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College of Petroleum and Mining Engineering

Department of Mining Engineering

STUDY THE EFFECT OF LASER PEENING ON CORROSION RATES IN METALS

A Project Submitted As Partial Fulfillment For The Requirements of The Degree of Bachelor of Science In Mining Engineering

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Acknowledgment

الاهداء

بِسۡمِ ٱللَّهِ ٱلرَّحۡمَٰنِ ٱلرَّحِيمِ

إلهي لا يطيب الليل إلا بشكرك ولا يطيب النهار الا بطاعتك..

ولا تطيب اللحظات الا بذكرك

ولا تطيب الاخرة الا بعفوك

"رب العزة"

إلى من بلغ الرسالة وأدى الامانة. ونصح الامة. إلى نبي الرحمة ونور العالمين "سيدنا محمد (صلى الله عليه وآله وسلم)"

إلى من كللهم الله بالهيبة والوقار ..إلى من علمونا العطاء بدون انتظار .. إلى من نحم لأسمائهم بكل افتخار

.. نرجو من الله ان يمد في اعمارهم لنرى ثمارها قد حان قطافها ..بعد طول انتظار وستبقى كلماتهم نجوم نهتدي بها اليوم وفي الغد وإلى الابد

"آبائنا الاعزاء "

إلى ملاكنا في الحياة .. إلى معنى الحب والحنان والتفاني . .إلى بسمة الحياة وسر الوجود إلى من كان دعائهن سر نجاحنا إلى أغلى الحبايب

"أمهاتنا الحبيبات"

من درر وعبارات من اسمى وأجلى عبارات في العلم ..إلى من صاغوا لنا من علمهم حروفا ومن فكرهم منارة تنير لنا مسيرة العلم والنجاح

"أساتذتنا الاكارم "

وفي الختام الحمد لله تعالى الذي وفقنا في تقديم هذا البحث، وها هي القطرات الاخيرة في مشوار هذا البحث وقد بذلنا كل الجهد والبذل لكي يخرج هذا البحث في هذا الشكل.

****والله ولي التوفيق****

Abstract

The Corrosion behavior of Carbon Steel and Copper for Impeller of molten sulfur pumps was investigated, since we done several testing of the samples from many side to get best results. Both type of specimens appears variable pattern into the molten sulfur, since approximately 40 days the behavior of the specimens was understand. We depended upon the reading of the weights during the Exposure time and Corrosion rate equations. Although the Copper have higher density if comapred with Carbon steel, but during the investigation appears bad and nagative results if compared with behavior of Carbon Steel . In the addtion the Laser shock peening technolgy appears beautiful way to improve the propeties of metals alloys. sine after the treatment the behavior of the specimens improved during to obtained more rsistance of Corrosoin effect and with less Weight losses.

The Air Laser peening (ALP) provide very bad and negative behavior for both types of metlas, because the higher temperature energy of the laser effects on the composition of structure of metal (covalently construct) in the final we gets bad results. The Water Laser peening (WLP) provide some improvement because the water act as insulator and prevent the specimens to take all energy. Compared with Coating laser (black paint laser peening) provide very beautiful pattern since it improved the properties of mechnical and structure of the both metals Copper and Carban Steel. In the the addtion most time in the tarnsporting activities of molten sulfur between the stages and processing unit in the industrial plants we need to provide a heating jacket in order to keep the temperature constant in all parts of the pumps, also the effect of hydrogen sulfide required special patterns to obtained best practical applications in the sulfur processing.

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CHAPTER ONE
Introduction

1.1. Introduction

Improvement of material surfaces has become an integral part of industrial operations, this is to improve the mechanical and metallurgical properties such as fatigue life, corrosion resistance, increase the efficiency, improvement of operation, erosion resistance, Hardness and yield strength. In the addition the exigencies of modern equipment needs special circumstances to get best production rates, safety conditions for worker and their equipment, and flexibility in the procedures [1][2].

Trouble of corrosion and provide best conditions to deal with sulfur consider one of most problems in Al-mishraq sulfur general company –one of Iraqi ministry of industry companies**.** Therefor we try to dabbing reality of the company through get to data and samples, through coordinating between our college (College of petroleum and mining engineering) and the company. To understand proceeding of company in provide bester conditions to dealing with problematic of sulfur and processing units. Through potentials existed to study the corrosion behavior of copper and carbon steel for impeller of molten sulfur pump by using modern technology (laser shock peening).

1.2. Laser Shock Peening and its effects on Corrosion behavior

Laser shock processing has been proposed as a competitive alternative technology to classical treatments for improving fatigue and wear resistance of metallic materials, and has more recently been developed as a practical process amenable to production technology [3]. Compared to other peening methods, laser peening shows an extraordinary compressive stress depth, yet low deformation. Because of this low-strain hardening it is possible to increase the stress field to an even greater extent [4]. Moreover, the process is fully controllable with every shot and allows the precise simulation of macro stress states.

Currently, the costs of laser peening steadily decreases rendering it more and more interesting for broad industrial purposes, including automotive [5].

Among the applications that have been identified are the manufacture of blades, impeller, disks, vans, structure, pipes etc. The basic principles of the laser peening can be summarized by two wave as a follow [6]:-

- The first one is essentially an elastic wave.
- Followed by a slower plastic deformation wave front.

The Figure below appears the Laser peening process, since this technique depended on apply amount of energy on the surface of metal to act as a way to improve the properties of the samples.

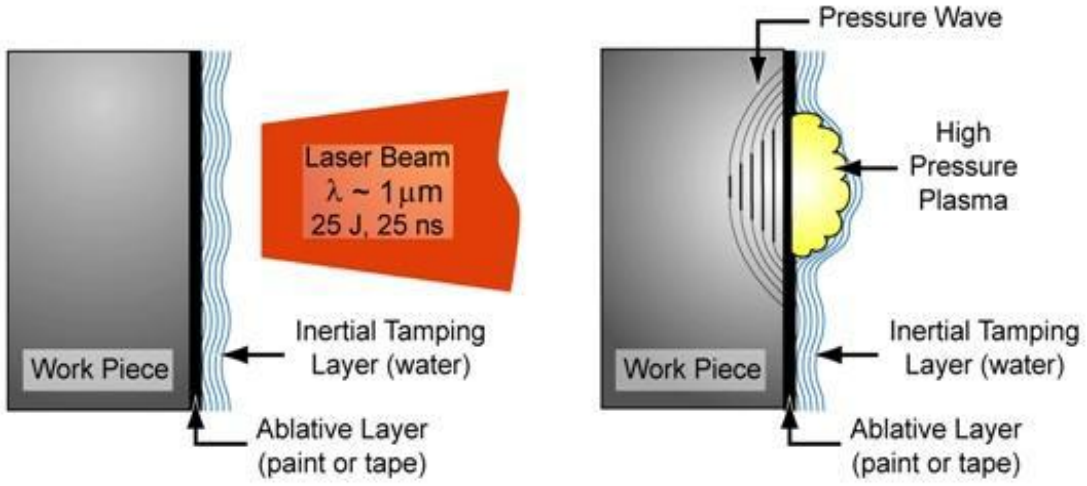

Fig. (1) Laser shock peening process

1.3. The molten sulfur pump

Pumping molten sulfur is a very challenging application with a wide variety of available solutions. Selection of the best solution depends on the requirements on site but also the process conditions. Many times the best solution is not chosen, due the process in the industry may be affected by several parameters. However, many aspects need to be considered to choose the best pumping system, properties of the liquid through the transport activity and material of construction [7].

Generally the molten sulfur pump required control of sulfur temperature by passage of steam or water solution with special properties through the transport

line to play act a medium active controller of temperature of molten sulfur through the transport.

Maintaining saturated steam in the pumping jacketing at a pressure of 35 psi will keep the sulfur at a good pimping temperature in the range of (138-148) °C [8]. Understanding the temperature-viscosity relationship of sulfur is critical to ensuring proper pump operation [9].

Impellers of molten sulfur are available in a variety of styles depending on the requirements for abrasion resistance and solids handling in the addition the presence of the contamination. For clean or slightly contaminated sulfur convenient external impeller clearance adjustment can be achieved using shims and built-in jacking screws [10]. In the Al-mishraq sulfur general company, there are several standard of pumps used to transport the molten sulfur between the processing stages. For example Hayward Gordon jacketed vertical and horizontal molten sulfur pumps provide reliable performance in both clean and dirty sulfur service [11].

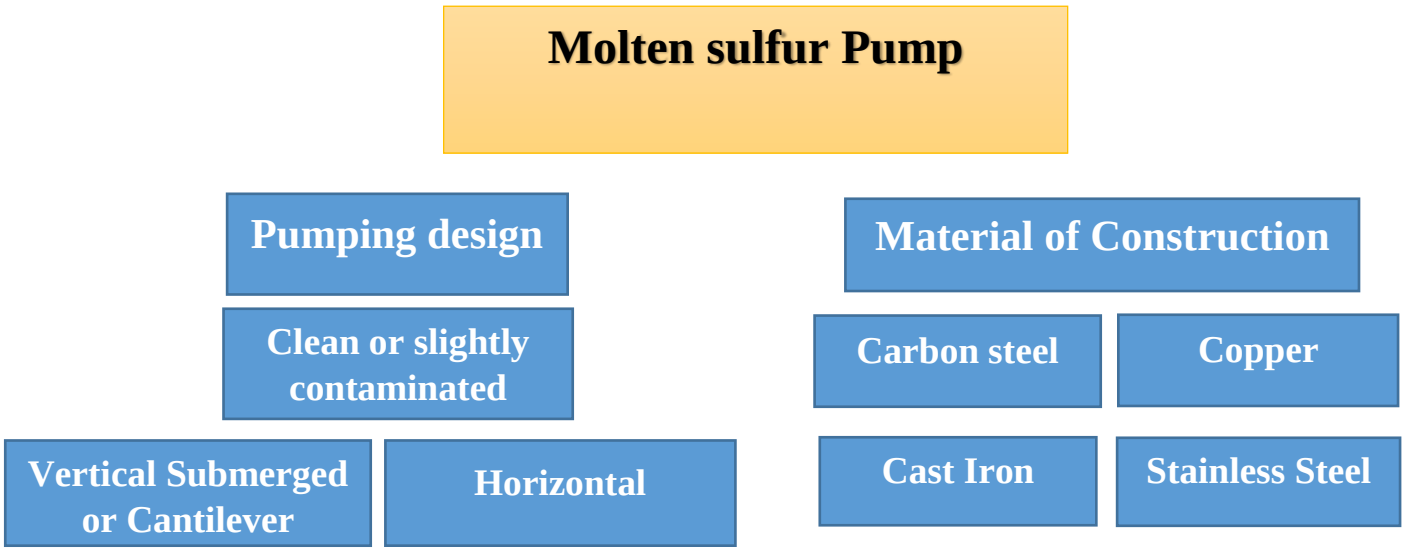

Fig. (2) Overview of pump designs, materials of construction

There are more information about the specification of the molten sulfur pumps as Appendix in the last of the project. In this part we summarized according to the contained our project since we dealing with carbon steel and copper Martials in the addition with pure sulfur

1.4. The basic objectives of the studying:-

- Increase the corrosion resistance of Carbon Steel and Copper alloys which are consider construction part of molten sulfur pump that used in transport the molten sulfur.
- Provide best conditions for transporting the molten sulfur between the stages and processing units.
- Discuss potential applied modern technologies such as laser shock peening to improve the mechanical properties of Martials that used for construction the surface facilities.
- Provide systematic pattern to control sulfur properties through the transportation process, especially Many times the best solution is not chosen, due to the lack of understanding of all possible solutions or from lack of experience.
- The investigation revolves about actual problems in the Al-mishraq sulfur general company - one of Iraqi ministry of industry companies competent by sulfur production so access to disbandment may be contribute with anther sectors especially industrial facilities not devoid with corrosion effect for example the petroleum industry since it consider the largest dissector in the country.

CHAPTER TWO
Literature review

2.1. Introduction

This chapter outlined the existing literature which is directly relevant to the topic of this thesis "laser shock peening improvement technology". Since laser shock processing (LSP) was invented in the early 1960s, lots of studies mainly focused on the physics process, the physical mechanisms, the plasma to achieve high pulse pressures and the development of mathematics models to characterize LSP processes .Since 1990, many researchers have further developed and enriched this technique by investigating the effects of laser spot shape, characteristics of shock waves and their propagation on the induced mechanical properties [12].

More attention on laser shock processing was paid to some important processing parameters related to LSP conditions, such as laser processing parameter, confined layer and absorbing coatings, which can significantly affect the mechanical properties of the alloys and metallic materials [13]. So, due to increase trend all over the world to utilize the material up to extreme levels in all the fields, various methods has been developed and successfully applied. Similarly, Improvement of material surface now a day is an integral part of industrial operations, mechanical and metallurgical properties of material has to be improved i.e. fatigue strength, toughness and corrosion resistance for long life of material [14]. It is very important analyze of literature review to understand the positives and minuses (Negatives) of the laser shock peening technology on different alloys and metals.

2.2. Examples investigation

We try in this chapter focus about different studies and investigation of metals and alloys that have likeness with the laser peening technology and studied of corrosion behavior and we also Accreditations by owner Qualifications and most articles diffuse in the world. Now we go direct to extricating some of these studies and in investigations through the following points for examples:-

- **TFH Mohamed Abed El Rahim and MAM Ibrahim(Cairo, Egypt) [15]**: Studied the Improving the Corrosion Behavior of Ductile Cast Iron in Sulphuric Acid (Heat Treatment), the investigation studied appears the effect of heat treatment on the corrosion behavior of ductile cast iron (DCI) in H2SO4 environment through the tempered specimens at different tempering times show better corrosion resistance in H2SO4 solution than that without heat treatment. In the additions the mechanical properties such as tensile strength also appears positives results.
- **Allan H. Clauer and John H. Holbrook, [16]**: Studied a high-energy LSP which can generate pressure pulses 6 to 10 GPa on metal surface of aluminum alloy. The propagation of these pressure pulses into the metal in the form of a shock wave produces changes the mechanical properties compared to unpeened. The main conclusions derived from this work were increases in hardness, tensile strength and fatigue life due to LSP. The increases in fatigue life are a result of significant residual surface stresses generated due to shock process.
- **Aniket Kulkarni1, Siddarth Chettri1 (India) [17]**: Studied the Effect of Laser Shock Peening Without Coating on Surface Morphology and Mechanical Properties of Nickel-200. The study appear the results improvement in the surface stress from 32.6 MPa to a maximum of 323.4 MPa. And the micro hardness test confirmed that the LSP process resulted in work hardening as well as the increase in the depth of hardened layer. Also Increase in the surface roughness after applied the laser peening process causative to improve the corrosion resistance, fatigue and wear resistance.
- **Prof. Yongkang Zhang, and Dr. Kaiyu Lu [18]:** are studied and investigation of AISI 304 SS subject to laser shock peening processing ,The LSP clearly appears improvement the nano-hardness and elastic modulus of the LSP region in near-surface layer. And the impacts of LSP can generate high-level compressive residual stress and refine original grain in the surface layer of AISI 304 SS. Finally

the Corrosion of AISI 304 with LSP impacts appears the improvement the corrosion rate of the samples are reduced.

- **Xing-Quan Zhang [19]:** Studied the fatigue properties of laser shock processing LSP on both side surfaces of fastener hole with diameter of 3 mm in the LY12CZ aluminum alloy specimens were investigated. The superficial residual stress was measured by X-ray diffraction method. Fatigue experiments of specimens with and without LSP were performed, The results indicate that the compressive residual stress can be inducted into the surface of specimen, and the fatigue life of the specimen with LSP is 3.5 times as long as that of specimen without LSP.
- **Yasuo Ochi et.al [20]**: Tested specimens of a 7050-T7451 aluminum alloy at axial fatigue tests to investigate the effects of laser peening treatment without protective coating LPWC on fatigue property. The fatigue crack propagation property from the pre-crack by the LPWC treatment was evaluated by the stress intensity factor range including the residual stress induced by the LPW treatment. It was observed that the laser peening increased the mechanical properties and fatigue life.
- **Rubio-Gonzalez et.al [21]**: Studied the crack growth for 6061-T6 aluminum specimens with and without laser shock peening LSP. They found a reduction in fatigue crack growth rates and increased in fatigue life and strength for LSP specimens comparing with unpeened specimens.
- **Omar Hatamleh [22]:** Compared between the laser peening and shot peening using friction stir welded of 7075-T7351 aluminum alloy specimens. It was found that the improvement was obtained using shot peening 7% , but a significant increase in fatigue behavior were noticed when using laser peening in a value was 146% .
- **Sathyajith et al [23]**: Tested aluminum alloy Al 6061 -T6 using low energy laser without coating and they found that laser peening can significantly improve surface compressive stress and micro-hardness with some increase in surface roughness.

The above increase in compressive stress leads to improve the life and strength of metal used.

2.3. Summary of the Previous Studies

From above Laser shock peening technology (LSP) appear importance pattern in the industrial plant to increase the efficiency and the safety and others, especially the costs the construct the industrial plant in general very high and required long time for building process. So we try from this tittles find best way to apply the laser peening on the carbon steel and copper to improve the corrosion behavior for them, especially the problems of corrosion very high in the industrial side.

However, a few investigations have considered the effects of laser shock peening on behavior of corrosion for Carbon steel and copper alloys, since these material have great and high application in the industrial plant especially for molten sulfur. So we try to find best way to improve the Corrosion resist for these alloys through laser peening technology with taken in account the efficiency, economic and safety patterns must be found in the studying, to get best results.

CHAPTER THREE
The Experimental work and Description

3.1. Introduction

We done several proceedings and preparation to get careful data. In order to touching graphicness in writing the project. In general, we dealing with two types of alloy carbon steel and copper, since there are very large different in properties of mechanical, chemical, and metallurgical between the types of alloys.

The corrosion is defined in different ways, but the usual interpretation of the term is an attack on a metallic material by reaction with its environment. Most the problems of corrosion is made due present of sulfur, especially when the sulfur teach the metals [24].

The problems of corrosion in the industry can be summarize by the points:-

- **Contamination:-** During the corrosion of a metal, the fluid being transported, stored, processed, or packaged in a metallic component can pick up metallic salts. With days a color alteration, and in some cases of intermediate products the inability to carry out succeeding process steps.
- **Loss of Efficiency**: - Corrosion in a piping system and pumping unit can result in the buildup of a scale. Cause a reduction in heat transfer as well as an increase in the power required to pump the fluid through the system. The efficient operation of other mechanical equipment can also be reduced by corrosion. This reduction in efficiency can cause an increase in operating costs as well as result in increased fuel consumption, lubricant loss, and reduced work output.
- **Environmental Damage: -** Corrosion of equipment used to control atmospheric pollution resulting from processing operations can result in a decrease in efficiency.

3.2. The General Properties of molten Sulfur

The General Properties of molten sulfur involve [12]:-

- Appearance: Amber Liquid.
- Odor: Slight Hydrocarbon Rotten-egg.

- PH: Neutral.
- Melting Point: 233 °F (111.67 °C)
- The Boiling Point about 832 °F (444.44 °C).
- Flash Point: 405 °F (207.22 °C).
- Freezing point: variable with the conditions.
- Vapor Pressure: 1 mm Hg at 362 °.
- Viscosity: not constant since it variables with the temperature.
- Specific Gravity: 2.06 at 60 °F.

3.3. The main methods that used to express the corrosion rate

Measurement the effect of corrosion on the samples consider very important part in assess of the project. In general, there are three main methods that are used to express the corrosion rate of the samples**:-**

1-Thickness reduction of the material per unit time.

2-Weight loss per unit area and unit time.

3- Corrosion current density.

We will depend on the weight loss per unit area and unit time in our study because the corrosion effect consider importance pivot in this investigation. Problem of corrosion should be considered during the early design stage of any project and why it is necessary to constantly monitor the integrity of structures, bridges, machinery, and equipment to prevent premature failure.

3.4. The obtainment on samples and data

Stage one: - we obtain data from al-mishraq sulfur general company –one of Iraqi ministry of industry companies. Actuality we get samples (sulfur) in solid state, al mishraq field distinct by produce pure sulfur approximately 99.7%, but in the fact there several stations and processing units in the field may be sometimes dealing with non-pure sulfur, since it required difficult process and control operations to get in finally pure sulfur. And we choice pure sulfur because the limitation laboratory technologies.

Fig. (3) Shows the pure sulfur in solid form

We convert the pure sulfur (solid form) to powder by crunching process to improve the Melts process of sulfur by increase the heat. To get easier system for solution testing of samples, especially the samples required several days and several operation time into the solution (molten sulfur) with controlled degree of temperature, since sulfur melt at approximately (120°C), These considerations very important in our project.

Fig. (4) Shows crushed sulfur

Stage two: - obtain samples metals copper and carbon steel though local source and with special properties attempting to get best outcomes. In the additions these types of alloys have more abundant and using for huge application in industrial operations. Since most parts of pumps are made from this type of metals.

After that from the Northern technical university – mechanical workshop, we convert the metals to geometrical samples (studied length and diameter).

The figure below shows the machine used to preparation of the specimens.

Fig. (5) Shows the mechanical machine (Turing) that used to make the Specimen in the Northern technical university – mechanical workshop

The specimen is made according to standard specification 80 mm long, thickness 10 mm in ends and decrease in the center. The final shape for the samples will be:-

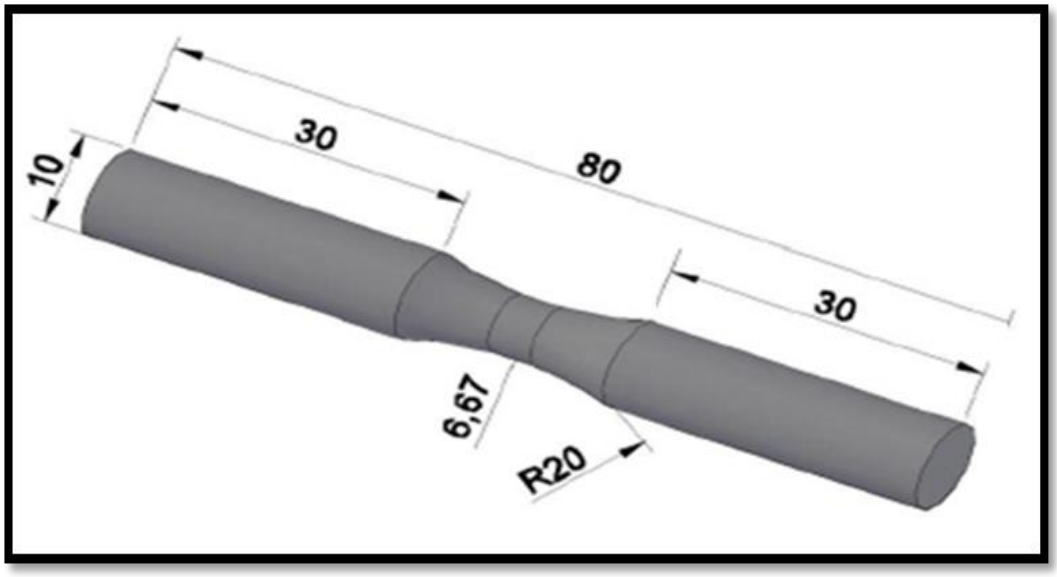

Fig. (6) Geometry of test Specimens

And we choice these types of alloys because they have several applications in industrial Surface facilities, so we go direct to study the behavior of these alloys to the corrosion to understand the behavior of impeller of molten sulfur pump. Since many part of sulfur pump are made from this type of alloys.

Fig. (7) Shows Geometry of specimen of copper alloys

Fig. (8) Shows Geometry of specimen of carbon steel

And in the final we get

- 20 specimen carbon steel.
- 20 specimen copper.

3.5. Chemical Composition of the samples

The Chemical composition of the alloys was analyzed at The Specialized Institute for Engineering Industries Baghdad-Iraq. Since the test carried using x-ray fluorescent (XRF).

Fig. (9) X-ray fluorescent (XRF)

Table 1. Chemical Composition of Carbon Steel alloy:-

Composition	Carbon	Manganese	Iron	copper	phosphorous	silicon	Sulfur
Content %	0.25-0.29	1.03	94	0.8	0.09	0.3	0.075

Table 2. Chemical Composition of Copper alloy:-

Composition	Zinc	Silicon	Iron	Titanium	Sulfur	Manganese	Others
Content %	0.7	0.08	98-95	0.11	0.035	0.9	2-1.28

3.6. Mechanical properties of copper and carbon steel alloys

Generally the mechanical properties of the sample in this type of studying consider very important to understand the behavior of the samples during the investigation. The mechanical test was done using 150 KN Instron 225 Testing Machine shapes and dimensions of the tensile specimen are taken according to (ASTM A370).

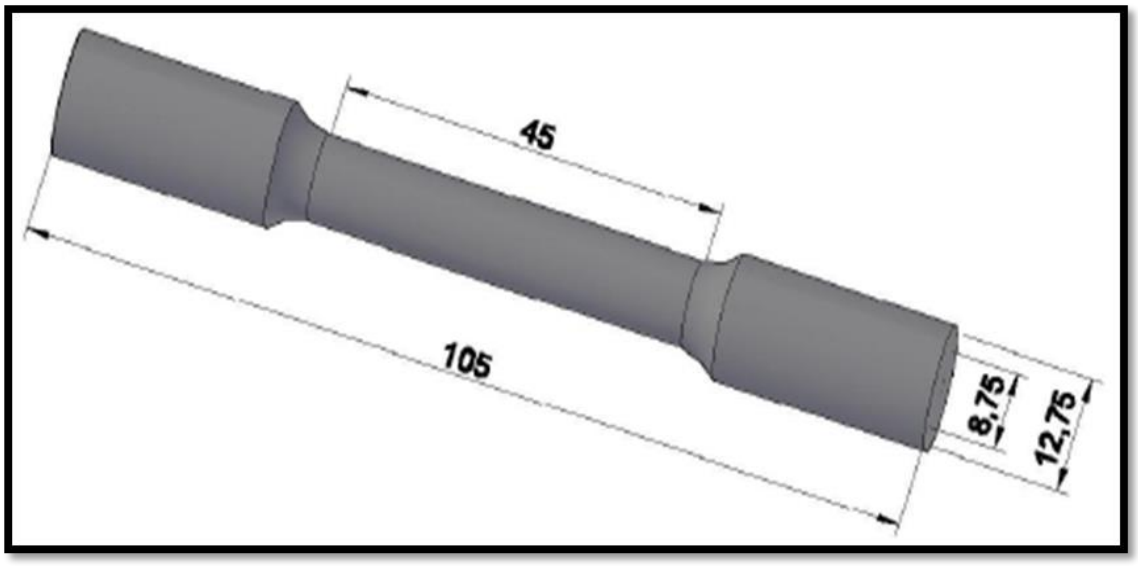

Fig. (10) Geometry of tensile Specimen

The experimental results are summarized in table below and we chose the properties which deals with our studying to full understanding the testing results

Table 3. Mechanical properties of copper and carbon steel alloys

Properties	Carbon steel	Copper
Density	7.85 g/cm^3	8.95 g/cm^3
Molting point	1425 °C	1083°C
Specific gravity	7.85	6.7
Corrosion resist	Good	Less than carbon steel
Elastic modulus(E)	200 Gpa	170 Gpa
Strength	Decrease with increase In temp.	Decrease with increase in temp.
Passions ratio (μ)	0.260	0.22
Elongation %	23%	20%
Shear modulus	79.3 Gpa	67 Gpa

Now we go direct to summarize the preparation of the systematic method used in project and the Details of laser peening test rig in University of Technology (laser and Electric optical engineering department). Since we divided the specimens into groups and in the same time we taking about the solution test for corrosion (molten sulfur). After that we compare the results to understand the behavior of corrosion for each type of alloys carbon steel and copper.

3.7. Laser peening treatment of specimens

Laser peening operation was carried out in a special devices (Q- switched Neodymium-YAG laser system) at laser department in the university of technology. This device enables treat the flat and round specimens, by spot laser peening. And there several method and specification for getting the results according to the requirement such as using air, water and similar to act as medium to control the specification of the laser peening.

Selecting the laser shock peening not only depended on the physical characteristics such as laser power density to achieve high pulse pressures and the mechanical responses but also needs to consider some specific requirements such as cost, efficiency, maintenance and part replacements and so on. Three types of laser peening were used as follows:-

1. **Air laser peening (ALP)**

Is the process of the specimen subject to laser directly and without any insulator separates the laser and the surface of the specimen and the distance between the lens and the specimen is (13.5) cm ,and is noticeable a clear deformities in the specimen's surface as a result of high thermal energy of the laser.

Since this type consider bad because the higher temperature energy of the laser may be effect on the composition of structure of metal (covalently construct) that existed near the surface of the metals resulting to great fracture and rend of the composition of metals and in the final provide bad results. The figure below appears the specimens during Air laser treatment

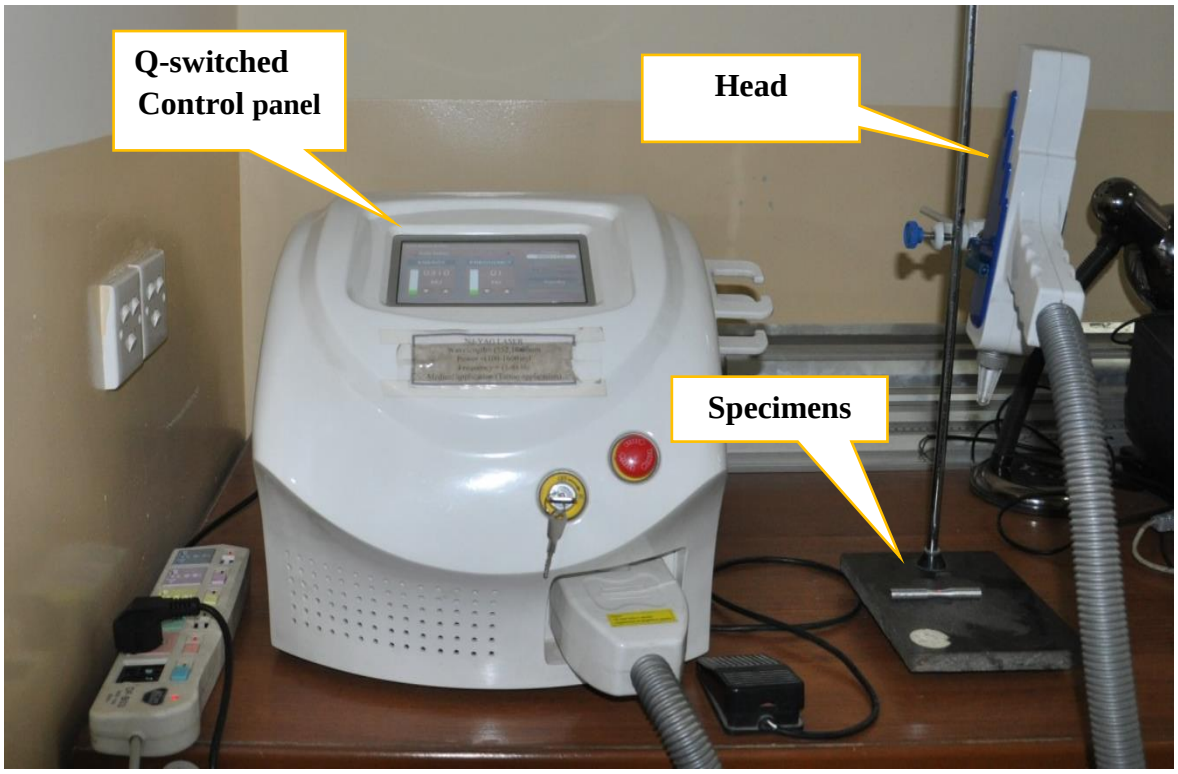

Fig. (11) Shows the specimens during Air laser treatment

2. Water laser peening (WLP):-

The basic principle behind laser peening with sample in water confinement can be explained as follows. When a laser pulse is focused on a target which is immersed in water, the target surface layer evaporates instantaneously.

This process converts the vapor to high temperature plasma. The specimen is subject to laser process after immersion in water at a depth of (5-10) mm and noted that the distortions that occur in the specimen surface as a result of high thermal energy of the laser to be much less than the air condition. The specimens during water laser treatment can be shown in figure below

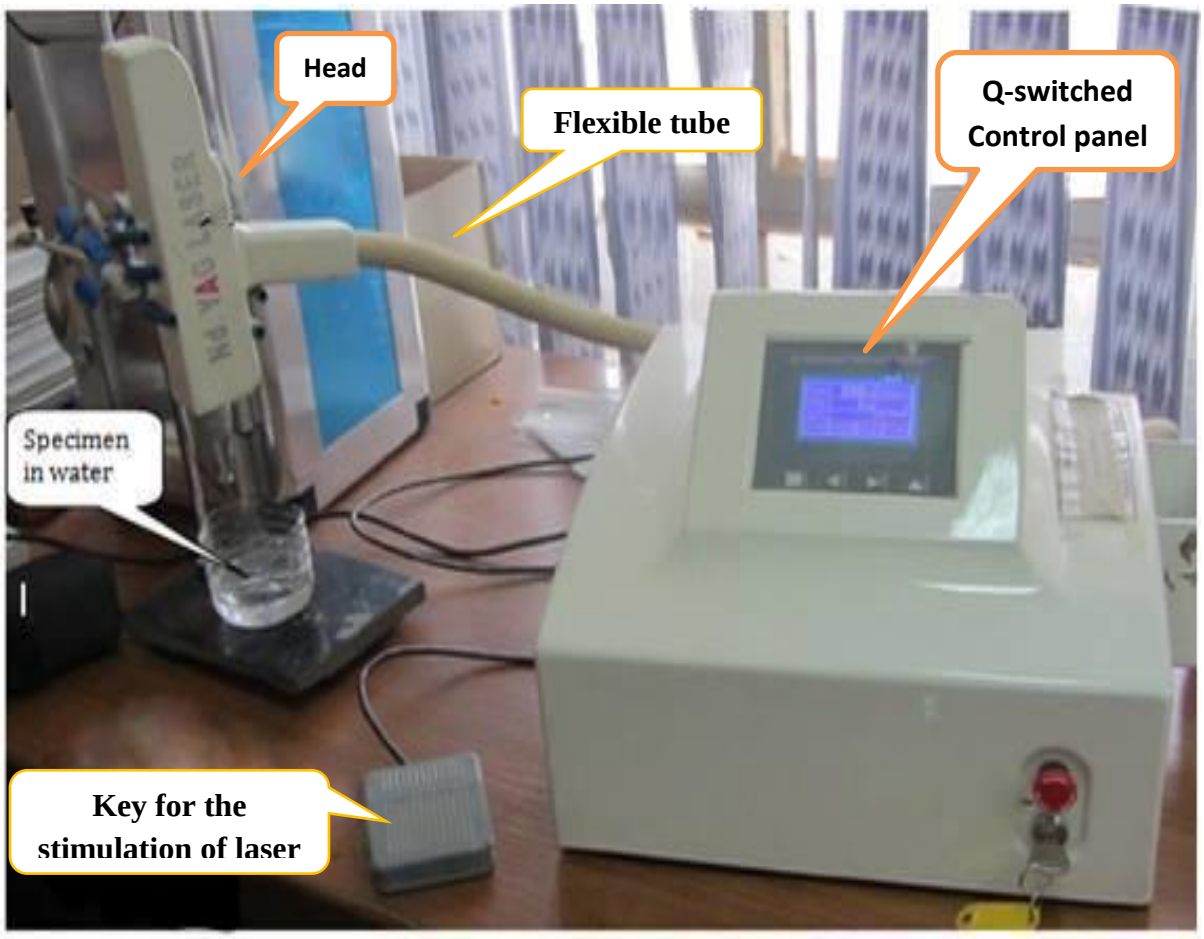

Fig. (12) Shows Specimens under WLP

3. Coating laser (black paint laser peening):-

The specimen is subjected to the laser process after a protective coating (sacrificial overlay) on specimen surface. The coating is usually formed from black paint prior to laser irradiation and the remaining paint is removed after the treatment, and place of the coating to be clear about the curvature area in the specimen where failure occurs here because it stresses concentration area.

This types consider bester method of laser peening applications. Because after the treatment the behavior of the specimens improved. the figure below shows the specimen with coating under effect of the laser peening

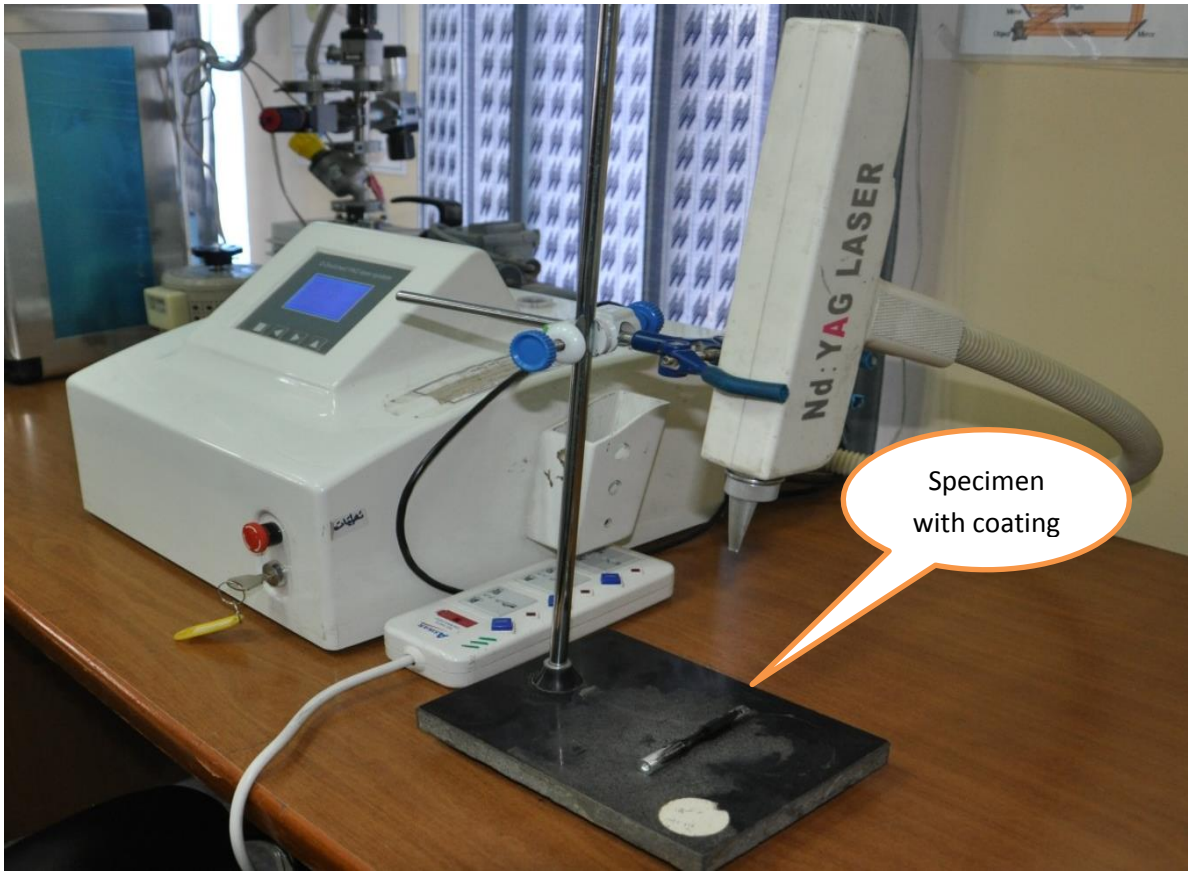

Fig. (13) Shows Specimens under black paint laser treatment (BPLP)

3.8. The laser peening device properties can be summarized as:-

- Laser wavelength is about 1.065 µm .
- Pulse duration 7 nano seconds .
- Pulse energy (1000)mJ .
- Frequency (6) Hz .
- The distance between the lens and the specimen is (13.5) cm.
- Spot size (1.5) mm.
- The laser spot is typically (8) aroud specimen's diameter .
- The deep water to the area that treated is typically (5-10)mm.

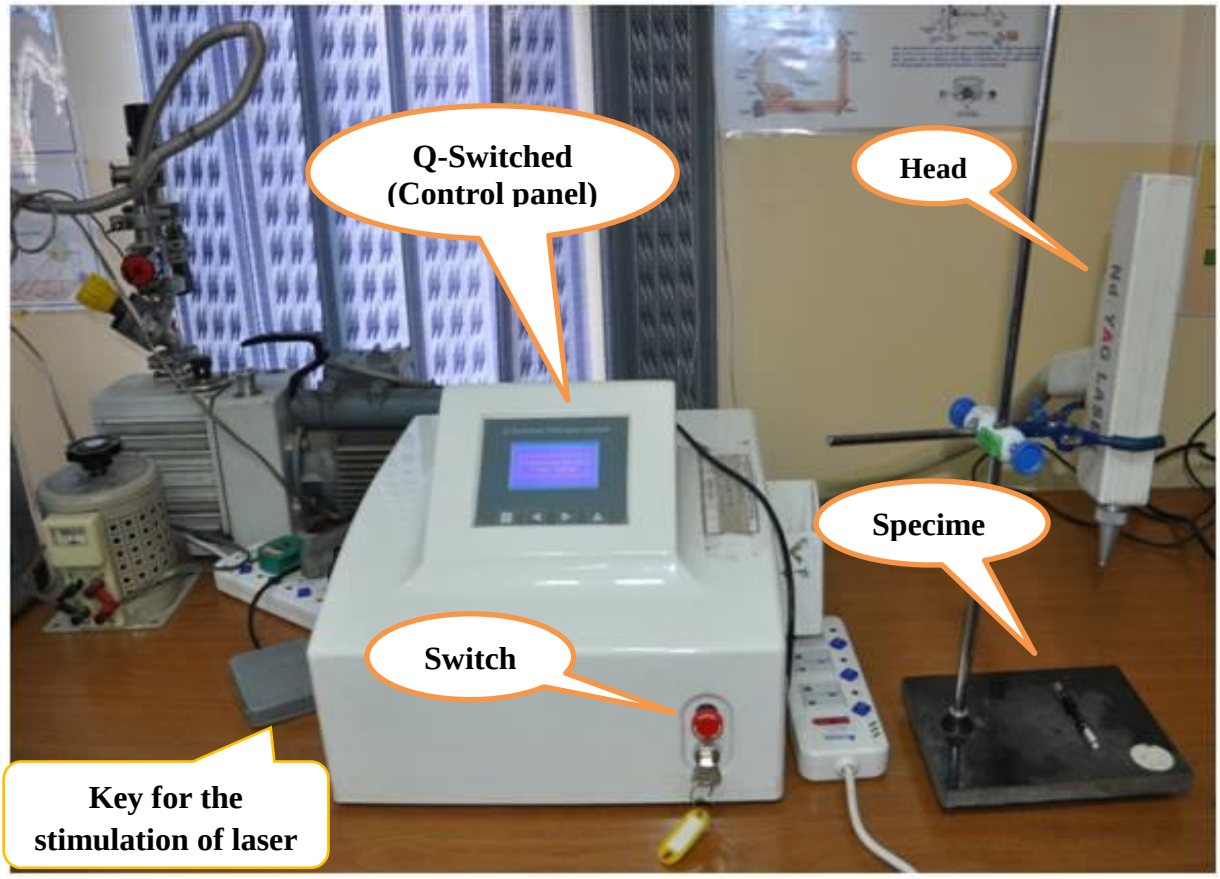

Fig. (14) Details of laser peening test rig in University of Technology (laser and Electric optical engineering department)

3.9. The preparation of the systematic method used in project

- **Heater: -** Which provide continuous temperature to keep the sulfur at melting temperature. And from gradations of temperatures we can control the degree of machine. The specification of heater that used in the investigation involved:
  Various heat operations, anti-heat product easy to clean, high quality, overhead Production, Power supply (220/230V, 50/60 HZ) to provide best environment Workspaces and in the final to get best results.
- **Beaker :-** Cylindrical construct and with special properties such as opportune volume 500ml according to size of samples (metal alloys) heat resistant, Anti-breakage, little effected with vapors product since we dealing with sulfur so resultant vapors may be breakneck and rapid interaction and influence.

- **Granules Sand: -** because all modern heater provider by sensors system, which automatically stopped to take rest and then completed to provide safety conditions especially we dealing with danger substances also to keep the temperature at point of melting of sulfur when the heater take rest.
- **Plate: -** increase the surface area of the reaction to containment the Pyrex and the solution (molten sulfur).
- **Thermometer: -** to assaying the degree temperature of the solution (molten sulfur) because we dealing with variable conditions such as disconnection current electrician, desistance of heater etc...
- **Safety laboratory tools: -** such as latex gloves, muzzles and tongs.

  Tentatively we try to study the different between the samples with the solution effect and without by applied the laser shock peening technology, since us dealing with two types of metal and with different conditions. By putting the samples into the solution through several times operations, the sulfur when melt convert the color fumes like to Amber Liquid and we see the volume of the liquid decreases day after day because characteristic of evaporation and liberation of gases.in the addition the color of the samples also effected.

  Specimens, about 40 days effected by molten sulfur with heat sources, then we try to find the weight losses of the Specimens. In the same time the second group after applies by laser shock peening process putting them with same time operation into the molten sulfur. the figures below shows the specimens into the molten sulfur since we deepened checking the weight losses during the time also summarized the all results in tables to full complete the understanding the behavior of the specimens for each types carbon steel and copper.

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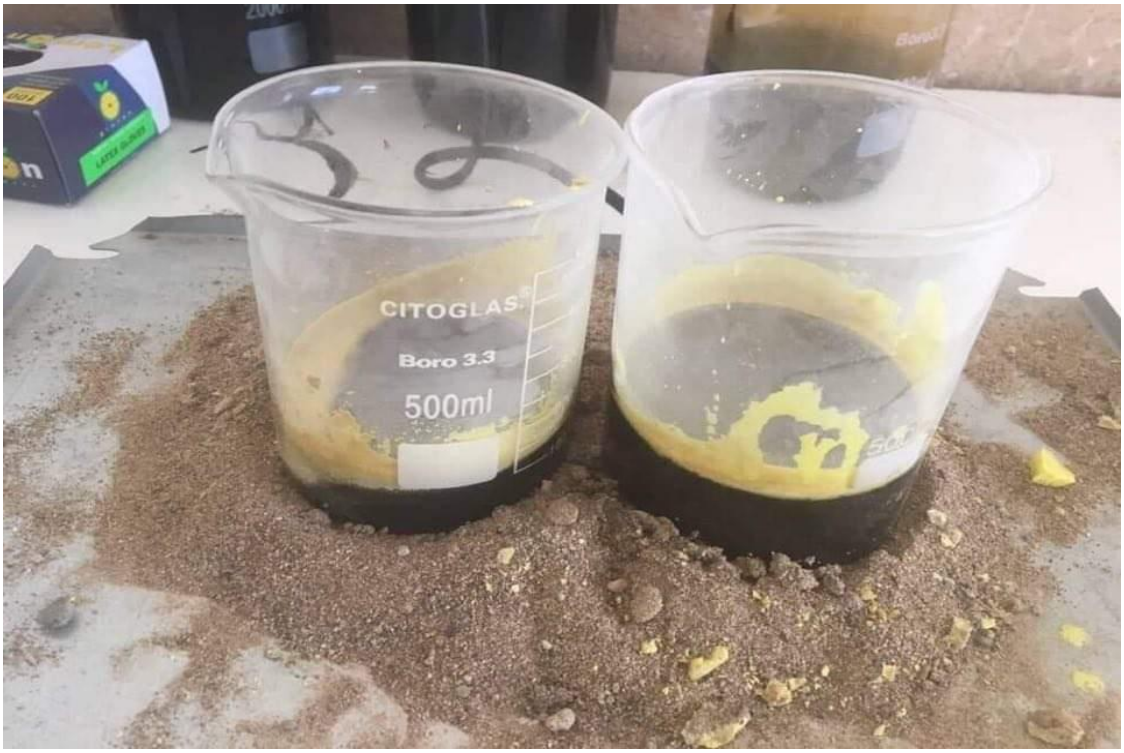

Fig. (15) Shows the specimens into molten sulfur with heater, sand and plate To completely transport the heat

CHAPTER FOUR
Results and Discussion

4.1. Introduction:-

After approximately 40 days the specimens effect by the molten sulfur with heat sources to completely continues present of the samples into molten sulfur and prevent the sulfur to be solidified through cooling. However we dealing with two types of metals Carbon steel and Copper, since each type have special chemical and mechanical properties. And from the first results the weight of a samples, especially after 10 days since the different between the original weight and weight during the time increased. We divided the specimens into two groups, Group one for carbon steel and group two for copper.

Each group contain for types of data , for unpenned, and Air laser peening(ALP), and Water Laser peening (WLP), and Coating laser or black paint laser peening (BPLP). The effect of the laser peening provide positive results on the specimens since weight losses after the treatment decrease by very beautiful values, that means the corrosion resistance of the specimens decreased also.

The black paint laser peening provide bester results, because it classified by providing large amount of energy into the surface of the specimens without effecting on the structure composition of the metals. Since form results, the (BPLP) type gives lower value of weight losses and provide economic patterns for Corrosion rates for both types of metal Carbon steel and Copper.

The Air laser peening (ALP) type appears negative results, Since this type consider bad for some metals because the higher temperature energy of the laser may be effect on the composition of structure of metal (covalently construct) that existed near the surface of the metals resulting to great fracture and rend of the composition of metals and in the final provide bad results.

4.2. The measurement of weight losses and Corrosion rate

We using these relationships to understand the behavior of the specimens during the time. Where:-

$$\textbf{Corrosion rate(mpy)} = \textbf{534} * \left(\frac{\textbf{W}}{\textbf{D} * \textbf{A} * \textbf{T}}\right)$$

Where: (mpy) means mils penetration per year, 1 mils= 10^{-3} inch.

W= weight loss (g).

D= density of sample g/cm3.

A= area of sample (inch2).

T= exposure time (hrs.).

$$\textbf{Weight losses(g)} = [\textbf{Initial Weight(g)} - \textbf{Final Weight(g)}]$$

From the equations above there are relative direct relationships between the Corrosion rate and weight losses, since the surface area, the exposure time, and the density acts as a resist parameter the increase the value of the corrosion rate.

The tables results depended on the divided the data as:

- First the behavior of specimens without laser peening.
- Second the behavior of specimens with Air laser peening (ALP).
- Third the behavior of specimens with Water laser peening (WLP).
- Fourth the behavior of specimens with Coating laser or black paint laser peening (BPLP).

4.3. The description and analyze the results of carbon steel investigation

The table below shows the measurement of original weight and after treatment with timing operation per days, and list of treatment according to the number of the specimens of carbon steel.

Table 4. The original weight and reading of weight of the Carbon steel specimens with the time and types of treatment according to the number of the specimens.

Sp. No.	Treatment	Original weight	Weight after 5 days	Weight after 10 days	Weight after 15 days	Weight after 20 days	Weight after 25 days	Weight after 30 days	Weight after 35 days	Weight after 40 days
1	**Unpeend**	44.70	44.1	43.3	42.6	42	41.1	40.4	39.8	39.1
2	**Unpeend**	43.80	43.2	42.4	41.8	41.2	40.5	39.9	39.3	38.7
3	**Unpeend**	46	45.4	44.8	43.9	43.2	42.6	42	41.4	40.8
4	**Unpeend**	45.20	44.6	43.8	43.2	42.4	41.6	41	40.4	39.8
5	**Unpeend**	44.60	44	43.2	42.6	41.8	41.2	40.6	40	39.1
6	**ALP**	45.11	43.81	42.41	40.01	39.71	37.91	36.61	34.81	32.91
7	**ALP**	44	42.7	41.3	39.5	38.1	36.6	35.2	33.4	31.9
8	**ALP**	45.50	44.1	42.6	40.8	39.2	37.9	36.5	34.9	33.4
9	**ALP**	45	43.7	41.9	40.3	38.7	37.2	35.9	34	32.1
10	**ALP**	44.5	43.2	41.7	40.4	38.8	37.3	35.3	33.4	31.5
11	**WLP**	44	43.7	43.4	43	42.5	42.2	41.6	41.2	40.9
12	**WLP**	46	45.7	45.3	45	44.5	44.1	43.8	43.4	42.8
13	**WLP**	44.3	44	43.7	43.4	43	42.6	42.3	42	41.5
14	**WLP**	45	44.7	44.2	43.6	43.4	43	42.5	42.2	41.6
15	**WLP**	45.5	45.1	44.8	44.3	43.7	43.3	42.9	42.5	42.2

16	**BPLP**	45.3	45.2	45	44.7	44.4	44.2	44	43.8	43.6
17	**BPLP**	44	43.8	43.6	43.5	43.2	43	42.8	42.6	42.4
18	**BPLP**	44.7	44.5	44.3	44.2	44	43.8	43.6	43.4	43.2
19	**BPLP**	43.8	43.6	43.4	43.2	43	42.8	42.6	42.5	42.3
20	**BPLP**	45	44.8	44.6	44.4	44.3	44.2	44.1	44	43.9

Table above contain high data so we go direct to summarize the data by taken average behavior for each type of the data. As a table below

Table 5. Shows the average weight losses For Carbon Steel per number of specimens per Exposure time (days).

Expsour time (days)	**After 5 day**	**After 10 day**	**After 15 day**	**After 20 day**	**After 25 day**	**After 30 day**	**After 35 day**	**After 40 day**
Averge weight loss(g) per No. of specimens per Expsure time (days)								
Unpeening	**0.6**	**1.36**	**2.04**	**2.74**	**3.46**	**4.08**	**4.68**	**5.36**
ALP	**1.32**	**2.84**	**4.62**	**5.92**	**7.44**	**8.92**	**10.72**	**12.46**
WLP	**0.32**	**0.68**	**1.1**	**1.54**	**1.92**	**2.34**	**2.7**	**3.16**
BPLP	**0.18**	**0.38**	**0.58**	**0.78**	**0.96**	**1.14**	**1.32**	**1.46**

The table above provied summerizes pattern to behavior of Carbon Steel specimens into the mplten sulfur during exposure Time. since depened on the difference between the weight in the original condition and effected weight during the time.

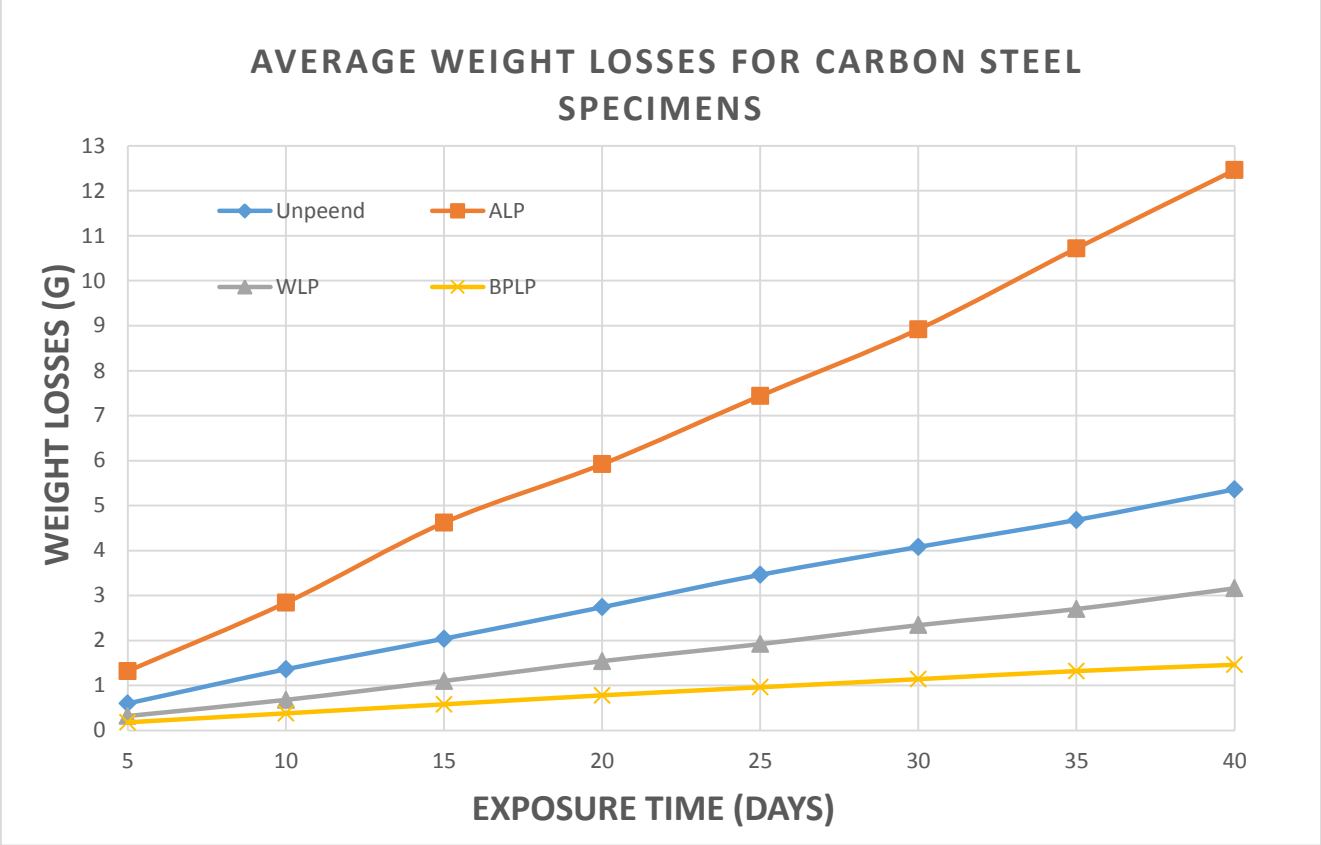

Fig. (15) shows the averge weight losses of Carbon steel during the expo. time

From The figure above the effect Air laser penning type gavies negative results since the weight losses of the samples increased with the time . subtended the black paint laser peening (BPLP) provide best results due to special properties of the energy that improved the composition structure of the specimens.

Table 6. The Corrosion rate per Exposure time for Carbon steel:-

Expsour time (days)	After 25 h	After 50 h	After 70 h	After 90 h	After 100 h	After 120 h	After 130 h	After 150 h
Types of treatment	Corrosion rate(mpy)							
Unpeening	0.486	0.550	0.590	0.616	0.700	0.688	0.728	0.723
ALP	1.068	1.149	1.335	1.331	1.505	1.504	1.668	1.681
WLP	0.259	0.275	0.318	0.346	0.388	0.395	0.420	0.426
BPLP	0.146	0.154	0.168	0.175	0.194	0.192	0.205	0.197

The figure below shows the Corrosion rate (mpy) of the Carbon steel according to density, weight losses, and surface area of the specimens.

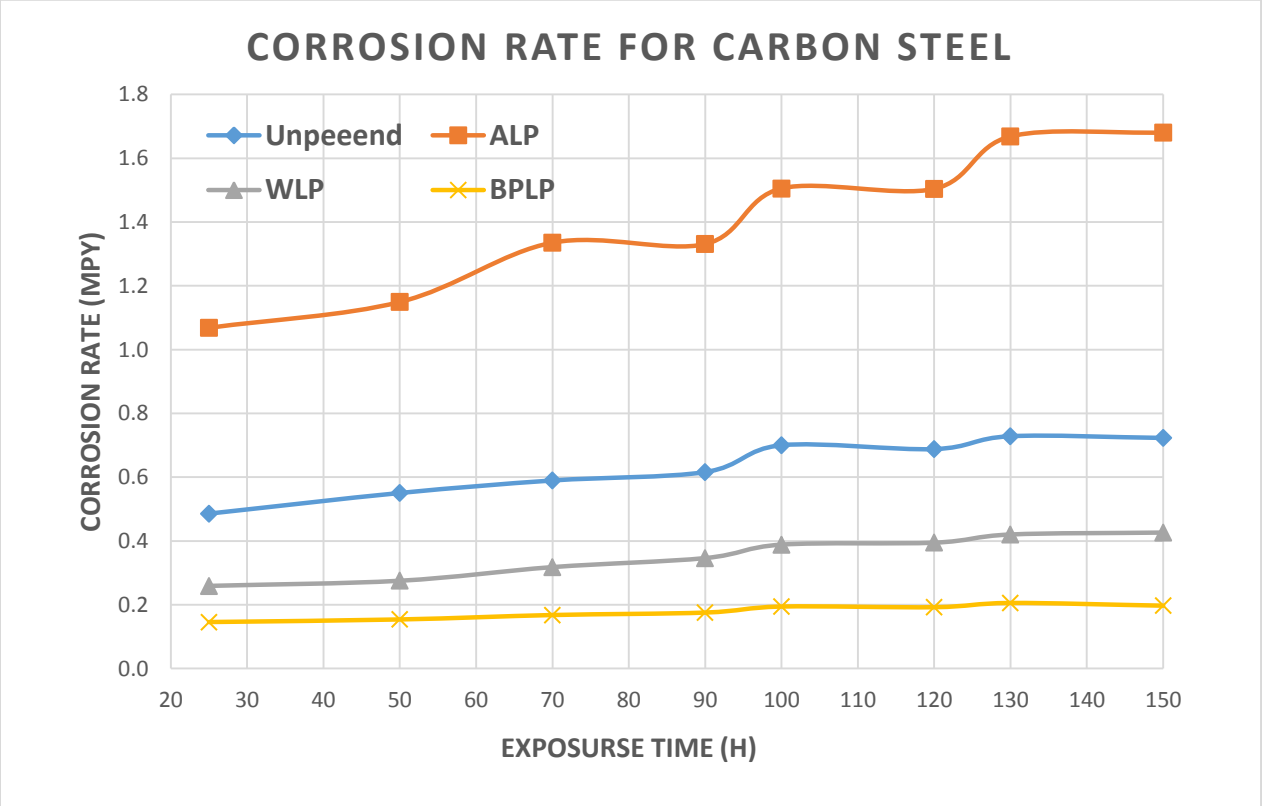

Fig. (16) Shows the Corrosion rate per Exposure time for Carbon steel

According to the figure above the (BPLP) appears bester behavior of corrosion effect of Carbon steel specimens during the time if compared with another types of laser shock peening technology.

4.4. The description and analyze the results of copper investigation

The table below appears the weight losses of Copper during the time of exposure, since the Data taken through 40 days. We have also four type of data

- First the behavior of specimens without laser peening.
- Second the behavior of specimens with Air laser peening (ALP).
- Third the behavior of specimens with Water laser peening (WLP).
- Four the behavior of specimens with Coating laser or black paint laser peening (BPLP).

Table 7. The original weight and reading of weight of the Copper specimens with the time and types of treatment according to the number of the specimens.

Sp. no.	treatment	Original weight	Weight after 5 days	Weight after 10 days	Weight after 5 1days	Weight after 20 days	Weight after 25 days	Weight after 30 days	Weight after 35 days	Weight after 40 days
1	**Unpeend**	54.29	53.09	51.79	50.29	48.69	47.39	45.99	44.39	42.89
2	**Unpeend**	53.75	52.45	51.05	49.65	48.25	46.85	45.45	43.65	41.85
3	**Unpeend**	55.20	53.9	52.5	51	49.4	47.7	46.3	45	43.8
4	**Unpeend**	50.90	49.6	48.2	46.9	45.1	43.7	42.3	40.8	39
5	**Unpeend**	51.73	50.43	49.13	47.73	45.23	44.63	42.83	41.33	39.73
6	**ALP**	51.80	49.7	47.4	44.9	42.2	40.1	37.4	35.2	33.1
7	**ALP**	50	47.9	45.7	43.4	40.9	38.5	36	33.1	30.2
8	**ALP**	55	52.9	50.2	47.7	45.2	42.8	40.7	37.8	35.3
9	**ALP**	51	48.6	46.5	44.3	41.8	39.2	36.3	33.8	31.2
10	**ALP**	53	50.8	48.3	45.7	43.1	40.5	37.9	35.5	33.3
11	**WLP**	54	53.7	53.4	53	52.8	51.5	51	50.8	50.4
12	**WLP**	55.5	54.9	54.3	53.3	52.7	51.7	50.5	54.9	54
13	**WLP**	54.7	54	53.4	52.4	51.8	50.8	49.8	49.2	48
14	**WLP**	51	50	49	48.4	46.9	46.2	45	44.6	44

15	**WLP**	50	49.4	48.2	47.9	46	45	44.1	43.7	43
16	**BPLP**	54.8	54.6	54.2	54	53.8	53.6	53.3	53	52.9
17	**BPLP**	53	52.8	52.5	52.3	52.1	52	51.9	51.7	51.5
18	**BPLP**	56	55.8	55.2	55	54.8	54.6	54.4	54.2	54
19	**BPLP**	55	54.9	54.6	54.4	54.2	54	53.9	53.8	53.6
20	**BPLP**	54	53.9	53.6	53.4	53.2	52.8	52	51.8	51.6

The summerizes of the data above showen in thable below, since we measure the average weight losses of the Copper specimens during the time exposure.

Table 8. shows the behavior of weight losses of Copper during the time of exposure.

Expsour time (days)	**After 5 day**	**After 10 day**	**After 15 day**	**After 20 day**	**After 25 day**	**After 30 day**	**After 35 day**	**After 40 day**
Averge weight loss(g) per No. of specimens per Expsure time (days)								
Unpeened	**1.28**	**2.64**	**4.06**	**5.84**	**7.12**	**8.6**	**10.14**	**11.72**
ALP	**2.18**	**4.54**	**6.96**	**9.52**	**11.94**	**14.5**	**17.08**	**19.54**
WLP	**0.64**	**1.38**	**2.04**	**3**	**4**	**4.96**	**4.4**	**5.18**
BPLP	**0.16**	**0.54**	**0.74**	**0.94**	**1.16**	**1.46**	**1.66**	**1.84**

When we Compare this results of Copper with Carbon steel results we see the Carbon steel provied best pattern with the time ,since the weight losses in it samller that in Copper .

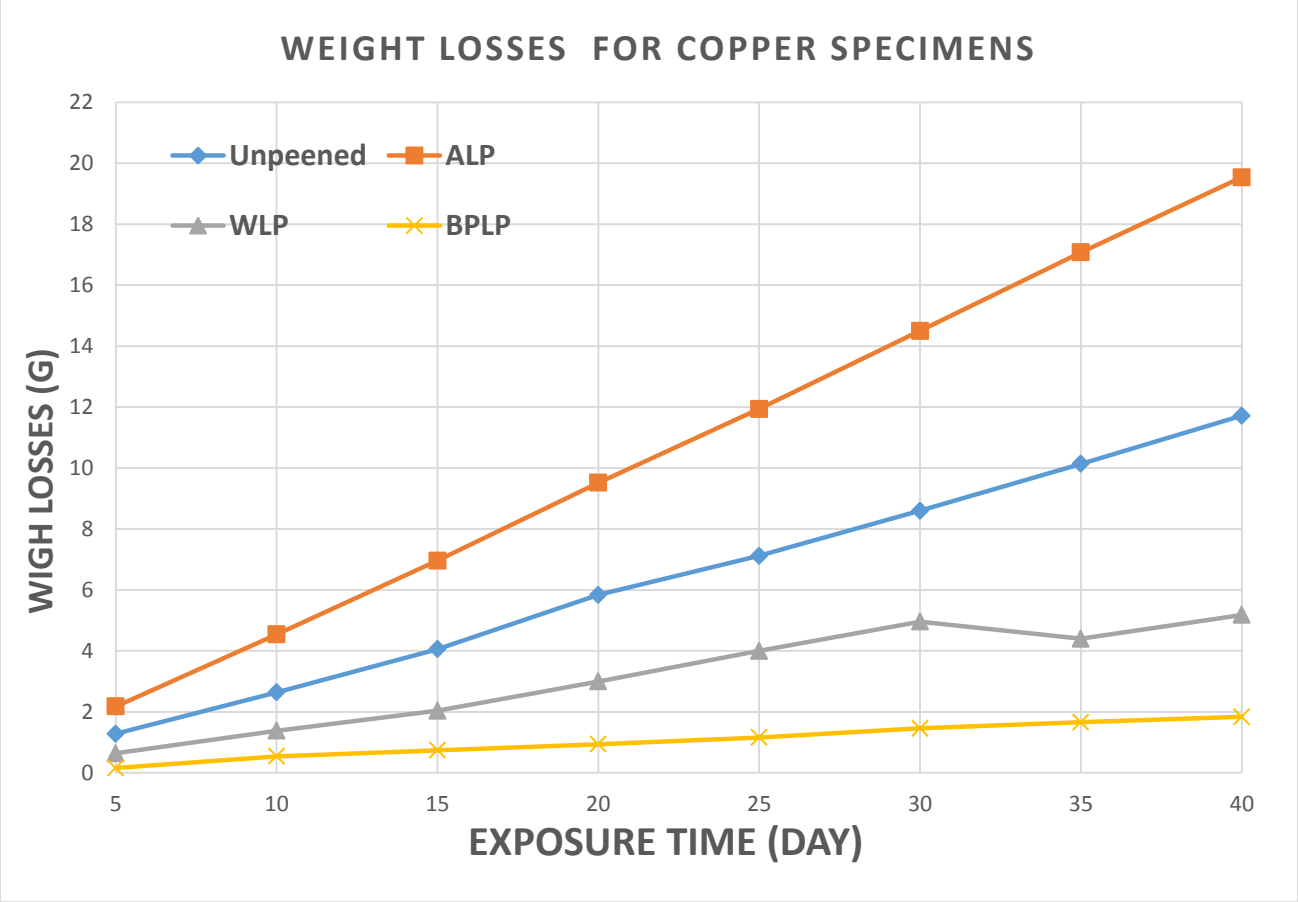

Fig. (17) shows the weight losses of Copper specimens with the Eposure time

Table 9. Shows the corrosion rate of Copper specimens during the Time

Expsour time (days)	After 25 h	After 50 h	After 70 h	After 90 h	After 100 h	After 120 h	After 130 h	After 150 h
Types of treatment	Corrosion rate (mpy)							
Unpenned	0.907	0.936	1.028	1.150	1.262	1.270	1.382	1.385
ALP	1.545	1.609	1.762	1.874	2.116	2.141	2.328	2.308
WLP	0.454	0.489	0.516	0.591	0.709	0.732	0.600	0.612
BPLP	0.113	0.191	0.187	0.185	0.206	0.216	0.226	0.217

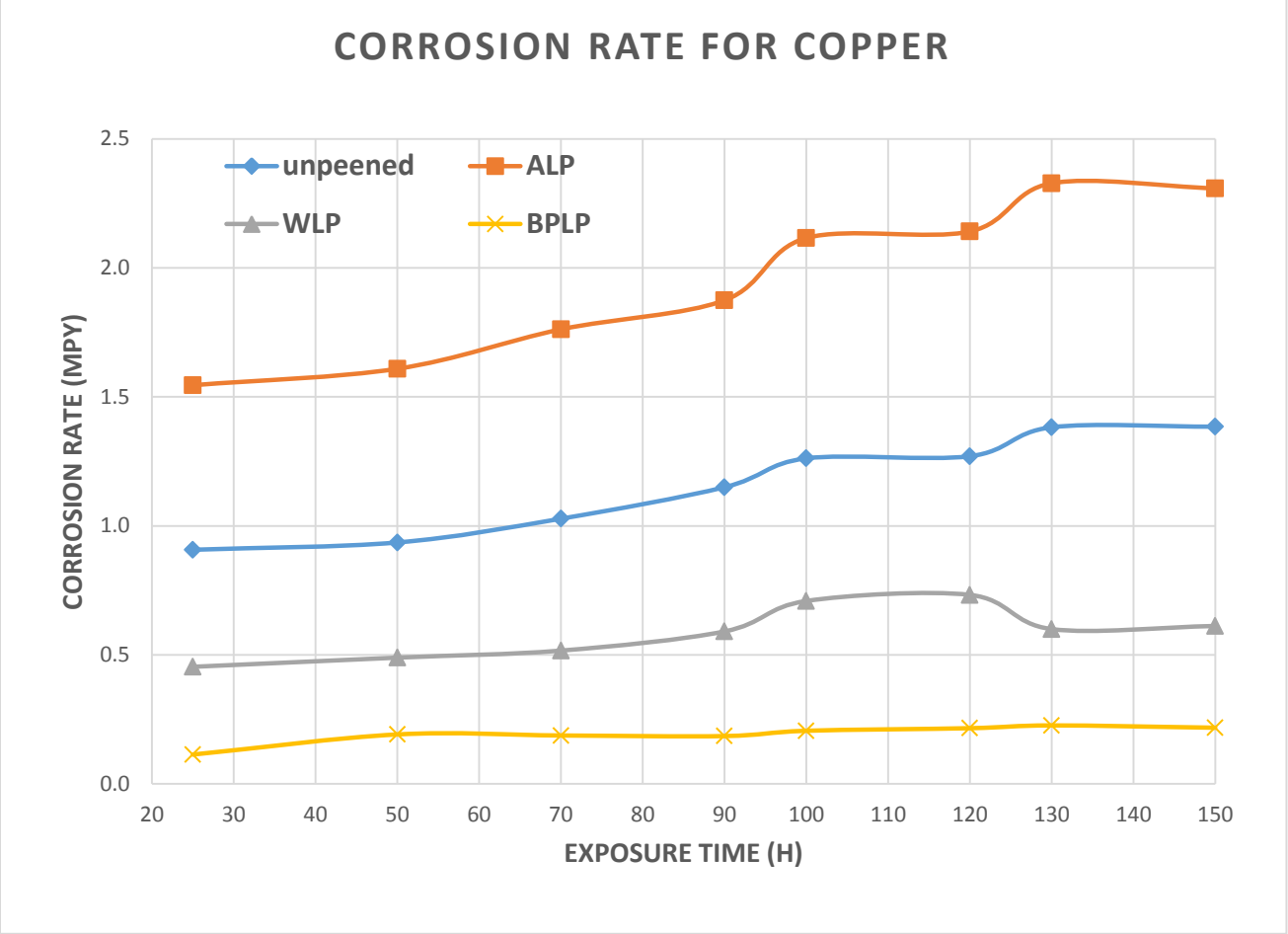

Fig. (18) Shows the Corrosion rate per Exposure time for Copper

From the figure above the Air laser peening (ALP) provied bad results that can be appeared by the Corrosion rate since it increse during the time .

CHAPTER FIVE
Future Work and Conclusion

5.1. Introduction:-

The Laser Shock Peening Technology through the investigation of molten sulfur provide beautiful results since we could to improve the Corrosion resistance. But in fact there are many problems in the industrial side, especially many times the best conditions cannot present for several results. In the addition the exigencies of modern equipment needs special circumstances to get best production rates, safety conditions for worker and their equipment, and flexibility in the procedures.

5.2. Conclusion:-

From all above can be summerizes the resulting values by the following points :-

- For both Carbon steel and Copper the weight losses increase with time, and becsuse the direct relationship between the weight losses and Corrosion rate, so the the Corrosion rate also increased with exposure time. Although the Copper have higher density if comapred with Carbon steel, but during the investigation appears it gives bad and negative results if compared with Carbon Steel.
- From the results we find that the Coating laser (black paint laser peening) provide very beautiful pattern since it improved the properties of mechanical and structure of the both metals Copper and Carban Steel, anthor types also provide improvent of metals but less than black paint laser peening (BPLP).
- The Air Laser peening (ALP) provide very bad and negative behavior for both types of metlas, because the higher temperature energy of the laser may be effect on the composition of structure of metal (covalently construct) that existed near the surface of the metals resulting to great fracture and rend of the composition of metals and in the final provide bad results.

- The Water Laser peening (WLP) provide some improvement because the water act as insulator and prevent the specimens to take all energy.
- The Corrosion rate not only depended on the weight losses but there another parametres my also play important rule, since according to the equation of Corrosion that used in the investigation , the surface area , the density, and the exposure time also play important patterns in the Corrosion determantion.
- Most pumps used for molten sulfur applications have a heating jacket in order to keep the temperature constant in all parts of the pumps, molten sulfur not only effected on the parts of pump. To reduce the corrosion rate by reduce the effect of the part of the pump.

5.3. Future Work:-

The main ambition for future development by the Laser shock peening may be involved:-

- Another properties such as fatigue life, increase efficiency, improvement of operation, erosion resistance, Hardness and yield strength can be also investigated and improved by the laser peening technology.
- The petroleum industry, since this side of surface facilities characterizes by Variety and complexity due to provide final products of patrol derivatives required special pattern to dealing with it. For example the pipe of crude oil transport system, tank storage, and similar can improved by the laser peening, in the addition the separation stages, petroleum refineries. Since most time the presence of sulfur with crude oil causes problems.
- In the mining presses, the plant of material and mineral processing, the excavation equipment for both surface and underground mining.
- The meditative side, especially in laboratories equipment to increase the life of them and other properties.
- And anther similar applications.

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