Determining the Cause of Faults in the SAE 1018 Carbon Steel Used in Potable Water Pipelines by Means of Digital Image Processing

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In this work the reason of the cracks found in SAE 1018 carbon steel pipelines used for potable water supply is determined. In order to accomplish it, some techniques of microanalysis using X-rays (SEM: Scanning Electron Microscopy) over some samples of faulty and normal pipes as well as the Digital Image Processing (DIP) of its microphotographs captured by means of SEM, were used. The obtained results prove that the low quality of the raw material and the steel manufacturing process were the reason of the cracks observed in the SAE 1018 carbon steel pipelines.

Introduction

Carbon steel has many applications, among which is the pipelines manufacturing for transporting drinking water; however, damage caused by corrosion (1), mechanical or structural failures, produce significant losses both economic and infrastructure, besides harmful health effects when used for human consumption.

Study object investigation from a corrosion point of view, through the electrochemical response obtained by means of the Electrochemical Impedance Spectroscopy (2) (EIS) technique, gave as a result that the watery medium (potable water) is not the causing of cracks in the structure of the carbon steel pipelines; on the other hand, potable water pH, measured by employing a pH-meter Radelkis, is near to the neutrality (6.9), which evidence that this factor is not the causing of faults. By analyzing some system operating conditions, such as water temperature (environment), the pumping pressure, friction, among other parameters, it is concluded the low probability that the mechanical factor was the causing of pipes faults.

For all the above, it was decided to consider that the features of carbon steel manufacturing related to the presence of certain chemical elements, such as silicon, at concentrations greater than permitted, could constitute probable causes producing cracks in the structure of pipe material, besides the health damage.(3)

Silicon is used in steel industry as a component of silicon-steel alloys. For manufacturing steel, molten steel is deoxidized by adding small portions of silicon; the common steel contains less than 0.03% silicon. Silicon steel, which contains 2.5 to 4% silicon, is employed for making electrical transformer cores, since the alloy has low hysteresis. There exists a steel alloy, the Duriron, which contains 15% silicon and is hard, frail and corrosion resistant; the Duriron is used in industrial equipment in contact with corrosive chemicals. Silicon is also used in copper alloys, such as bronze and brass. (4)

Steels are classified into carbon steels, alloyed, stainless, for tooling, and ultra-resistant low alloy. Carbon steels contain different proportion of carbon and less than 1.65% manganese, 0.60% silicon, and 0.60% copper.

In many cases, carbon steels are coated with a zinc cover in order to increase their corrosion resistance, and they are called galvanized steels.

Alloy steels have vanadium and molybdenum, as well as greater quantities of manganese, silicon, and copper than carbon steels. Stainless steels have chromium and nickel, among other alloying elements. Tool steels contain wolfram (tungsten), molybdenum, and other alloying elements that give them larger hardness and durability. Ultra-resistant low alloy steels possess less quantity of alloying elements, and their high resistance is due to the special treatment they receive during their manufacturing. (5)

In this work, the faults of SAE 1018 carbon steel pipelines used for transporting drinking water have been studied from a structural point of view, with the aim of determine if the causes of such faults are due to the silicon presence in proportions out of normal. In order to accomplish it, some techniques of microanalysis using X-rays as well as the Digital Image Processing (DIP) of the microphotographs of the inner surface of the pipelines, taken by means of an Scanning Electron Microscope (SEM) PHILIPS brand XL30 TMP New Look model, were employed.

In this field, diverse research has been developed for studying faults in pipelines transporting fluids, standing out mostly hydrocarbons. It is known the use of the SEM for characterizing the carbon steel SAE 1018 that has suffered microbiological corrosion at Petróleos Mexicanos (PEMEX) (6) pipelines.

Also there exist antecedents about a research project leaded by the *Instituto Politécnico Nacional* (IPN), Mexico, in collaboration with the *Universidad Michoacana de San Nicolás de Hidalgo*, Morelia; the Instituto Tecnológico de Estudios Superiores de Monterrey (ITESM), and the *Russian Academy of Science* (PAH), with the objective of searching strategies to control and reduce damage and failures in mexican and russian pipeline systems; in this way, a new method based on the application of kinetic theory has been proposed to determine both the useful and service remainder life of the systems with an interdisciplinary approach using X-ray microanalysis, together with another set of techniques for obtaining results. (7)

Research works related to potable water have been focused on finding alternatives, environmentally friendly, for supplying the vital liquid for human consumption, as reported in (8), where it is expounds the production of an environmental good at

Chapala's Lake and the potable water supply to Guadalajara City, in Jalisco State, Mexico, through a simulation analysis using a networks model.

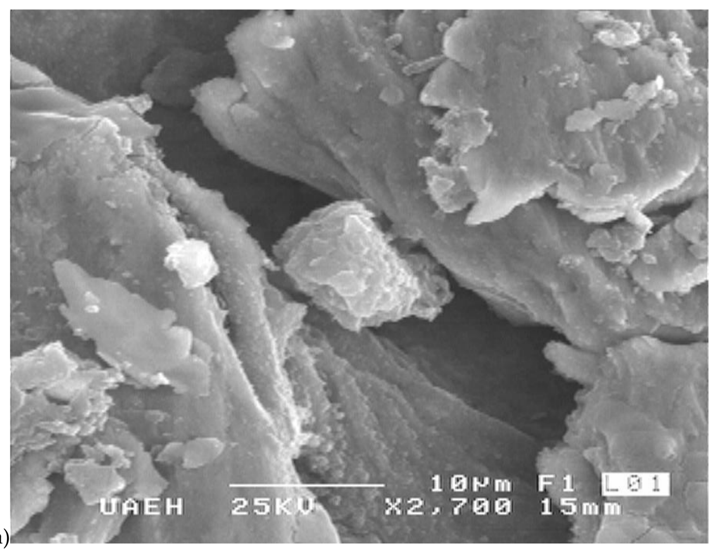
As reviewed in scientific-technical literature, no works have been found reporting the use of DIP through thresholding procedures to detect silicon presence in carbon steel pipelines, which allows investigate its effect on the structural faults in pipes made with this material and employed to transport potable water.

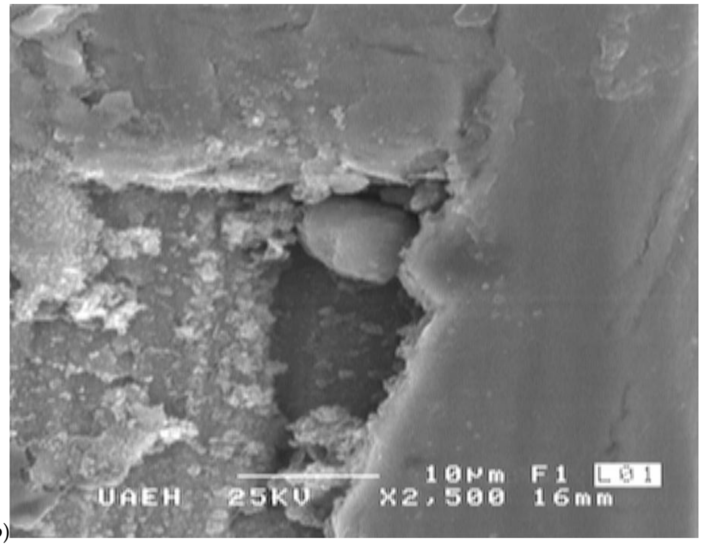
Method and Material

Three 2x2 cm samples of SAE 1018 carbon steel pipelines both faulty and normal were studied through SEM PHILIPS brand XL30 TMP New Look model, coupled to a Wavelength Dispersive Spectrometer (WDS) using crystals. (9)

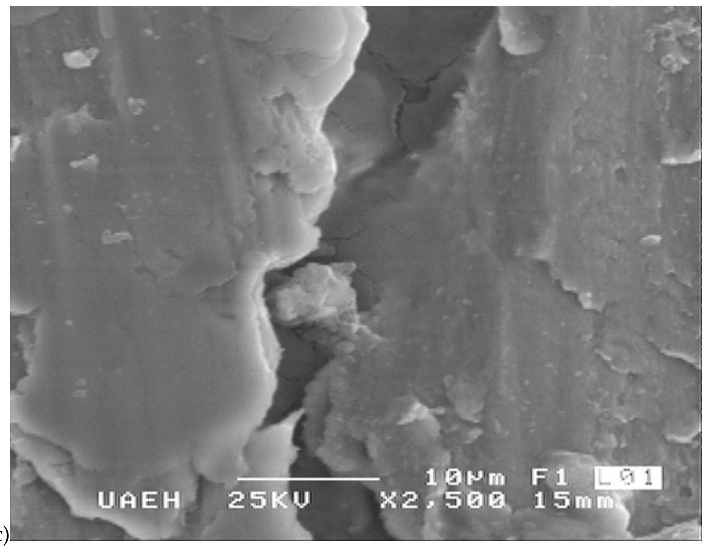
Images taken from test tubes with damaged material (Figures 1(a), 1(b), 1(c)) were analyzed by using SEM, described above, to determine the silicon concentration present in the carbon steel constituting the pipes; the principle of determination of elemental analysis through X-ray is applied to the samples subjected to electron bombardment, which allows to identify the elements present and establish their concentration. As observed, this chemical element is manifested in the material as white color inclusions, with irregular edges, deposited into overlapping layers at different levels, in a similar way to how the atheroma's are deposited inside the human beins, which finally produce the atherosclerosis.

(a)

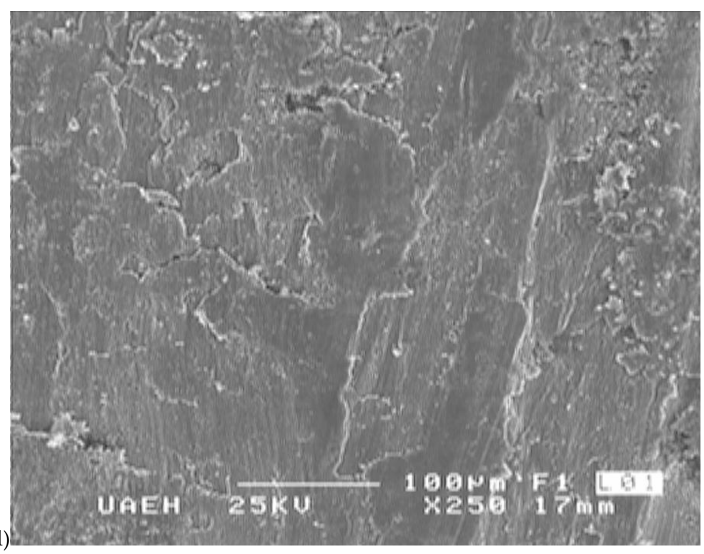




(b)



(c)



(d)

Figure 1. (a) (b) (c) Microphotographs, taken by SEM, of three samples from inside the SAE 1018 carbon steel pipes with damage; d) Idem for a non-damaged sample.

The analysis of images (a), (b) and (c) in Figure 1 captured from the faulty samples, and of image (d) obtained from the normal sample, is accomplished employing a thresholding procedure to extract (to segment) the image's lightest regions that indicate silicon presence, for the purpose of quantifying the percent of the area occupied by this element, regarding the whole sample area.(10) If the image contains no silicon signs, then the segmented area will be practically equal to zero, as shown in Figure 1(d).

Since by several factors the silicon inclusions can appear along time in a random way, inclusion may occur at several levels overlapped among themselves, as observed in Figures 1(a), 1(b) and 1(c).

Results and Comments

Table I shows the result obtained by analyzing the images of damaged samples captured by means of SEM and the corresponding characterization by X-ray microanalysis, of the average of each of the elements constituting the alloy expressed in weight percent.

TABLE I. Chemical composition of the SAE 1018 carbon steel with cracks in its surface.

Element	% in weight
Iron (Fe)	79
Carbon (C)	0.15
Zinc (Zn)	5
Silicon (Si)	15
Manganese (Mn)	0.70

Comparing the silicon concentration present in the damaged carbon steel samples, it can be observed that is much higher than that reported in the literature for this type of steel. (11) This irregular silicon concentration probably is related to the homogenization time inherent to the material.

Table II presents the average results obtained from the characterization of the SAE 1018 carbon steel samples without damages in the outer surface, through X-ray microanalysis.

TABLE II. Chemical composition of the SAE 1018 carbon steel without damage in surface.

Element	% in weight
Iron (Fe)	93.6
Carbon (C)	0.15
Zinc (Zn)	5
Silicon (Si)	0.35
Manganese (Mn)	0.70

The samples without damages in the material, exhibit an average chemical composition of the elements conforming the alloy, within the ranges expressed in weight percent established for each element and which are reported in the Mexican norm NMX-B-324-2006 and international norms SAE-J403-2000 and ASTM-A-510-2003 for this type of carbon steel, indicating that the required quality specifications are fulfilled.

To continue, the processed images of the three samples of damaged pipelines (Figures 2, 3 and 4) and of the sample of undamaged pipeline (Figure 5) are shown. In order to introduce no errors into subsequent calculations, that would be caused by the presence of white characters superimposed on the original microphotographs detailing the parameters with which were captured, the images being analyzed have been reduced in size by a cut made at higher level of such characters; these images have been called cropped images.

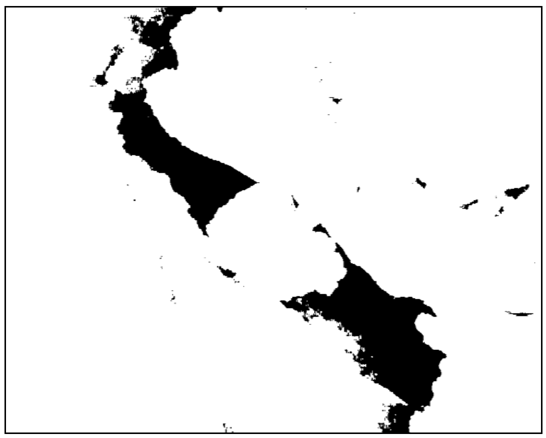


Figure 2. Processed microphotographs of the sample 1 inside the damaged SAE 1018 carbon steel pipe.

Figure 3. Processed microphotographs of the sample 2 inside the damaged SAE 1018 carbon steel pipe.

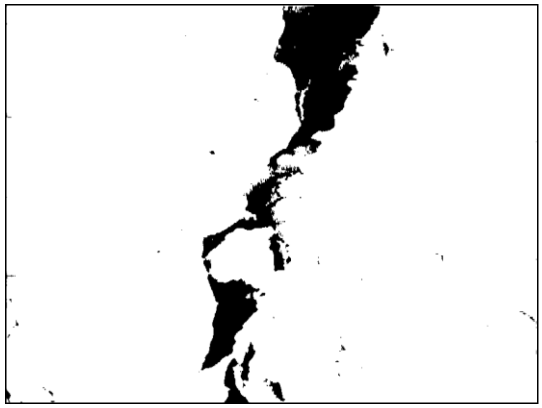


Figure 4. Processed microphotographs of the sample 3 inside the damaged SAE 1018 carbon steel pipe.

Figure 5. Processed microphotographs of the undamaged sample inside the SAE 1018 carbon steel pipe.

It is important to note that the measurements on the microphotographs have been made on the basis of the area in pixels of the areas targeted, without taking into account the eventual thickening of the inclusions of silicon that with the time normally takes place in the interior of the pipes.

By employing DIP, according to the scale of the captured digital microphotographs of 10 μm equivalent to 5.25 cm -measured on a screen with a space resolution of 96 pixels/in-, it is calculated that the space resolution of the microphotographs is 20 pixels/micron (0.05 micron/pixels). The average width of the cropped images is 48.6 microns, equivalent to 972 pixels wide. The average height of the cropped images is 32μm, equivalent to 640 pixels high. These give 622080 pixels of maximum whole area, equivalent to 1555 μm. However, the total number of pixels corresponding to each cropped image was measured accurately and is shown in Table III.

The percent occupied by the inclusions of the three images damaged is 92.30%, which is significant. In the three samples of pipes sound without inclusions of silicon (Figure 5), the percent occupied by the silicon is 0.16%, which is negligible. The results of the analysis of the images are tabulated in Table 3.

TABLE III. Results of measurements of the area with silicon inclusions.

Number	1	2	3	4
Type	damaged	damaged	damaged	Non-damaged
Size (px)	534, 612	532, 208	536, 703	529, 840
Area without inclusions (black px)	47,909	37,350	38, 099	528, 942
Number of independent inclusions	37	61	86	132
Inclusions area (white px)	486,703	494,858	498,604	898
Percent of total (%)	91.03	92.98	92.90	0.17

In the samples of the pipes damaged notes that the inclusions are distributed evenly on the inside of the pipe, which shows that the problem is not possible or casual, but that has been created by the structural characteristics typical of material.

Conclusions

In the evaluation of pipes of carbon steel used for the supply of potable water are detected structural problems in the SAE 1018 carbon steel, with which were manufactured the pipes, which is caused by the inclusions inside due to the high concentration of silicon that originates cracks and faults in material.

Through the image thresholding technique, to extract (to segment) the image's clearest regions denoting silicon presence, the percent of the area occupied by this element, regarding the whole sample area, has been quantified. It is shown that the presence of high concentration of silicon in the used SAE 1018 carbon steel pipelines is the cause of faults and cracks.

Acknowledgments

This work can be maked by financial support from project PROMEP UAEH-PTC-455: Monitoring System to Process in Chemical Industry.

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