Study the Effect of Surface and Internal Heat Treatment on Mechanical Properties of C40 Steel Alloy

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ABSTRACT

The research aims to study the effect of quenching, tempering and laser surface treatment on the mechanical properties of C40 steel. The steel specimens were heated to a temperature of 860°C, soaked for 60 minutes and quenched in oil and then tempered at different temperatures (100,200,300,400,500,600,700) °C.
Laser hardening were carried out by using Nd: YAG laser with different pulses up to 5 pulses, the applied laser energy was 500 mJ.

The mechanical tests such as: impact test and microhardness, were carried out for the specimens before and after heat treatment. Microstructure evaluation was carried out using computerized optical microscope. The results showed an improvement in the internal and surface properties of the metal.

Keywords: Mechanical Properties, C40 Steel, Quenching, Tempering, Impact Test, Micro hardness And Microstructure.

دراسة تاثير المعاملات الحرارية السطحية والداخلية على الخواص الميكانيكية للفولاذ C40

الخلاصة

يهدف البحث الى دراسة تاثير التقسية ,المراجعة والمعاملة الحرارية السطحية الليزرية على الخواص الميكانيكية للفولاذ C40. تم اجراء معامله حرارية للعينات عند درجة حراره860C° ولمدة 60دقيقة وبعدها تمت عملية تبريد بالزيت, بعدها تمت عملية المراجعة عند درجات حرارية مختلفة (700,600,500,400,300,200,100) درجة مئوية. تمت عملية التصليد الليزري باستخدام ليزر النديوم-ياك النبضي ولعدد مختلف من النبضات يصل الى 5 نبضات وبطاقة ليزر 500 ملي جول. الاختبارات الميكانيكية التي اجريت قبل وبعد المعاملة الحرارية هي اختبار الصدمة والصلادةالميكروية وقد تمت عملية الفحص المجهري باستخدام المجهرالضوئي. وقد اظهرت النتائج تحسن في الخواص السطحية والداخلية للمعدن.

INTRODUCTION

Iron is one of the oldest known metals, and carbon is the cheapest and most effective alloying element for hardening iron. Iron carbon alloys are known as "carbon steels" and account for more than 70% of the tonnage of metallic materials used for engineering applications. Carbon is added to iron in quantities ranging from 0.04 to 2 wt% to make low, medium, and high carbon steels. The microstructure and resulting mechanical properties of these steels are amenable to modification via heat treatment, and a wide range of mechanical properties can be obtained by proper variations of heating and cooling cycles [1]. In analyzing plastic deformation and failure processes of metal materials, usually the following factors are usually discussed: material structure, deformation rate, temperature, etc. However, the influence of surface layers on deformation process is taken into account very seldom, though they very often influence the mechanical properties, mechanisms of plastic deformation and failure [2,3]. Modern industrial applications require parts with special properties such as high corrosion and wear resistance and hardness. The most effective and economical approach to improve surface ability of machine parts and high surface stresses is by creating surface layers that would possess a high level of corrosion and wear resistance. In this way unique service characteristics can be obtained such as a combination of high surface hardness with high impact strength of the bulk [4-7]. The modified surface thus produced can have superior chemical, physical or mechanical properties. The depth of the alloy zone can be controlled by the power and the dwell time of the laser beam. Depending upon the type of alloy required at the surface, a less-expensive base material can be locally modified to improve resistance to corrosion, erosion, wear and oxidation [6, 7]. Laser surface treatment is divided into several methods: transformation hardening, melting, alloying and cladding. Each of them is characterized by set of process parameters (power, diameter, transverse speed), which determine results of application. Laser alloying and cladding both need melting of component surface and introduction of additional material. This material can be in powder or solid form and can be preplaced or fed during melting process [8, 9].

RESEARCH AIM

In this research a C40 medium carbon steel was chosen to be studied to show the effect of heat treatment and a laser surface hardening on its mechanical properties. Also, the aim of this work is to gain a full understanding to the impotent of laser in surface hardening. Laser is distinguished by several properties which are not available in any other optical source, these properties are: high intensity, coherence, monochromatic and little divergence, laser travels in a very narrow beam for long distances. So, for all the above mentioned properties of laser, laser technology has a big and important role in processes connected to laser. Surface treatment of materials has been used in industry for several years to improve some of the mechanical properties of materials. Most failures, which may take place at material surface as a result of lassitude, erosion and corrosion, are because of the stresses which mostly take place at the surface and material exposure to environment conditions. So the solution is to make the material acquire surface properties which differ from the inner part. There are several ways to change the surface structure for example by carburizing, nitriding, aluminizing, chromizing , shot and phase transformation hardening using flame, electrical inducation, electron beam or plasma. Because of the advantages that laser has, it has been used in surface thermal processes to change the microstructure of the surface layers to improve the surface properties in comparison with the material original properties . Using laser in surface hardening of metals is regarded very important in several industries.

The advantages of laser hardening can be summarized as follows:

• Selected areas can be hardened without affecting the surrounding material.

• Minimal heat input causes little macro distortion and reduces the need for additional machining.

Treatment depth is accurately controlled and highly reproducible.

• Superior hardness, strength, lubrication, wear resistance and fatigue properties can be obtained compared to conventional processes.

• It can often be used without external quenching.

• No geometry specific tools such as that required for induction hardening is necessary.

• It can be integrated as an online computer controlled process.

• Time saving (no heating-up or soaking time is required).

• Minimal environmental impact. [10]

EXPERIMENTAL DETAILS

Metal used

In the present investigation we used 25 mm diameter bars of C40 steel, the nominal composition of which is given in Table (1). Table (2) shows the mechanical properties of the steel [11].

Table (1) The nominal composition of the medium carbon steel C40.

Element	C	Si	Su	Ph	Mn
Actual value	0.37%	0.15	0.038	0.036	0.79
Standard value	0.37-0.44	0.40 max	0.045 max	0.045 max	0.50-0.80

Table (2) The mechanical properties of the hot – rolled medium carbon steel C40 [11].

Tensile Strength (MPa)	Yield Strength (MPa)	Elongation%	Impacting energy(J)	Poisson's Ratio	Hardness (HB)
590	355	17	47	0.27-0.30	229

Quenching and tempering

The steel specimens were heated to a temperature of 860°C, soaked for 60 minutes and quenched in oil and than for 10 min. Tempered at many different temperatures (100,200,300,400,500,600,700) °C.

Heat Treatments by laser

Laser surface heat treatment was carried out by using pulse Nd:YAG wave length, while the frequency of laser system is laser with (1064 nm) wave length (1-6)Hz frequency pulse duration (100 ns) spot size (1.5mm) and full energy of laser system 1J. Laser beam was applied from distance 30 cm for 10 min, by using beam spleter (4Cm length, 1.5Cm width) for impact specimen, whilst for microhardness specimen we used converge lens to avoid the dispersion in the output power because the diameter of microhardness specimen (10mm). In this investigation we applied laser energies of 500mJ.This energy was applied by one, two, three, four and five pulses respectively.

The same conditions were done for the specimens of impact energy test and microhardness test. Figure (1) shows the laser pulse Nd:YAG system.

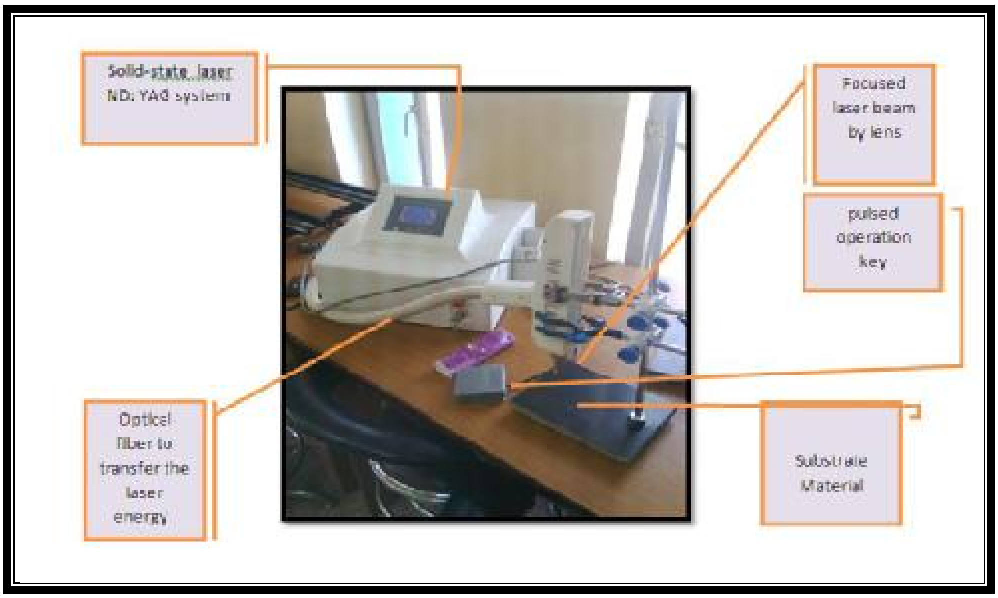


Figure (1) Shows laser pulse Nd:YAG system.

MECHANICAL TESTS

A: Impact test:

Representative sample of as-received specimens and heat-treated specimens were subjected to impact test on a Charpy impact testing machine. Specimens for this test were manufactured according to (ASTM E23) Standard [12].

B: Microhardness test

Microhardness test was carried out by using (Digital Microhardness HVS1000 apparatus). The magnification used was 400X and load 500 gm for 15 second. Many readings of the indentation length were taken for each sample, and the average was taken finally.

Depth of hardening for the specimens treated by quenching, tempering and 5 number of pulses of 500mJ laser energy was measured by using hardness method.

C: **Microstructure Examination:**

A computerized optical microscopy (MEIJI TECHNO) was used to examine the microstructure of the specimens before and after treatment with Nd:YAG laser. The optical microscopic examinations were carried out on a metallurgical microscope at a magnification of 250X.

RESULTS AND DISCUSSION

Impact test

The mechanical properties of steel were improved after various heat treatment processes, the impact, tensile, wear, chemical corrosion, fatigue and microhardness [13].The impact of the steel specimens before and after heat treatment processes are shown in Table (3). The impact strength of the heat-treated specimens are higher than that of the as received; at as received the impact is equal 7.0 and after (quenching, tempering) become 16.2. This is as a result of the martensite formed during the heat treatment processes quenching, tempering which is very strong and hard [14, 15]. After laser treatment; also it causes to increase in impact at 5 pulses is become 28.7 more than any other pulse.

Table (3) The result of impact test specimens.

specimens	Impact risistance Kg.m at different number of pulses					
Tempring Temperature	0	1 pulse	2 pulses	3 pulses	4 pulses	5 pulses
As-received	7	7.9	8.3	8.9	9.4	9.9
100°C	10,2	12.5	14.7	17.9	18.2	18.9
200°C	11.9	15.9	16.7	18.8	19.9	20.3
300°C	12.5	16.3	18.6	22.0	22.9	23.5
400°C	12.3	16.1	18.4	21.5	22.6	23.2
500°C	14.6	17.6	19.3	22.4	23.8	24.5
600°C	16.5	20.4	22.5	25.7	27.9	28.4
700°C	16.2	20.7	23.2	25.6	28.1	28.7

Microhardness test:

The effect of treatments on the microhardness was illustrated in Figure(2). Microhardness results showed a fascinating improvement for the quenched and tempered alloy, they are attributed to the formation of fine hard martensite observed by microstructure examination, this phase was created as a result of rapid quenching from the austenitic region. The improvement in microhardness of the laser surface treated alloy is noticed by the increasing of laser number of pulses. Atthe first pulse microhardness is equal to 324 and the fifth pulses the microhardness was 578.The increasing number of the pulses has and effective increase in microhardness due to the attributed refining of the grains, which was activate the grain growth and formation of fine microstructure. Figure (2) show is that the increasing in laser pulse leads to increase in microhardness. From Figure (3), it is clear that microhardness number is decreased with the specimen depth of hardening that is due to a large gradient of temperatures which vary across a layer from tens to hundreds of micrometers wide [16,17].

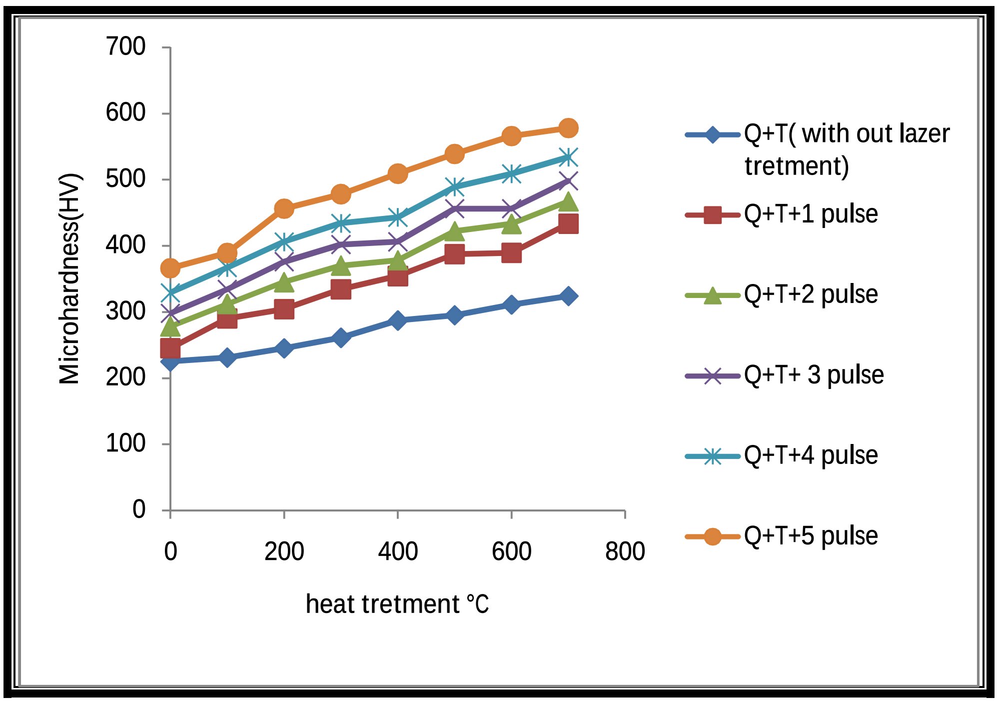


Figure (2) The relation between heat treatment and microhardness.

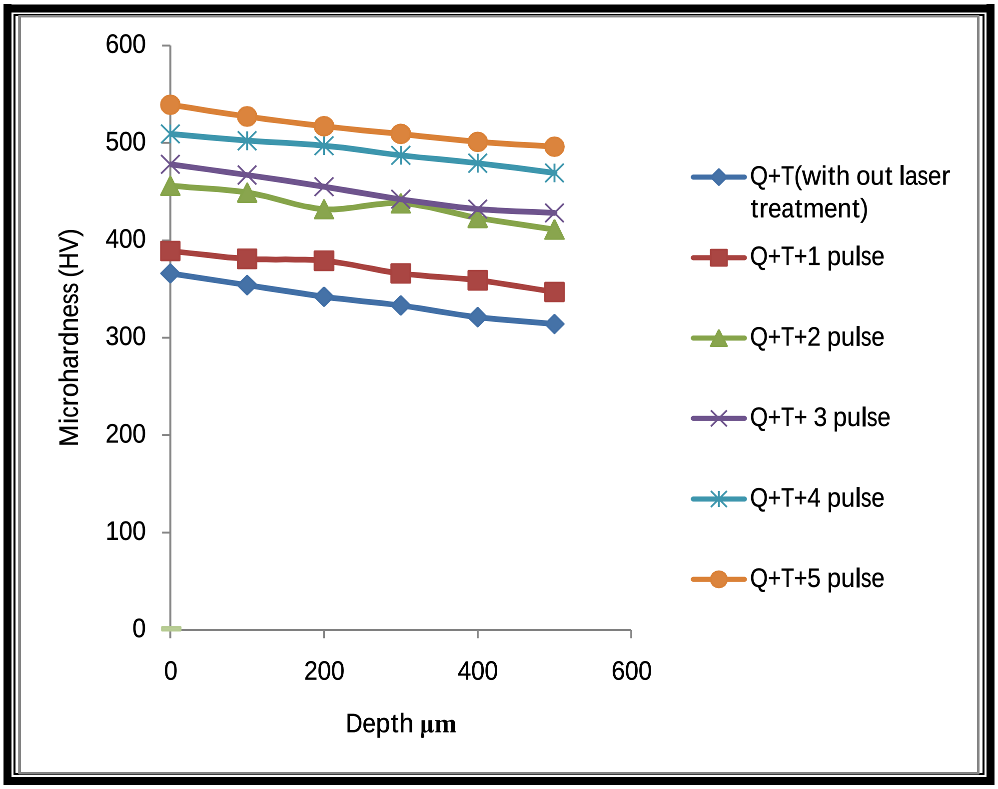
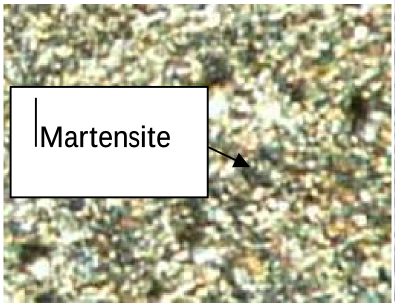
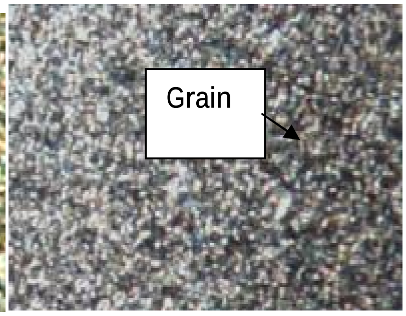


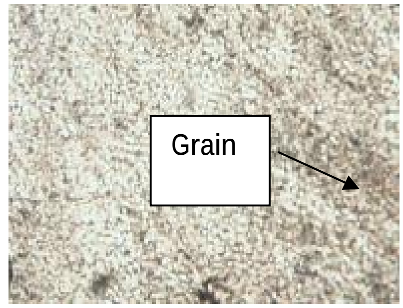
Figure (3) Microhardness distribution curves along specimens depth at tempering 700°C.

MICROSTRUCTURES EXAMINATION

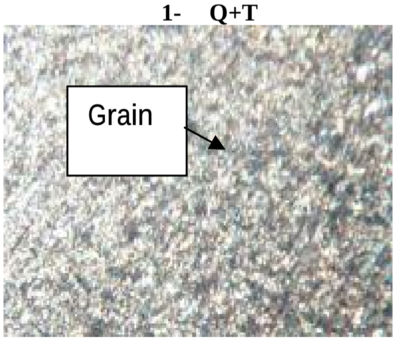
The microstructure obtained is shown in Figure (4).Optical microscopic examination, revealed that the quenched and tempered structure is homogeneous fine-laths of tempered martensite Figure (4) (Image 1)whereas, the laser surface treated structure consist of fine-laths of tempered martensite at the surface only, but the internal layers consists of grains of ferrite and pearlite,Figure (4) (Image 2,3,4,5,6)andfrom Figure (5)as shownthe microstructures inthe surface, medium and core region . It is shown that refining in grains because of one of the most important of laser surface engineering methods is laser surface hardening which is meant for only microstructural modification of the surface without any change in composition [18, 19, and 20]. Hence, we obtained improvementinthe microstructure with pulse 5 when compared with the other pulses used in this investigation because of very high thermal gradient and ultra rapid solidification.

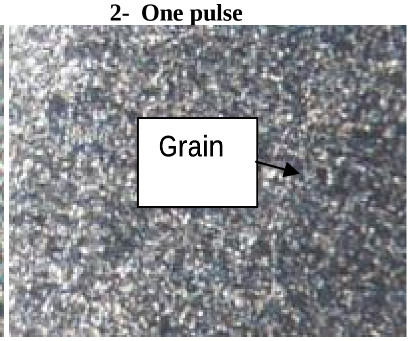


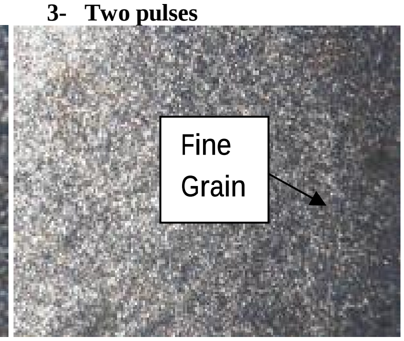




1- Q+T **2- One pulse** **3- Two pulses**

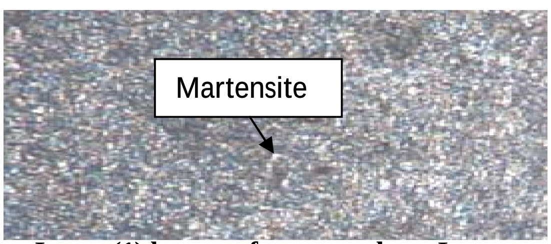






4- Three pulses **5- Four pulses** **6- Five pulses**

Figure (4) Optical micrographs for the specimens before and after heat treatment with Nd: YAG Laser for the surface at tempering 700°C. 250X magnify.



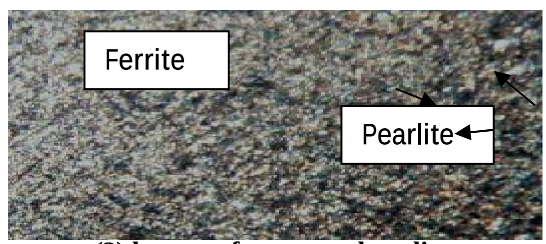


Image (1) laser surface treated caseImage (2) laser surface treated medium

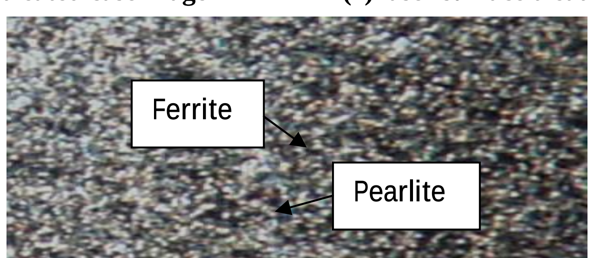


Image (3) laser surface treated core

Figure (5) Optical micrographs for Microstructures illustrate the case, medium and core region with Nd: YAG Laser at tempering 700°C 5 pulses. 250X magnify.

CONCLUSIONS

1- In this research the heat treatment of the steel specimens like quenching, tempering and laser process gives the superior properties regarding the impact strength and microhardness.

2- The best results for impact strength at 5 pulses are equal 28.7.

3- The best results for microhardness at 5 pulses are equal 578.

4- The microstructural study revealed that martensite is formed inside the metal but for laser surface treatment shows that the martensite phases at the surface skin only.

5- Laser surface treatment gives a change in the grain size, so that the variation in grain size caused change in mechanical properties.

6 - The grains are more refined by laser pulse 5 if it is compared by other tests.

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