



Effect of Thermal Cycling on Corrosion Rate of Carbon Steel (0.4%C), Water Cooled

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Research Article

Abstract

The effect of thermal cycling was carried out on steel bars (0.4 %C). A single run was performed at a lower temperature of 32°C and an upper temperature of 500°C cooled in water and seawater. For several numbers of cycles up to 30 cycles for an accurate determination of heating and cooling times. The effect of thermal cycling on the corrosion rate was evaluated. The effect of thermal cycling on the following properties was evaluated the corrosion rate. The comparison between the effect of thermal cycling on carbon steel (0.4% C) seawater cooled (previous results, sea-water cooled [1]) and the effect of thermal cycling on carbon steel (0.4 C %) (in this manuscript, water-cooled) has been studied. From the obtained test results (previous and in this paper, it was found that the type of corrosion is uniform, the corrosion rate of the first stage gradually increases with the number of thermal cycling up to 15 cycles, then it takes steady-state up to 30 cycles. It was found that the rate of corrosion (previous results, seawater cooled) is more than (the results in this paper, water-cooled).

Keywords: Thermal Cycling, Corrosion Rate, Heat Treatment Hardening, Carbon Steel, Sea water-cooled, water-cooled.

1. Introduction

Plain carbon steels are emerging as the backbone structural materials in high-temperature applications such as spray towers turbine engines, missiles, etc. Carbon steels have many advantages, high strength, and ductile materials and very easy to alloyed with other elements, etc. On the other hand, its disadvantages are the high ability to corrosion. So, a lot of researches has been studied corrosion mechanisms through which a better understanding is obtained of the causes of corrosion and the available means for preventing or minimizing resulting damage. Many factors have a great influence on corrosion

rate, environments, metallurgical factors, the effect of stress. A tendency of new cast austenitic-ferritic steels to stress corrosion cracking have been investigated in different aggressive environments to determine the regions of their most efficient application studied by Halyna Chumalo [2]. While C.P. Atkins and J.D. Scantlebury et. al. [3] studied the activity coefficient of sodium chloride in a simulated pore solution environment. S.H. Zhang, S.B. Lyon, et. al. [4] investigated the retention of passivity on iron after several months' atmospheric exposure.

Shin-ichi Komazaki et. al. [5] using six different plates of steel. Slow strain rate tensile test and thermal disruption spectroscopic analysis were applied to specimens subjected to wet-dry cyclic corrosion tests in a NaCl solution. Hideki Katayama, et al [6] was conducted the corrosion simulation in a chamber to carbon steels in an atmospheric environment by controlling the environmental factors such as temperature, relative humidity, and the temperature of carbon steels. Akira Tahara and Tadashi Shinohara, et al [7]. They found that there are two kinds of corrosion patterns were distinguished, uniform corrosion and local corrosion and the addition of Cu, Ni, and Cr changed the form of the corroded surface from the uniform corrosion to the combined pattern (uniform corrosion + local corrosion) While M. Yamashita, et al., [8] studied the initial rust formation process on carbon steel under Na₂SO₄ and NaCl solution films with wet/dry cycles using synchrotron radiation X-rays. Robert E. Melchers, et. al. [9] reported that the corrosion loss vs. time behavior is initially highly non-linear and then almost linear until corrosion product formation begins to control the rate of corrosion. On the other hand, mathematical modeling was carried out by Hiroshi Kihira, et. al. [10] to corrosion prediction for weathering steels.

2. Iron-Carbon Equilibrium Diagram

A study of the constitution and structure of all steels and irons must first start with the Iron-Carbon Equilibrium Diagram, the Iron- Carbon Constitutional Diagram should extend from 100 percent Iron to 100 percent cementite (6.67C%) [11-15], the plain carbon steels (0.4%C), water-cooled were used, shown in Fig.2.1.

3. Experimental Work

3.1 Materials

In this work hypo-eutectoid carbon steel (0.4% C) has been used as their chemical composition are given in Table 1.

Table I. Chemical composition of the used sample [1]

Carbon, C	0.40 %
Iron, Fe	98.51 - 98.98 %
Manganese, Mn	0.60 - 0.90 %
Phosphorous, P	≤ 0.040 %
Sulfur, S	≤ 0.050 %

3.2 Thermal cycled experiments

Thermal cycled experiments were conducted:

To study the effect of thermal cycling [10, 20, and 30 times] on the corrosion rate, water-cooled.

The thermal cycling was carried out in the Material Science Laboratory at *The Bright Star University*, the details of the furnace are: [Gallenkamp, Cat. No. (FSW - 670 - 010 J), APP. No. (7B9714 B)].England, S302AU. For this furnace, the heating and cooling rate was recorded as shown in Fig.3.1 and Fig.3.2 respectively [1].□

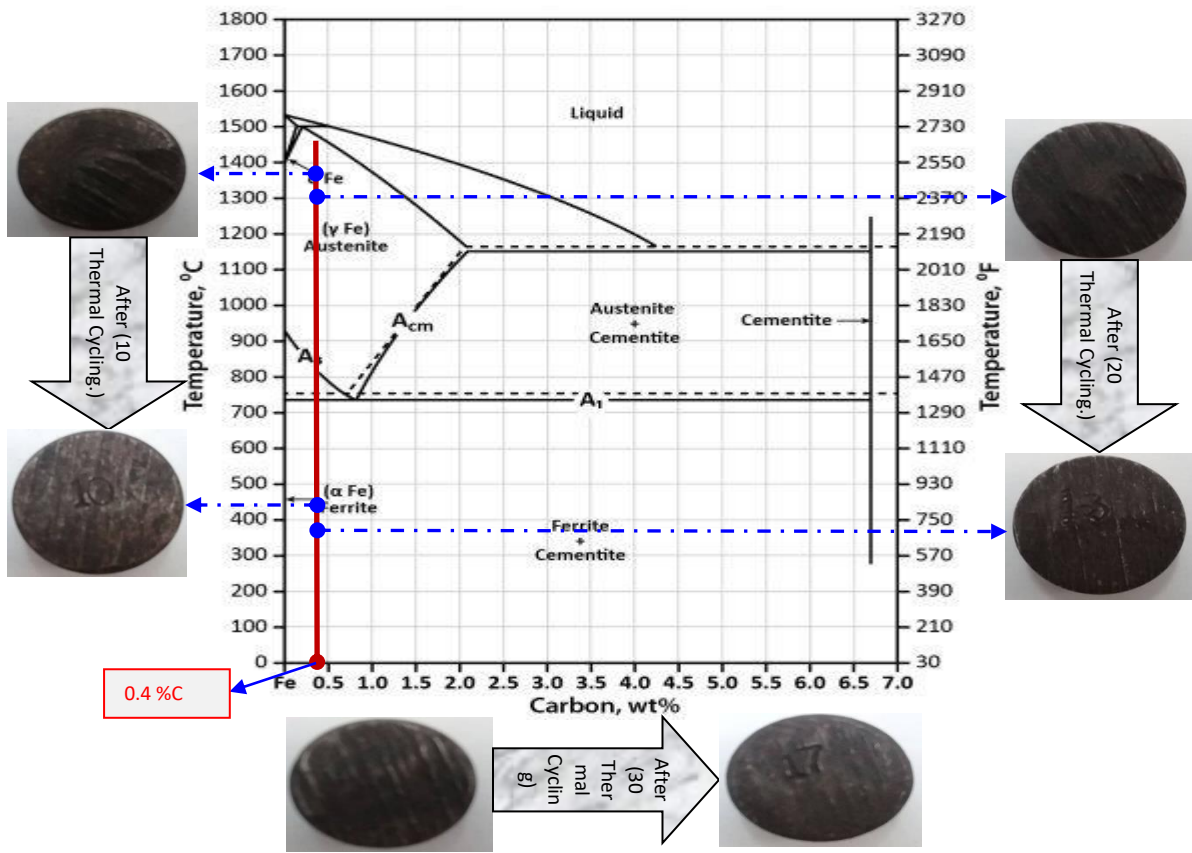


Fig.2.1. Iron-Carbon Equilibrium Diagram

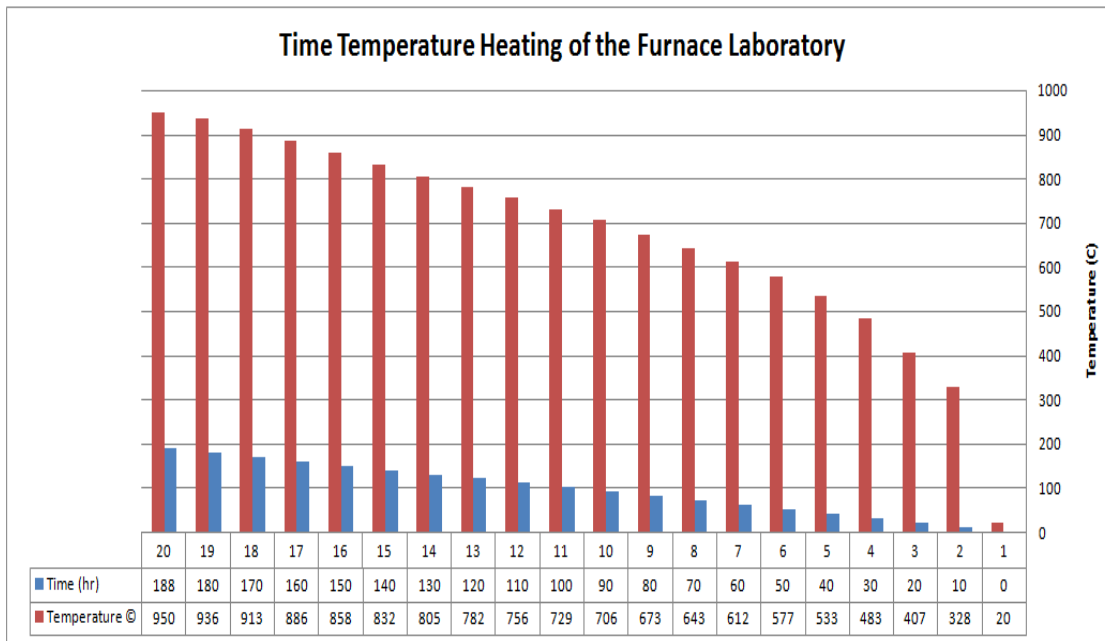


Fig.3.1. The furnace heating rate [1]

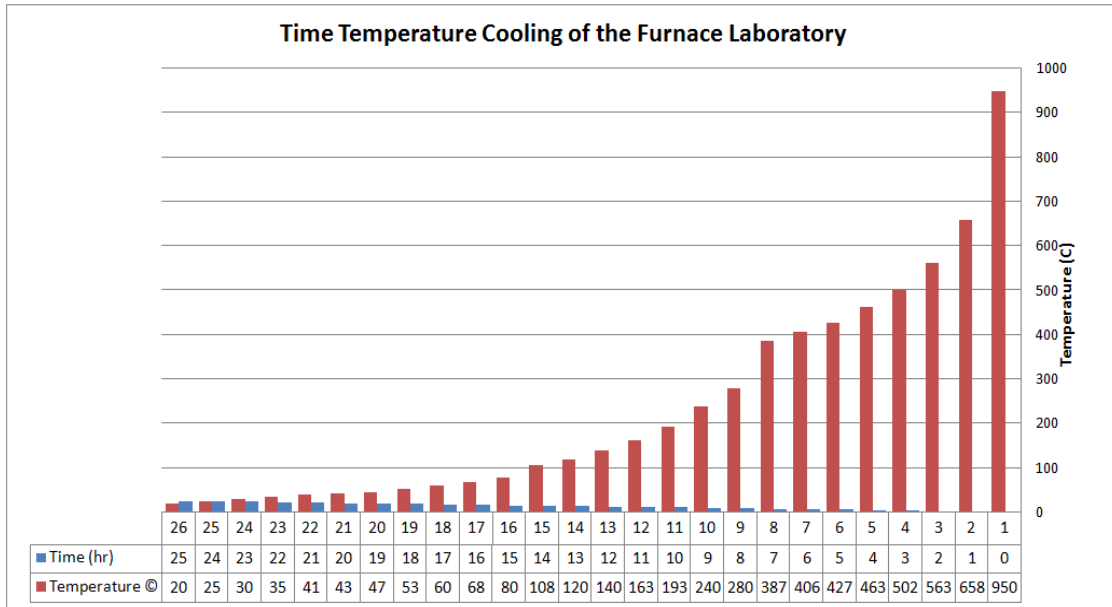


Fig.3.2. The furnace cooling rate [1].

The samples were divided into three groups, and each group was subjected to different numbers of thermal cycling (10, 20, and 30 cycles). All samples were subjected to the same heating cycle, in which the samples were heated below A1 to 500°C and held in the furnace for 15 min. Three samples of each heating cycle were cooled in water. The total time of a single cycle was 40 min, as shown in Figs.3.3.

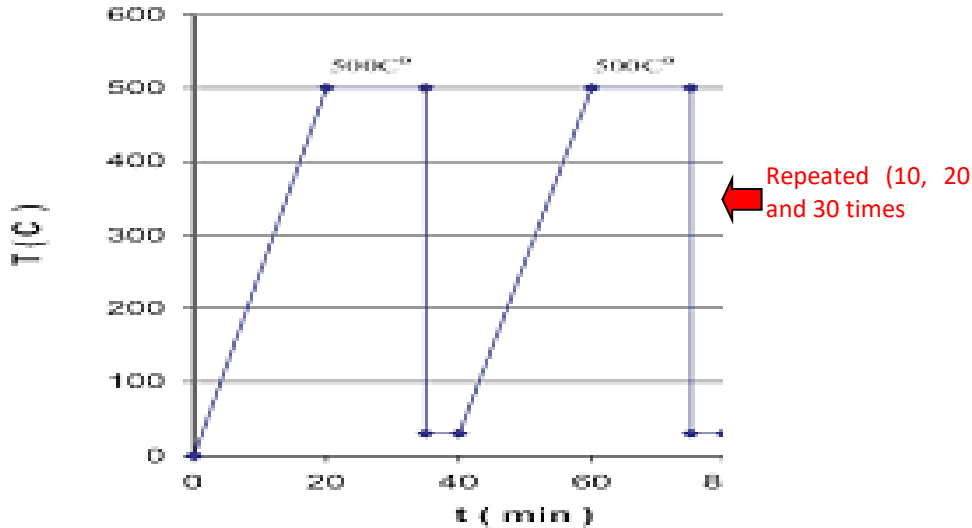


Fig.3.3. T.T. Diagram shows the [10, 20, and 30 cycled cooled in water].

3.3 Corrosion Testing

Thousands of corrosion tests are made every year. The value and reliability of the data obtained depend on the details involved. Unfortunately, many tests are not conducted or reported properly, and the information obtained is misleading. Corrosion rate has been measured by using the weight loss method for thus a [(Bulgur) calvarias (Varese) DEC.MIN.24-1-2003 N0 205295] were used. The difference between the weighted sample after and before

subjecting it to thermal cycling then removal the corroded layer by a piece of wood (softer than steel).

This loss of weight (ΔW) is considered as weights of corroded materials were:

$$\text{Losses of corrosion \%} = \Delta W / W_o * 100$$

Where ΔW : losses of weight (mgr) due to thermal cycling.

W_o : original weight (gram).

4.Results and Discussions

4.1The effect of thermal cycling on corrosion rate water-cooled

The samples subjected to a number of thermal cycling 10, 20, and 30 cycles then exposure to corrosion attack for (one week about 168 hr). We used water as a cooling media, Fig.4.1 shows the effect of thermal cycling on the corrosion rate. The increase in thermal cycling leads to an increase in the corrosion rate for carbon steel. This increase can be divided into two stages:

In the first stage, the corrosion rate increases gradually with increasing thermal cycling up to 10 cycles. Above that (more than 10 cycles) the corrosion rate increasing slowly until 30 cycles. This behavior can be attributed to the increase in the number of residual stresses, this amount of residual stress increases with increasing cycles up to (10 cycles), and then there is slowly increasing in residual stresses after that. The lead to introduce residual stresses which have a strong influence on corrosion rate.

Based on the above results, it can be safely concluded that thermal cycling introduced residual stresses which lead to an increase in the corrosion rate. Stages by increasing the number of cycles corrosion rate increases through two depending on the amount of thermal cycling.

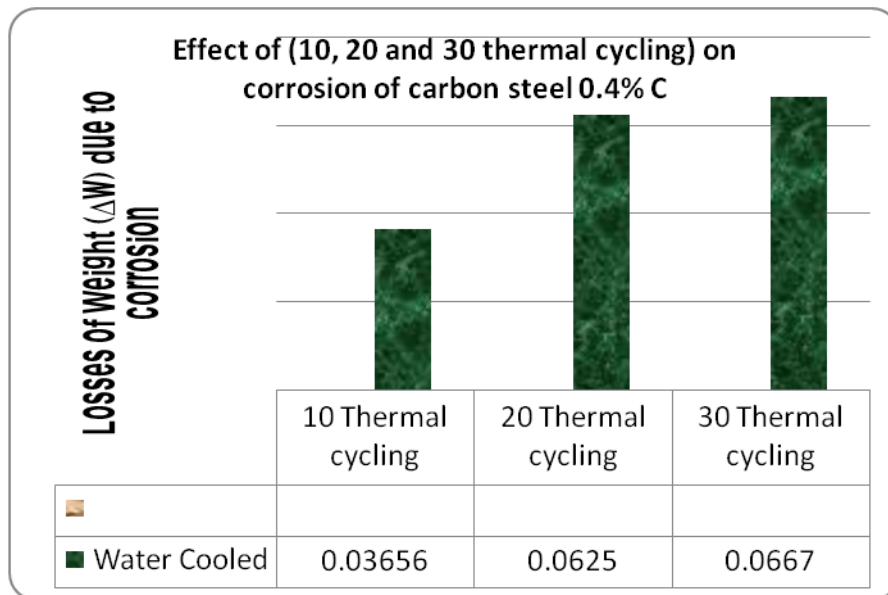


Fig.4.1. The effect of (10, 20, and 30 thermal cyclings on corrosion rate, water-cooled. □

The comparison between the effect of thermal cycling sea water cooled (previous results [1]) and the effect of thermal cycling water-cooled (in this manuscript) shown in Fig. 4.2.

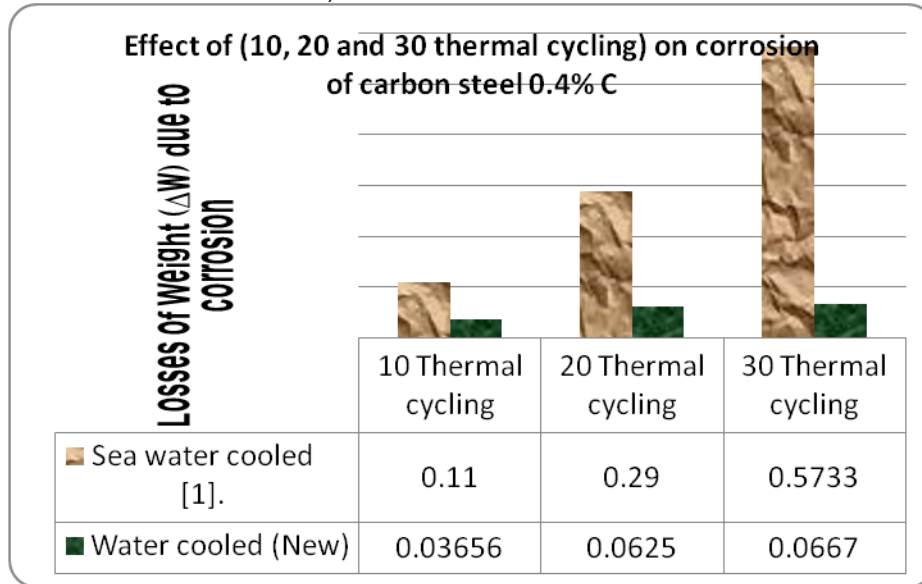


Fig.4.2. The effect of (10, 20, and 30 thermal cyclings on corrosion rate, water, and sea water-cooled. □

5. Conclusion

The results of this investigation show that:

- Thermal cycling causes a uniform corrosion attack for steel bars (0.4 C%).
- The corrosion rate of the first stage gradually increases with the number of thermal cycling up to 15 cycles, then it takes steady-state up to 30 cycles.
- The rate of corrosion (previous results, seawater cooled) more than (corrosion's results in this paper, water-cooled).

From the obtained test results (previous and in this paper, it was found that: the type of corrosion is uniform attack; corrosion rate of the first stage gradually increases with the number of thermal cycling up to 15 cycles, then it takes steady-state up to 30 cycles.

It was found that the rate of corrosion of previous results, (seawater cooled) is more than corrosion's results in this paper, (water-cooled).

For future papers, the cooling media and thermal cycling should be changed.

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Conflict of Interest: The authors declare no conflict of interest.

REFERENCES

- [1] Abdmanam. S. A. Elmaryami, Salem Ahmed Salem, Ali Saleh Saad, MokhtarHussien Omar, and Khaled Rafaa Ali, "Corrosion Rate Calculation of Carbon Steel (0.4%C) After Subjected to Thermal Cycling, Sea Water-Cooled". Journal of Multidisciplinary Engineering Science and Technology (JMEST) Vol. 7 Issue 6, pp. 11991-11996, 2020.
- [2] HalynaChumalo, Stress Corrosion Cracking Resistance of New Austenitic Ferritic Steels, Journal Corrosion Science Engineering, Volume 1 Paper 9, 1999.
- [3] C.P. Atkins and J.D.Scantlebury, the Activity Coefficient of Sodium Chloride in a Simulated Pore Solution Environment, Journal Corrosion Science Engineering, Volume 1, Paper 2, 1995.

- [4] S.H.Zhang, S.B.Lyon, Retention of Passivity on Iron after Several Months. Atmospheric Exposure, Journal Corrosion Science Engineering, Volume1 Paper1, 1995.
- [5] Shin-ichiKomazaki, Kazuya Kobayashi, ToshiheiMisawa, and Tatsuo Fukuzumi, Environment embrittlement of automobile spring steels caused by wet-dry cyclic corrosion in sodium chloride solution, Corrosion Science, Volume 47, Pages 2450-2460, 2005.
- [6] Hideki Katayama, Kazuhiko Nada, Hiroyuki Masuda, Makoto Nagasawa, Masayuki Itagaki, and Kunihiro Watanabe, Corrosion simulation of carbon steels in the atmospheric environment, Corrosion Science, Volume 47, Pages 2599-2606, 2005.
- [7] Hideki Katayama, Kazuhiko Nada, Hiroyuki Masuda, Makoto Nagasawa, Masayuki Itagaki, and Kunihiro Watanabe, Corrosion simulation of carbon steels in the atmospheric environment, Corrosion Science, Volume 47, Pages 2599-2606, 2005.
- [8] Hideki Katayama, Kazuhiko Nada, Hiroyuki Masuda, Makoto Nagasawa, Masayuki Itagaki, and Kunihiro Watanabe, Corrosion simulation of carbon steels in the atmospheric environment, Corrosion Science, Volume 47, Pages 2599-2606, 2005.
- [9] Hideki Katayama, Kazuhiko Nada, Hiroyuki Masuda, Makoto Nagasawa, Masayuki Itagaki, and Kunihiro Watanabe, Corrosion simulation of carbon steels in the atmospheric environment, Corrosion Science, Volume 47, Pages 2599-2606, 2005.
- [10] Hideki Katayama, Kazuhiko Nada, Hiroyuki Masuda, Makoto Nagasawa, Masayuki Itagaki, and Kunihiro Watanabe, Corrosion simulation of carbon steels in the atmospheric environment, Corrosion Science, Volume 47, Pages 2599-2606, 2005.
- [11] Guy Lack, Elements of Physical Metallurgy, Third Edition, copyright©1984 by AddisonWestley Publishing Company, Inc. 1984.
- [12] AbdImanam. S. A. Elmaryami, Effect of Thermal Cycling on Hardness of Plain Carbon Steel, The Fourth International Conference on Multiscale Materials Modeling (MMM-2008), Mathematical issues in multiscale materials modeling, Vol. 3, 2008, pp. 1502-1514, Scopus, Elsevier, ISBN 978-0-615-24781-6, Florida State University, USA, 2008.
- [13] AbdImanam. S. A. Elmaryami, "Effect of Thermal Cycling on the Corrosion and Microstructure of Plain Carbon Steels". Materials science & technology conference and exhibition: MS&T'07, Detroit, Michigan, USA, V. 6, pp. 3771-3784. 2007.
- [14] Badrul Omar, Mohamed Elshayeb, and AbdImanam. S.A. Elmaryami, The Microstructures and Corrosion of Carbon Steel after Subjected to Heat Treatment then Thermal Cycling, Oil Cooled. International Conference on Science, Technology, and Innovation for Sustainable Well-Being (STISWB), Mahasarakham University, Thailand, 2009.
- [15] Badrul Omar, Mohamed Elshayeb, and AbdImanam. S.A. Elmaryami, "The Microstructures Badrul Omar, Mohamed Elshayeb and AbdImanam. S.A. Elmaryami, "The Microstructures and Corrosion of Carbon Steel after Subjected to Heat Treatment then Thermal Cycling, Water Cooled". 5th European Metallurgical Conference [EMC 2009]. ISBN: 978-3-940276-20-9. Vol. 4, pp.1492-1495, Innsbruck, Austria. 2009..



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