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Effect of Surface Treatment with Laser Beam on the Residual Stress of Carbon Steel

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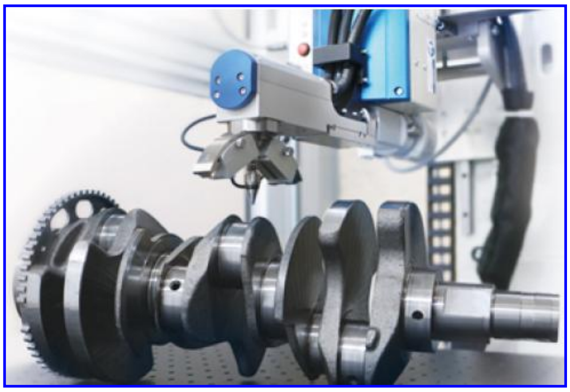
Abstract:
The aim of this study is to study the effect of laser treatment on residual stresses of carbon steel. The results showed the concentration of residual stresses in the laser treated steel compared to the treated steel (850) for 15 minutes and quench it with water. The results also showed the dispersion of residual stresses when the wavelength of the laser beam was increased.

Keywords: *laser treatment, Quenching, microstructure, Tensile Strength, carbon steel.*

I INTRODUCTION

Residual stresses are stresses that remain after removing the underlying cause of stress such as external forces and thermal gradients. These stresses remain in the cross section of the element even after the external cause has disappeared. Residual stresses occur for a variety of reasons including inflexible deformation and heat treatment. The heat produced by the weld may cause local expansion during welding either in molten metal or in welded parts. When the welded parts are cooled, the chilled parts shrink in varying degrees leaving residual stresses [1, 2]. Residual stresses or locked-in stresses can be defined as those stresses existing within a body in the absence of external loading or thermal gradients. In other words residual stresses in a structural material or component are those stresses which exist in the object without the application of any service or other external loads [3]. Thermal stresses can occur in the welded parts at the weld point. Residual stresses are left behind after the welding process is completed. Sometimes the welding joints are not welded. High tension stresses are produced especially in the vicinity of the weld, which may cause welded joints to fail. If the remaining stresses are of the stress type, they are useful and improve the properties of the joint [4]. Residual stresses can be present in any mechanical structure because of many causes. Residual stresses may be due to the technological process used to make the component. Manufacturing processes are the most common causes of residual stress. Virtually all manufacturing and fabricating processes such as casting, welding, machining, molding, heat treatment, plastic deformation during bending, rolling or forging introduce residual stresses into the manufactured object [5]. Residual stress could be caused by localized yielding of the material, because of a sharp notch or from certain surface treatments like shot peening or surface hardening. Among the factors that are known to cause residual stresses are the developments of deformation gradients in various sections of the piece by the development of thermal gradients, volumetric changes arising during solidification or from solid state transformations, and from differences in the coefficient of thermal expansion in pieces made from different materials [6]. Thermal residual stresses are primarily due to differential expansion when a metal is heated or cooled. The two factors that control this are thermal treatment (heating or cooling) and restraint. Both the thermal treatment and restraint of the component must be present to generate residual stresses. When any object is formed through cold working, there is the possibility for the development of residual stresses [7]. A good common example of mechanically applied residual stresses is a bicycle wheel. A bicycle wheel is a very light and strong because of the way in which the components are stressed. The wire spokes are radial aligned and tightening the spokes creates tensile radial stresses. The spokes pull the rim inward, creating circumferential compression stresses in the rim. Conversely, the spokes pull the tubular hub outward. If the thin spokes were not under a proper tensile preload load the thin wire spokes could not adequately support the load of the rider [8].



Residual stresses have the same role in a structure's strength as common mechanical stresses. However, while stress due to external loads can be calculated with a degree of accuracy, residua stresses are difficult to foresee. It is, therefore, very important to have a reliable method able to measure them directly with minimum damage to the surface [9]. Residual stresses can play a significant role in explaining or preventing failure of a component at times. One example of residual stresses preventing failure is the shot peening of component to induce surface compressive stresses that improve the fatigue life of the component. Unfortunately, there are also processes or processing errors that can induce excessive tensile residual stresses in locations that might promote failure of a component. It must be kept in mind that the internal stresses are balanced in a component. Tensile residual stresses are counter balanced by compressive residual stresses. Residual stresses are three- dimensional [10].

II EXPERIMENTAL PROCEDURE

The effect of laser beam treatment and treatment on fatigue resistance of carbon steel was investigated. The steel was treated at 850 ° C for 15 min. The thermal treatment was carried out in a medium size electric oven of ESFI-PID from Carbolite. The laser system was used . The system is equipped with a scale that gives the system charging voltage in kilowatts. The output of the laser beam is a function of voltage and charge. The samples were treated with single pulses, different cards and multiple distances to determine the appropriate conditions to increase the microstructure while reducing dispersion and fusion. The distance between lens and sample when processing samples was 16.5 cm. : YAG-Nd laser is visually pumped using flashtube or laser diodes. This is one of the most common types of laser, used in many different applications. Nd: YAG laser beams typically emit light of 1064 nm wavelength, in infrared [11]. The YAG laser beams operate in pulsed and continuous mode. High intensity pulses may be twice as efficient as generating the laser light at 532 nm. Fig. 1 below shows the device used in the search.

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Fig.1.Shows the device used in the search

The laser system has been calibrated to determine the energy of the outgoing laser beam measured by the Joule. The system is equipped with a scale that gives the voltage of charging the system in kV and the output laser energy is a function of the load voltage. It is increasing and decreasing. The samples were treated with single pulses, to select the appropriate conditions that achieve an increase in micro-hardness with minimal dispersion and fusion. Among the many different types of surface treatment, laser surface treatment has proven to be an effective means of modifying the surface properties of materials. Laser radiation is used to adjust the surface due to its flexibility and high precision of radiation. Electromagnetic radiation of the laser beam is absorbed into the surface layer of metals. Material properties are affected after laser surface treatment. The treated surface layer has a strong metal bond. This increases surface resistance. Laser treatment does not require mechanical operation later; It is a clean and quick process of surface engineering. There are many methods to measure residual stresses. The methods are commonly grouped as non-destructive, semi-destructive and destructive or diffraction based, strain relaxation based and other methods. All the residual stress measurement methods are indirect. Residual stresses are calculated or derived from a measured quantity such as elastic strain or displacement.

Low carbon steel (15%) was used in the form of thickness sheets (mm 1) because of its good mechanical properties, making it good for use compared to other high-priced alloys. Use the Instron Machine 1195 to measure tensile strength and total elongation of all cases used in the research. After the tensile test was performed and the appropriate conditions were selected for each of the variables, the samples were prepared for microscopic examination and hardness measurements. The wet cleaning process was performed with water using Sic grades of different grades (1000, 500,320,220). The polishing process was done using a 1μm diamond paste. The sample was then washed with water and alcohol and dried. The demonstration solution, which consists of 1% (HF + 99% H20), was then immersed in the sample for 20 sec. Then the sample was washed with water and alcohol and dried to be ready for microscopic examination. For measuring the hardness, the Vickers Test was used to measure the hardness by measuring a load of 20 g for a period of up to 15 sec. The resulting effect diameter was measured on the basis of which the hardness was calculated across the cross section.

III SIMULATION OF TENSILE TEST

The tensile test was modeled by using Ansys 5.4 and using the specific elements method as follows: [10]

1- The tensile test specimen is drawn in the case of (3D).

Length (L) = 100mm, Width (W) = 25mm, Thickness (t) = 1mm

2- Introducing the properties of the metal

The properties of the metal used in this research are low carbon steel and table (1), showing mechanical properties.

3- Item type and network operation

The final objective of the analysis of the specific elements is to recreate a mathematical model of the real geometrical system. In other words, the analysis must be based on the mathematical model created to represent the physical properties. Form generation means the engineering arrangement of the model, elements and Mesh work and the quality of the mesh. Bilinear Kinematic hardening Rue and Elastic Plastic. The applied element is Solid 98, which was used in the program to represent the coupling state of coupling. This element has many degrees of freedom and four degrees are identified Stresses, (Ux, Uy, Uz). Note that the total degrees of freedom of the test process according to the model analyzed in this research 8876 knots x 4 degrees in freedom we get the degrees of total freedom of the model.

The degrees of total freedom of the model 35504 = 4 × 7772

A small size of the component was determined at the fracture area for the importance of this area compared to the adjacent area and for high accuracy of the stress distribution results. Figure 2 shows the network work for the tensile sample and by design.

4- Set the boundary conditions that make the model of the specific elements of the tensile sample as if during the tensile process are actually two types:

First: Marginal conditions for fixing the tensile sample so that they are not free under the influence of the force they contribute to the calculation of stresses and distortions.

Second: Special boundary conditions that are as similar as possible to the real conditions in which the sample is during the tensile process.

5- Display the results

In this step the results of the analysis are displayed, ie the distribution of stresses for the tensile sample.

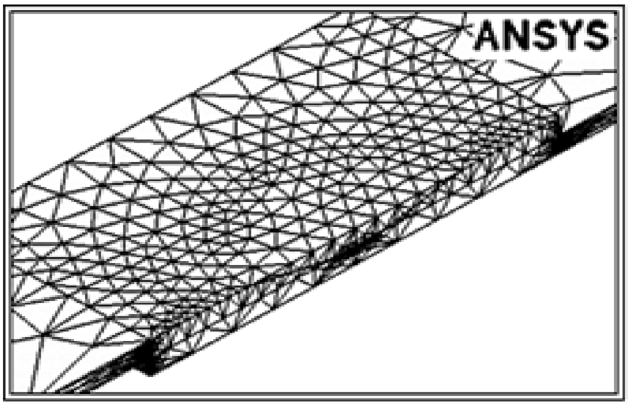

Fig.2.ANSYS

Table (1) shows the Mechanical Properties of cases used in the search.

Total Elongation %	Ultimate Stress MPa	Angle °	Case of treatment	sample
37.2	**291**	**10°**	**Steel as received**	**1**
38.3	**288**	**10°**	**Treated of 850C°**	**2**
23.1	**320**	**10°**	**(532) laser treated (A)**	**3**
21.8	**510**	**6°**	**(532) laser treated (A)**	**4**
24.5	**319**	**10°**	**(1064) laser treated (B)**	**5**
25.1	**317**	**6°**	**(1064) laser treated (B)**	**6**

IV RESULTS AND DISCUSSIONS

The result of this research is that it has a significant impact on steel resistance. This is due to the increase in the amount of the martensitic phase, the small size of this hard phase particle and its homogeneous distribution in the phase of the ferrite. This ensures greater strength between the ferrite and martensitic phases, , While the results of the research on the treatment of steel by laser showed the highest resistance to steel when compared with the types of steel as received and this is due to the first increase in the amount of martensitic and the small size of the particles of this phase, because the laser beam generates a strong energy turns into heat, The metal surrounding the affected area works as a very fast cooling tubing which leads to quenching and thus increases in the martensitic phase and the small particles of this phase due to the very rapid cooling rate. Secondly, due to the steel hardness of the laser directly, it led to a steel depth of 0.22 mm and a total depth of 0.47 mm). The presence of the remaining austenite at a depth of 0.47 mm reduces the of its transformation into martensitic through laser treatment and thus increases the resistance of the steel through the reinforcement made by the ferrite with the austenite or through its knowledge of anode for the austenite.

Third, it is due to the role of laser treatment in the fragmentation and expansion of carbides in the martensitic structure and in a homogeneous manner, which can improve the resistance of laser treated steel when compared to the steel as received types.

1-Microstructure

Figure (3a) shows the Microstructure of the steel as received, which is a low carbon steel (C 0.15%). This steel contains a floor of Ferrite in light color. Iron carbide (Fe3C) known as Cementite To a small amount of perlite on the crystalline boundary.

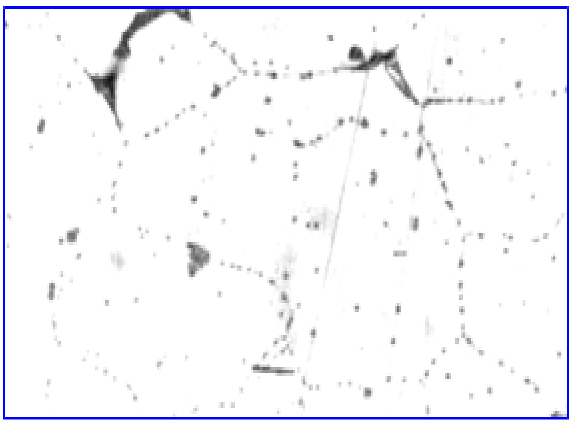

Fig. 3(a).The Microstructure of the steel as received

Figure (3b) shows the Microstructure of low carbon steel (0.15% C) that was heating to 800 ° C for 15 minutes and then water-proofing. The Microstructure was a light turf floor Islands or patches of the dark Martensitic phase, where the volume fraction of Martensitic, which was calculated by means of Point Counting, is 12.4%.

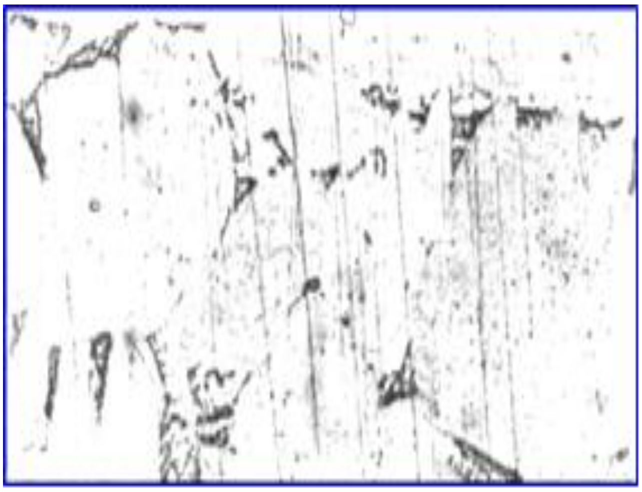

Fig. 3(b).The Microstructure of the carbon steel heating to 850

The figure (3c) shows the Microstructure of the steel received when it was hit by laser irradiation (11.13 joule with single pulse). It is a floor of the ferrite, in which the high-hardness matrix of martensitic is spread. The meringue fraction is 22.6%). It has been shown that laser hardening is accompanied by a change in the Microstructure. This change is in the formation of the precise martensitic phase on the surface of the steel with a continuous fragmentation of the carbide network and may degrade and disappear within the martensitic structure Homogeneous as a result of laser bombardment, is characterized Microstructure as seen by the shape of the presence (Acicular) of the martensitic phase With a little remaining austenite.

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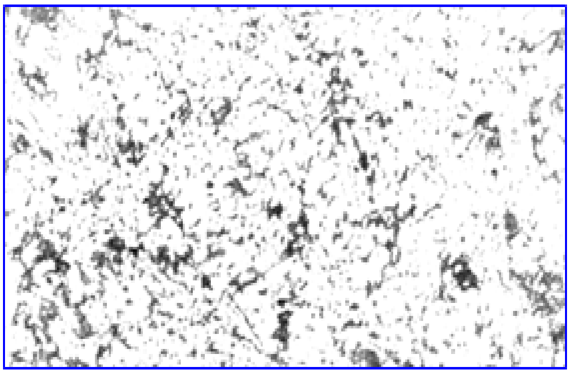

Fig.3(c).The Microstructure of the carbon steel hardened laser

2- Results of the software

The normal heat treatment or laser treatment is accompanied by the formation of stress and intensity stresses. This means that the metallurgical and mechanical properties vary between the samples before and after the heat treatment. The residual stresses are concentrated when dealing with laser and the value of these stresses increases when treated with laser.While the dispersion in the distribution of stresses and irregularity increases when the wavelength increases [12-16].

3-Hardness Resistance

On the other hand, another study showed [12] high hardness due to laser steel treatment. This study was performed using the neodymium- Yak laser system. The steel hardening of the laser directly led to solid steel depth of 0.22 mm and a total depth of 0.47 mm reduces the possibility of converting it to martensitic through laser treatment. The hardness results showed a high hardness rate at the surface of the hardened steel in comparison to the steel as received. Hardness at the surface of steel reached (410) hardness due to the presence of the hard martensitic phase, which is one of the basic components of this steel. In hardened hardness samples, the hardness at the surface was 605, where the presence of the carbide network in the martensitic floor was able to increase the macromolecular hardness in this case and the previous case due to the homogeneous distribution of the martensitic phase in the clay floor. As shown in Figure (4).

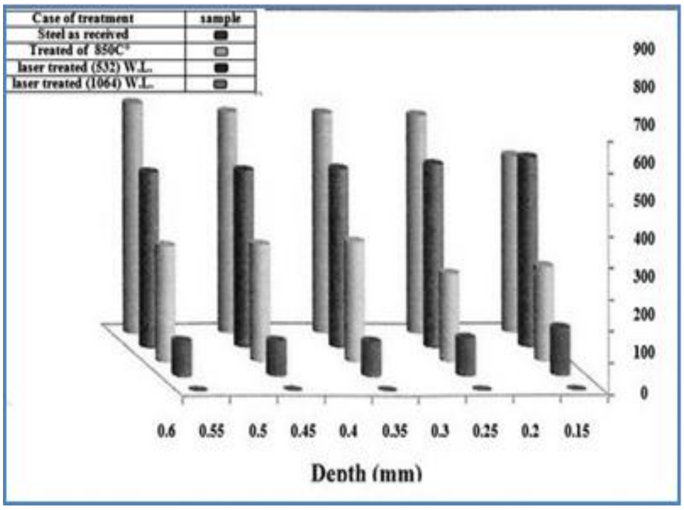

Fig.4.Hardness distribution of cross section of the samples of the received steel and the treated steel according with different numbers

The results in Table (1) indicate that the increase in the angle of the device (the angle of the lever of the device) increases the load on the sample in the calibrator, thus reducing the endurance of the samples. This means that the number of failure cycles for the sample is lower, the lower the load, the lower the angle. The sample was not broken at a small angle of 3 °. At the temperature treatment (850 ° C) for 15 minutes and water treatment, the samples were not broken at 5 ° or 7 °, but were broken at the angle (10 °). While laser beam treatment showed the results shown in Table (1), increasing the wavelength of the laser beam (1064) reduces the resistance of the calf compared with the wavelength (532). The number of loading cycles increased when the wavelength of the laser beam decreased.

V CONCLUSIONS

1- The residual stresses are concentrated when dealing with laser and the value of these stresses increases when treated with laser.

2- The dispersion in the distribution of stresses and irregularity increases when the wavelength increases.

3- Use of short wavelengths of laser beam is better in Tensile Strength when compared to long wavelength.

4- Lower-angle means low loading on samples and this leads to an increase in the number of loading cycles for the samples.

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