AN APPRAISAL AND ANALYSIS OF BOILER PIPES IN AL-MUSAIB ELECTRIC POWER STATION

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ABSTRACT

It is hoped in this paper to find out the reasons behind the failure in boiler pipes used in Al-Musaib electric power station. Multi types of mechanical and chemical reasons were found behind the failures of these pipes. Two pipes were selected for this analysis (pipe no. 6 in coil 93) and (pipe no. 7 in coil 48) were they failed selectively. It was found that these pipes of boiler respectively have failed due to overheating as first reasons. In addition, failures are due to hydrogen damage can be considered in failed pipes that lead to form (Fe_2O_4) phase. The high sulfur containing fire products are also deposited on the outer surface of the tubes making the condensed water around the cracks acidic. In consequence, the examined pipes of boiler are respectively undergoing pitting corrosion. Un-regularity in thickness of failed tubes where measured and gives an indication about how much they eroded. Microstructural observations of the failed and un-failed show quenched microstructure with small amount of carbides present at the grain boundaries.

KEYWORDS: Boiler pipes failure, hydrogen damages, pitting corrosion.

تقييم وتحليل انابيب المرجل البخاري في محطه المسيب الكهربائيه

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الخلاصه :

تم في هدا البحث دراسه اسباب الفشل في انابيب المرجل البخاري المستخدم في محطه المسيب البخاريه. وقد تم تحديد العديد من انواع الفشل الميكانيكي والكيمياوي في هده الانابيب. ولاجراء التحليل تم اختيار انبوبين من المرجل البخاري هما (انبوب رقم ٦/ كويل رقم ٩٣) و (انبوب رقم ٧/ كويل رقم ٤٨) اللدان يعانيان من الكثير من انواع الفشل. وقد وجد ان هده الانابيب قد تعرضت لدرجه من الافراط في التسخين. بالاضافه الى دلك فان من المتوقع حصول نوع من ضرر الهيدروجين يصيب فولاد الانابيب ويؤدي الى تكون طور (Fe_3O_4) ويتحرر غاز الهيدروجين الدي يتفاعل بدوره مع كاربيد الحديد الموجود في البنيه بنسب قليله مؤديا الى تحرر غاز الميتان. بالاضافه الى دلك فان وجود الكبريت في نار المرجل البخاري والدي يترسب على سطح الانبوب. ايضا هناك تعريه واضحه في الانابيب المفحوصه اثبتها قياس سمك الانبوب من جراء الفقاعات المائيه الموجوده في البخار اضافه الى ظهور تاكل تنقري. وتشير صور البنية المجهرية للانابيب الى وجود كميات من الكاربيدات عند الحدود الحبيبيه.

1. INTRODUCTION

The general arrangement of the basic elements of a steam plant is illustrated schematically in the **figure** (1). Steam is generated in a boiler from which it passes into the steam main. The steam main feeds the steam into a turbine or engine or it may pass into some other plant such as heaters or process machinery. After expending through the turbine or engine or passing through some other plant, if the plant is working on "dead-loss" system, then the exhaust steam passes away to the atmosphere.

This system is very inefficient and is rarely adopted in modern plant. It is used in the steam locomotive since in this case the plant needs a sufficient place for the complex steam recovery equipments, which can be installed in power station. If steam recovery plant is installed then the exhaust steam passes into a condenser where it is condensed to water, called condensate [1].

Boiler pipes can be defined as the part of the boiling system that carries the steam from the boiler where the steam generated in wet state to the steam main as shown in the **figure** (1). If however, superheated steam is required, then the wet steam is removed from the steam space and is piped into a super heater. These pipes must be sealed reliable and working properly without any burst or leakage during the working time. The proper working of these pipes required the following:

1. Uniform thickness of the steel pipe without any leakage or burst.
2. Little or no scaling inside surface with no existence of any flow chocking along the pipes.
3. An advance heat transfer across the thickness.
4. Capability to withstand the hot stem pressure without any deformations such as swelling.

It known that these pipes actually corroded and swelling up until the burst occurs. The changes into the pipe material properties can lead to disaster consequences as mentioned above where the burst can be so expected machined onto their surfaces. Ultimately, a pipe will simply wear out-of-tolerance overtime and use; however, several failures, such as heat overheating and gross cracking, may cause the pipes to fail before they should. The premature failure of boiler pipes costs the electric station many thousands of dollars each year. The output electric power in the middle of Iraq is seriously affected by these failures.

Electric power generation is one of the most demands that every country looking to develop it continuously. In our country as well as the other growing country, the electric power generation has a many problems. These problems are starting from the planning to generation, installing of power plants, and operation of plants, maintenance, and distribution of power…etc. However, our country has passed many strategically steps in the building of the many power stations that utilizing a heavy gas oil or the high pressurized liquidized natural gas...etc. Most of these stations have suffered from many failure problems such as depreciation and corrosion or other electrical and mechanical failure. Al-*Musaib power station* is one of the national stations that used the steam turbines to derive its generator units. Steam generation and delivering was the primary objective in its operation. The boiler units are suffering continuously from many failures accidents during its working. Failures sometimes leads complete or partly shutdown the station. One of the most frequent failures is occurring at the pipes that connect the boiler to the supercharger or at the pipes of the supercharger itself.

The objective of the failure analysis project at hand was to investigate and realize the mode and cause(s) of premature failure of boiler pipes composed of steel T 22. To obtain such purpose some boiler pipes taken from the boiler units of *Al-Musaib power station*. The Engineering staff at the station supplied failed pipes used in this work officially. A variety of testing and background research on topics such as metallographic, hardness, erosion, and corrosion testing has provided several possible solutions to the failure analysis problem. Visual inspection has revealed oxide inclusions near the suspected failure initiation points.

Anees U. Malik et al [2], studied the leakage that observated from the roof tubes on the second pass of boilers 6, 7 and 8 of Jeddah phase – 3 plant, pipes were examined a surficial cracks and pits on the fire side of the tube wall.

Zhang Baoyou et. al. [3], studied the rupture of a boiler pipe by using chemical analysis, scanning electron microscope, and energy dispersive spectroscopy. The results show that excess temperature caused by obstruction of stream flow was associated with the bubble clusters on the bore surface, which resulted in the creep deformation responsible for elongated grains and wall thinning. The pipe burst because the high temperature strength was below the designed standard.

Weili-wa **et. al.** [4], studied the metallographic and metallic materials of three boilers burst tube in accident, which provide a basis for diagnosis and determine the common cause of the boiler tube burst accidents, and also set a foundation for the prevention measures of the steam boiler tube burst accident. By analysis and comparison of the components, macroscopic and microscopic morphology of three blast tubes, the major cause of the boiler tube burst is too high wall temperature of boiler tube. Because the circulated water in steam boiler have more carbonate content, the carbonate was crystallized in the wall of tube at the point of the overheated section, so the thermal resistance increases and the boiler tube wall temperature growths and metal performance failures, finally the accident of steam boiler tube burst happens.

Chen qi-sheng et. al. [5], investigate the tube burst accident in the oil filed. It not only influences the length of boiler life, but also creates the huge economic loss. In view of tube burst accident arising from factory of production crude oil, based on the examination data, the reason of burst has been analyzed and the final conclusion also has been draw. The preventive measure and the identical accident were prevented.

2. EXPERIMENTAL PROCEDURE

The properties of T22 steels are dependent on the microstructure, the composition, and the heat or surface treatments. The microstructure of T22 steel is composed of Pearlite in ferrite matrix with various alloying element distributed within colonies. The size and distribution of pearlitic structure plays a key role in fracture. Coarse pearlitic result in facilitating fractures propagation.

(**Zhang, 2006**) There are many types of pipe failures including deformation, fracture, cracking, burst, erosion, etching, pitting, and exfoliation. Of these failures, there are many possible causes. To decrease the likelihood of failure the following criteria should be met:

1. Design that is compatible with the pipe material selected and with the planned processing procedure.
2. Selection of material that is compatible with the design and processing procedure.
3. Selection of a heat treating procedure that is compatible with design and material.
4. Control of the specified heat-treating procedure.
5. Control of the finishing operations.
6. Control of boiler pipes setup (particularly alignment) in the equipment.
7. Boiler operation, specifically avoidance of overloading and overheating.
8. Control the quality of water used to generate the steam such as PH level and other water properties.

All the potential failure causes are associated with stress present in the pipe, which are generated during its manufacturing, or during its service life, or both." Design errors such as sharp corners, undersized radii, inadequate welding or assembly, and thin sections or sudden variations in section thickness, are often the causes of these stresses that can cause pipe failure.

The paper concentrated on the criteria one and seven and eight as starting points. These criteria were most easily discernable as potential causes of premature pipe failure.

Criteria 1, 7 and 8

Initially, criteria one, seven, and eight were investigated as well as literature reviews. For instance, T22 steels have typical applications as boiler pipes due to the metallurgical and chemical behavior. The simplicity of a boiler pipes as compared to other intricate part coupled with the fact that T22 steel has been used as an industry-wide boiler pipe material for many years eliminated criterion one as a potential cause of failure. However, the chemistry specifications of T22 will be checked to positively eliminate criterion one.

(Boiler operation, specifically avoidance of overloading and overheating) was a clear starting point because all pipes were subjected to the same operation conditions. Only definite numbers of pipes were failing prematurely (and most often), and so this did not indicate an overloading or overheating issue. Criterion 7 is investigated as a possible cause of premature pipe failure.

Criterion 8 was a starting point due to the use of single grade of stock materials in the boiler pipes. The objective was to find out whether pipes were failing more often (or all of the time). The cleanliness of the steel is a measure of the amount of inclusions in the microstructure, an abundance of inclusions can cause premature pipe failure.

Visual Examination

Upon receipt of each pipe sample, photographs were taken and the samples were labeled systematically. A list of sample conditions can be verified in **Table** (1). Both the failed and un-failed pipes (of varying part number) saw various service conditions. All of the failed and un-failed samples were positions on the bottom during service; and, all pipe-operating temperatures (that were recorded) were less than 265 °C. n

The manner in which each of the failed pipes failed was identical. **Figure** 2 is a representative photograph of the appearance of the failed pipes. The failures appeared to have started at the inner surface of the pipe and propagated across the thickness.

Test Procedures

The two types of boiler pipes were analyzes for material deficiencies using hardness testers, metallographic. A limited amount of mechanical properties testing also conducted on the boiler pipes.

Marco-hardness readings were taken on a cross-section of each pipe material and in numerous places on each received pipe. This was conducted with a New Age Brinell Tester. Any signs of poor heat treatment or wrong alloy composition would be identified from this testing.. This test was conducted with a 50 Kg load. The intent of this test was to determine the presence of, approximate depth and hardness of the each place across the thickness of each pipe. The selected locations for hardness test are as follows in the following schematic diagram as shown in **figure** (3):

Metallographic

Four samples of each pipe were sectioned from the failing region and prepared for microstructural analysis via standard metallographic procedures. A 2% Nital etch was used on all samples. This would reveal any signs of poor heat treatment or other imperfections in the microstructure.

Chemical Analysis

To ensure that all samples met the manufacturer's requirement of a T22 steel alloy, sections were sent to an outside laboratory (Ministry of Science & Technology-Baghdad) The chemical composition was measured using *"Spectrum Analysis for Metals*" for chemical analysis. The results of actual chemical composition are given in **table** (2).

3. RESULTS AND DISCUSSION

The following chapter aims to explore and discuss the results obtained from the experimental procedure. Results can be classified into three categories; mechanical, metallurgical and electrochemical results. A recent accident in most power plants and in Al-Musaib electric power station involving a bursting steam pipe that leads may be to disaster. Investigated set of pipes in the station above registered a few accidents of pipe burst. The bursted pipes received shows a noticeable remarks about the reasons by which the burst occurs.

Pipe bursting is caused by corrosion and erosion of areas inside the pipe that cause the pipe walls to thin down and eventually burst under pressure. These corrosion and erosion areas can be found by using ultra-sound as a detection method. Unfortunately, this method is very restricted to use nevertheless that the pipe must be installed and hot stem flowing through it [4].

In this paper, the failed pipes have not burst but they suffer from a sever pitting corrosion and erosion. Measuring thickness along the pipe samples can give a clear indication about the corrosion-erosion along the steam side as can be seen in **figure** (4).

Erosion of pipes

A common type of erosion is known as cavitations erosion and is caused by sudden flash of liquid into vapor bubbles followed by immediate collapse of bubbles; the subsequent shock wave generated by the flashing and collapsing of vapor or dissolved gas creates stress erosion on the pipe wall. Similar phenomenon can be seen on high-speed boat propellers, which run in cavitations conditions.

Erosion of investigated pipes is so clear according to the figures above. The degradation in thickness along the pipe reflects the ideas about some expected kind of erosion has occurred. Pipe no.6/coil 92 had been eroded clearly in the locations (2-12 cm) and (20-26 cm) in the 30 cm long investigated.

Pitting corrosion observations

Tubes 6/coil93 and 7/coil48 had few crack openings and deep pits around it. From the **figures** (5), it is evident that pitting started at the surface of the tube near the crack and progressed downwards undercutting the surface. It was also observed that depth of the pit increased as one moves away from the crack. No chemical attack was found on the steam-side of the tube wall.

Pitting corrosion of the surface of these tubes does not appear to be due to difference in oxygen concentration, because for such type of pits presence of crevices and/or deposits is essential. Visual inspection of the pits and their size indicate that they have formed under highly acidic condition. When the steam flowing in the tube at a pressure of around (7 Mpa) escapes through the narrow cracks, it will cool down near the end of the crack due to the pressure gradient (Joule-Thomson effect). This cooling of the steam will result in:

1. Condensation of steam into water near the crack.
2. Dissolution of sulfurous gases of the fire product and formation of acidic water.

As the temperature of the surface of the tube will be less, the condensation of escaping steam will be more, and consequently pitting corrosion will be more. If we try to analyze the temperature history of all the failed tubes under study on the basis of their extent of swelling, reduction in the wall thickness and spheroidized and quenched microstructures, it seems that the temperature experienced by the tubes 6coil93, 7coil 48 and was less than other failed tubes according to some historical accidents in station. Therefore, severity of the pitting corrosion of above mentioned tubes is more.

Overheating inspection conditions

One of the roof panel tubes of boiler 6, designated as 6/93 in **Fig.** (5) had a swollen portion with many un-regularities and pitting on it. Longitudinal section of the failed area, cleaned with inhibited 3% hydrochloric acid solution, revealed that the fine cracks had initiated at the steam -side of the tube. Some of the cracks had crossed the entire thickness of the tube and had opening at the other side.

Failure of roof panel tube of boiler 7/48 also appears to be due to overheating of the tube. Tube 7/48 had pits around the fine crack opening.

Analysis of Oxide Scales

Thick black oxide scales deposited on the steam-side surface of the tube and brown oxide scale formed on the outer surface of the tube. It was found that the oxide scales deposited on the steam-side surface is composed of magnetite (Fe_3O_4) while the scales on outer surface contains hematite and wustite (Fe_2O_3 + FeO) as expected.

Metallographic Evaluation

Metallographic analysis is an important tool for analyzing material temperature history. When carbon steels are exposed to temperatures above 482°C but less than the lower critical temperature (723°C) this steel is subjected to spheroidization. The carbides present in the steel in annealed condition are not in their lower energy state and exposure to higher temperature results in the coalescence of these carbides into spheroidal form. If the tube wall is ruptured and temperature is more than the lower critical temperature, the rapid cooling effect of the escaping steam will result in a distinct quenched microstructure form.

Microscopic studies of cross-section of failure zone of boiler tube 6/93 and 7/48 show quenched microstructure with small amount of carbides present at the grain boundaries (**Fig.** 6 and 7). On comparing the above microstructures of failed area with un-failed area of tube 6/93, 7/48, the former appears as quenched overheated microstructures.

This shows that the exposure temperatures of the above failed areas have exceeded the lower critical temperature and were exposed to this temperature for quite long time. Knowing that, the strength of steel is nearly constant up to about 454°C.

Boiler tubes are overheated due to the internal deposits insulating the tube metal from the cooling effect of steam. As the deposits do not form uniformly along the tube, overheating is always localized in nature. Overheating failures are of two types: short-term and long-term. Short-term overheating failures result when (i) tube metal temperature increases hundreds of degrees above design temperature (ii) there is blockage of the tube and (iii) loss of drum water level. This type of tube failure exhibits considerable creep elongation resulting in considerable reduction in wall thickness. Sometimes the tube blows up into the furnace and shows a knife edged failure opening.

Hydrogen Damage

A serious and catastrophic failure of carbon steel pipes of boilers, exposed to high temperature (> 500°C) and high pressure of steam (>1500 psi) for a long time is that associated with the decarburization of steels resulting into hydrogen damage. Characteristically a deposit plays a key role in: (a) overheating of metal and (b) creating relatively high rates of carbon diffusion, which is evident by the decarburization of the steel on both surfaces. Nevertheless, the cause of decarburization of steam-side surface is expected to be steam while that of fireside it is the CO2 gas. Decarburization at the steam-side surface is represented by the equations, [6]:

$$3\ Fe + 4H2O = Fe_3O_4 + 4\ H_2 \quad (1)$$

$$Fe_3C + 2H_2 = 3Fe + CH_4 \quad (2)$$

Decarburization at the fire-side surface is represented by the equation:

$$Fe3C+4CO2 = 3FeO+5CO \quad (3)$$

An illustration of the environment that results in hydrogen damage is shown in **Fig.** (8).

As the partial pressure of hydrogen eq. (1) increases, it diffuses into the steel and reacts with carbides forming methane gas eq. (2) which exerts an internal pressure. The decarburized metal gets embrittled and fails to withstand this internal pressure. As the size of methane molecule is bigger than CO molecule and there is a high pressure of steam inside the tube, more cracks have initiated at steam-side surface of the tube. The reason for cracks being circumferential in nature appears to be thermal residual stresses which developed due to localized heating and acted parallel to the length of the tube.

Hardness testing results discussion

Hardness numbers reflects to some extent, the change in the microstructure along the cross section of boiler shown in the **figure** (9 and 10). The following figures show a comparison between the hardness numbers of failed and un-failed of the two pipes adopted in this project.

It is clear from both figures down that a noticeable difference between the failed and un-failed hardness results. In **figure** (9), pipe no.7 in coil 48 shows a distinct difference in hardness numbers, gave a clear picture about what is going on in this pipe. The first indication put that, a softening phenomenon has occurred clearly in this failed pipe. Furthermore the swinging of hardness numbers and their drops in comparison with the un-failed pipe gives an indication that, the pipe has subjected to an overheating during its operation.

It is usual that, the boiler pipe operating with temperature up to (256°C) in most cases. Any increasing in operating temperature affects the microstructure of the pipe materials. Pipe materials were manufacturing from low carbon steel (i.e. 0.18% C).

4. CONCLUSIONS

The following remarks can be concluded:

1. Pipes 6/93 and 7/48 of boiler respectively have failed due to overheating.
2. In addition, failure by hydrogen damage can be considered in failed pipes.
3. The high sulfur containing fire products are deposited on the outer surface of the tubes making the condensed water around the cracks acidic.
4. In consequence, pipes 6/93 and 7/48 of boiler respectively undergo pitting corrosion.
5. Un-regularity in thickness of failed tubes gives an indication about how much they eroded.
6. Microstructural observations of the failed and un-failed show quenched microstructure with small amount of carbides present at the grain boundaries.

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Table (1): Boiler characteristics as provided by *Al-Musaib electric power station*

Pipe no.	7	2
position	Coil no. 48	Coil no. 93
condition	Failed	Failed
Outer diameter	OD (100mm)	OD (100mm)
Thickness	5mm	5mm
Operating pressure (Mpa)	5	5
Operating temperature °C	265	265
Manufacturing method	Deep drawing	Deep drawing

Table (2) Chemical composition analysis of failed boiler pipes samples

	C%	Mn%	Si%	Fe%
Sample no. 1	0.18	0.45	0.20	Remainder
Sample no. 2	0.18	0.45	0.20	Remainder

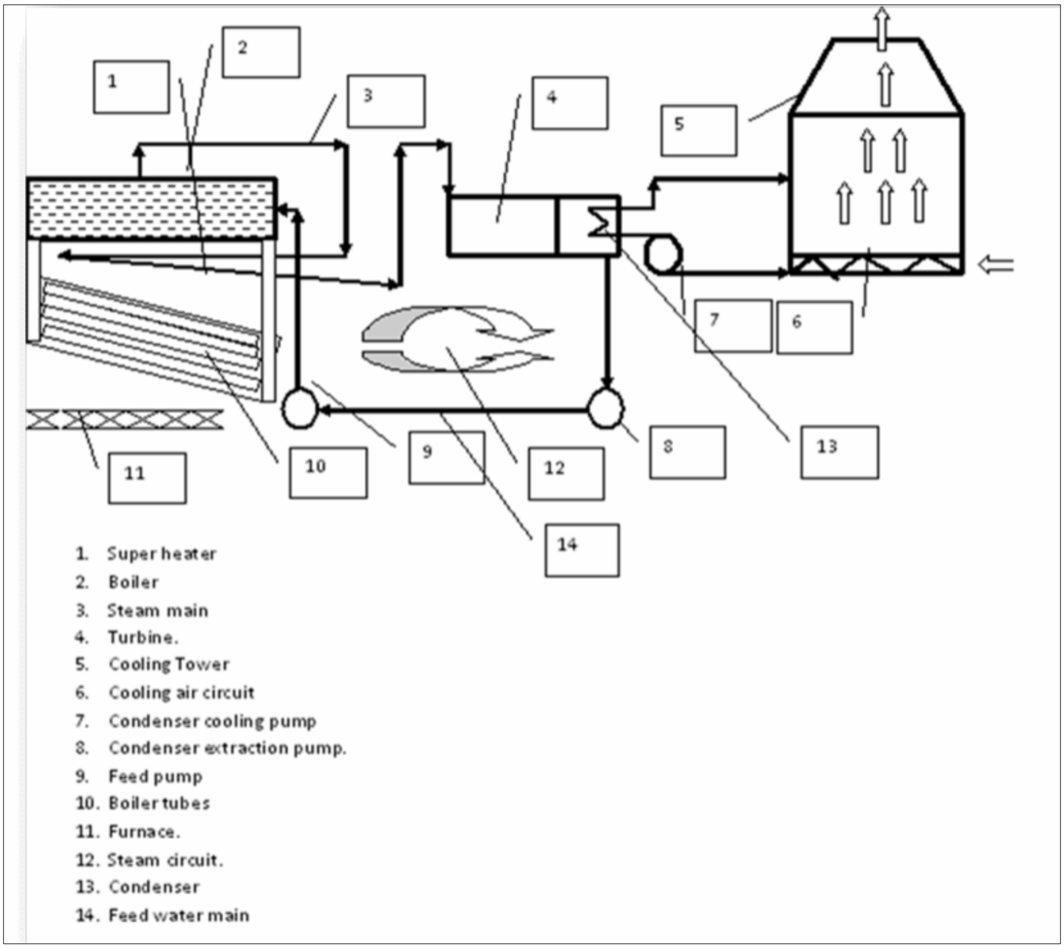

Figure (1): A schematic representation of the electric power station using a steam turbine

Figure (2): A-Longitudinal cross section of damaged and undamaged boiler pipes.
B- Half rings samples taken from each pipe.

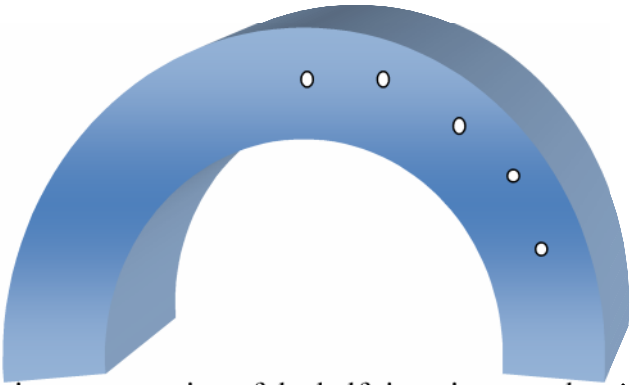

Figure (3): Schematic representation of the half ring pipe sample with specific locations of hardness readings.

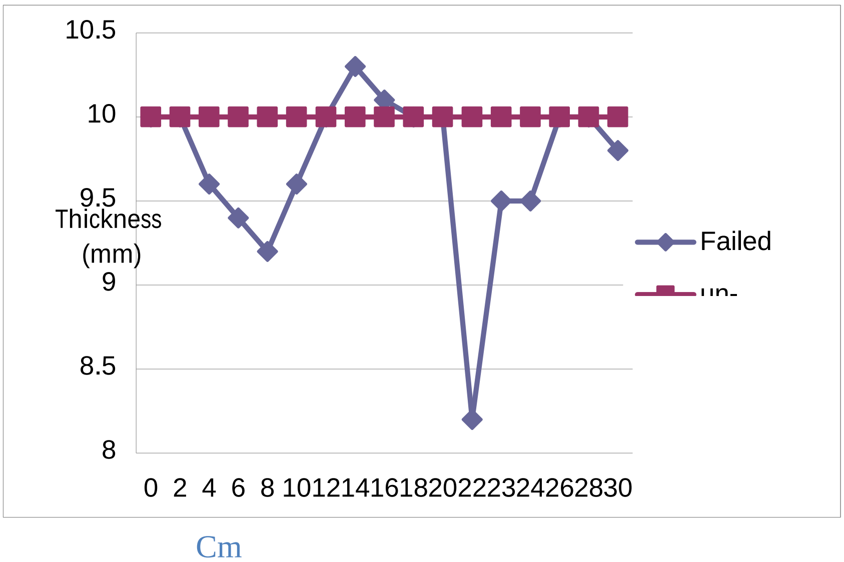

Figure (4): Thickness measurement along the failed and un-failed pipe no.6/coil92.

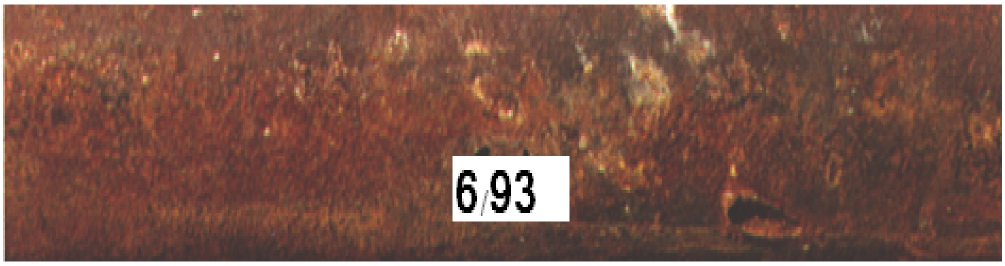

Figure (5): surface of pipe (6/93).

Figure (6): Micrograph structure of the un-failed pipe no. 6/93, (200X)

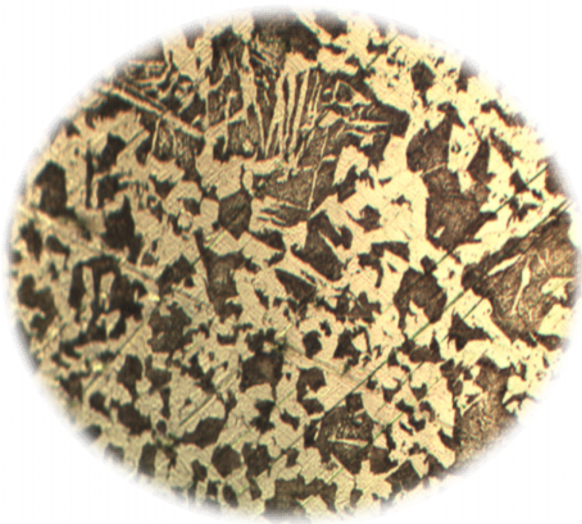

Figure (7): Micrograph structure of the failed pipe no. 6/93, (200X)

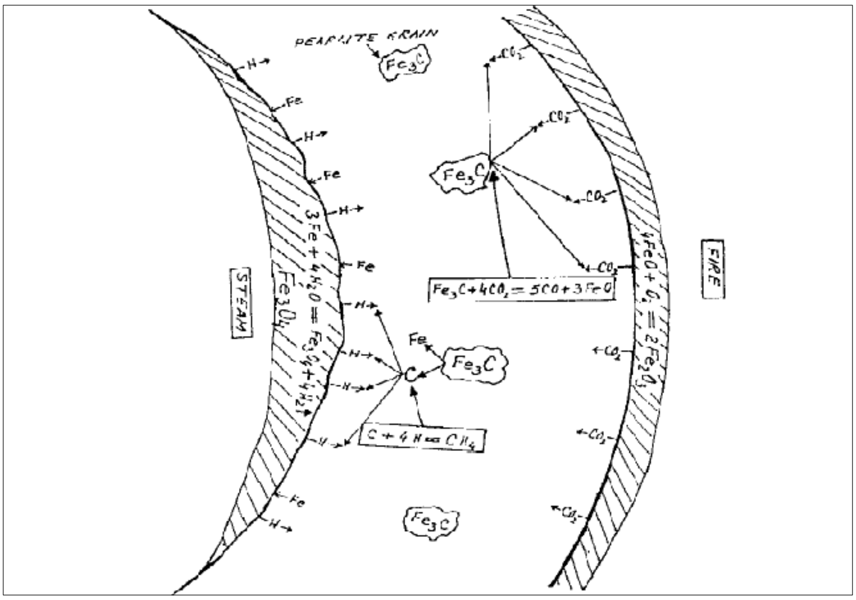

Figure (8): Schematic representation of expected hydrogen damage mechanism in boiler tube. [5]

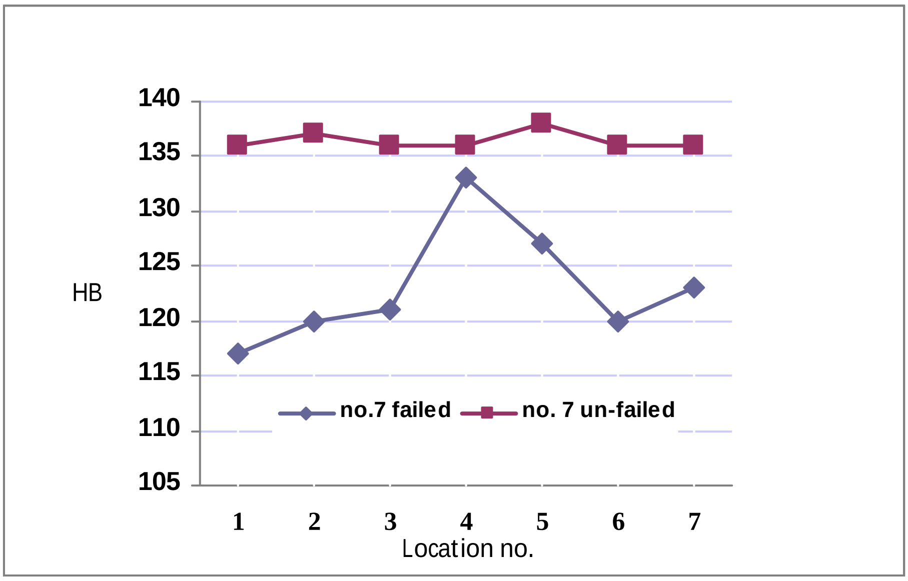

Figure (9): Comparison between hardness results of failed and un-failed pipe no. 7/coil no.48

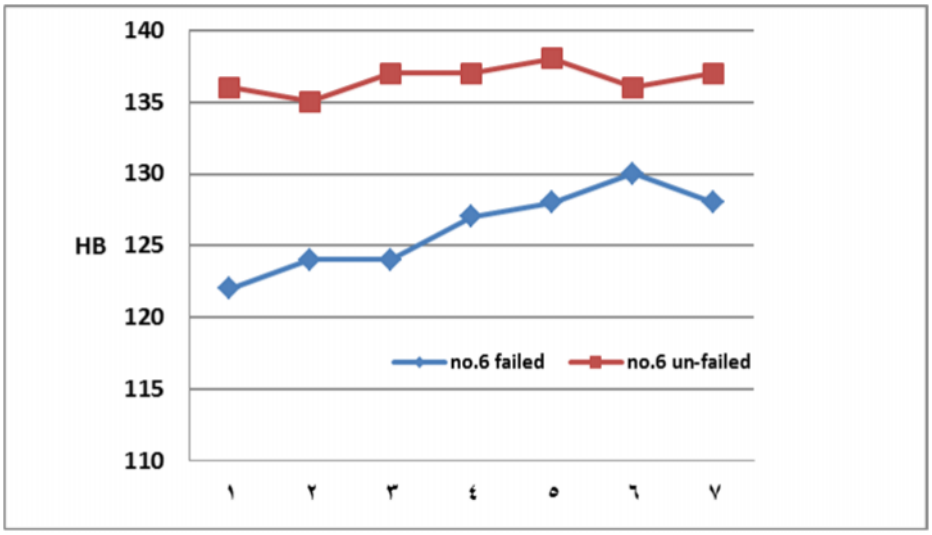

Figure (10): Comparison between hardness results of failed and un-failed pipe no. 6/coil no.93