intergranular corrosion. This means that in the processes of SS304 steel, was presented a phenomenon diversity and different defects intergranular corrosion which led to the loss of hardness and corrosion resistance of such materials evaluated in different periods of the year as explained above. These SEM analysis were performed in a different deterioration analyzes company as shown below.

3.4 Forming alloys with SS304 steel
The coupling process of the materials was carried out with CVD technique mentioned above, where the required proof of all chemical elements proposed were developed to avoid intergranular corrosion, evaluating costs of materials, CVD process costs, costs manufacturing as competitive factors and functionality of the materials with the process of each element doped suggested. This is observed in the figure 5 where the chrome entrapment process shown in the central areas of the vanadium steel evaluated (figure 5a) and titanium (figure 5b) in the study period mentioned. This photomicrograph shows that the vanadium has better keeping association with chromium in the central zones of the steel and preventing intergranular corrosion.

Figure 5. SEM analysis stabilized steel SS304 alloy (a) vanadium and (b) titanium to prevent intergranular corrosion at 850 °C in furnace annealing process (2013).
Figure 5 shows a microanalysis of chromium carbide particles (Cr$_{23}$C$_6$), dispersed in the SS304 steel, with more grouping observed and small when the vanadium alloy is formed with (a), and more dispersed and a larger in the titanium alloy, in a central area of the grain. This means that a greater affinity with carbon vanadium occurs, as mentioned in previous studies (Patent Reference http://www.google.com/patents/US4822556). In contrast with the titanium alloy particles are formed Cr$_2$3C$_6$, a little scattered due to such a compound tends to be transported to a nearby grain boundary area, creating areas of the metal surface with chromium depletion levels and decreasing the corrosion resistance.

4. CONCLUSIONS
Types of steel in the metallic industry is to manufacture new products and processes to achieve better economic benefits that achieve greater competitiveness in industries of this type. This is because currently companies must reduce their operating costs and selling their products by the great competition in the world market. Based on this, materials such as SS304 stainless steel type having a wide variety of applications for processing easily and corrosion resistance, which is an essential part of industrial competitiveness are used to prevent to deterioration rapidly. The study was made from 2012 to 2013, which is presented to evaluate the competitiveness of companies in the metal industry in the city of Mexicali, located in northwest of Mexico, with analysis of the types of stainless steels used and the processes operation. This investigation are used to found a method of protection for the materials evaluated, even with good properties of corrosion resistance, that are affected by agents in aggressive environments such as acids containing sulfur derivative. This is generated air pollution in combination with higher levels at 80% relative humidity (RH), which damages the environment with a greater effect in the winter time, causing a negative effect with the rapid deterioration of steel as the SS304 evaluated in this study. This reduces the competitiveness of these businesses in this region of Mexico and sometimes affects that causes a decrease in the economy, causing health problems to workers and creating social problems.

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REFERENCES
Gerhardus H. Koch, Michiel P.H. Brongers, and Neil G. Thompson (NACE); Historic Congressional Study: “Corrosion Costs and Preventive Strategies in United States”; 9; Vol. 5; (1); ISSN 2007 – 0705; 2012
Gustavo López Badilla, Rosa Angélica Arreola Álvarez, Lluisa S. Martinez Valdez, Yuliana Mendieta R. Rodriguez, Mariela Garcia Rodriguez, Maria del Carmen Perez Marmolejo,Jose L. Rocha Crespo; “Corrosion of electronic devices of the electronics industry of Mexicali, B.C. Mexico influenced by H$_2$S Pollution”; Revista Nova Scienta; Vol. 5 N°1; 2013
Jones A., Humbert G., Lyon P.; ‘Brazing and soldering”; American and Metal Journal; Elsevier Publishing;: pp. 78-88; 2005
L. Veleva, B. Valdez, G. Lopez, L. Vargas and J. Flores; “Atmospheric corrosion of electro-electronics metals in urban desert simulated indoor environment”; Corrosion Engineering Science and Technology; 2008
López B.G.; Tesis de Doctorado; “Caracterización de la corrosión en materiales metálicos de la industria electrónica en Mexicali”, B.C., 2008
Ramírez T., Yescas J., Urias H.; “Ingeniería e Investigación en el mecanismo del fenómeno de corrosión intergranular”; Ed. Oceánica; 2002
Sánchez, C; Tesis de Doctorado; “Análisis de un modelo de competitividad aplicado a las comercializadoras de autos en Mexicali, Baja California, México.” Septiembre de 2010