Journal of Engineering and Development
www.jead.org
Vol. 20, No.02, March 2016
ISSN 1813-7822

IMPROVING THE MECHANICAL PROPERTIES OF CK35 STEEL USING ND: YAG LASER SURFACE HARDENING

*Dr. Khansaa Dawood Salman[1], Dr. Muhannad Zedain Khalifa[1]

1) Assist Prof., Electromechanical Engineering Department, Technology University, Baghdad, Iraq.

(Received: 20/09/2015; Accepted: 26/ 01/2016)

Abstract: In this investigation CK35 steel was treated by using laser surface treatment and make comparison with conventionally heat treatment. Laser hardening was done by using pulse ND: YAG laser with energy of 1000mj, whilst the conventionally heat treatment was carried out by quenching at 840℃ with cooling in oil and then tempered at 200℃for 2hr. Mechanical tests were made for all the specimens which were used in this research before and after heat treatments such as: Tensile test and Micro hardness test. Also grain size measurement and micro structural evaluation were done by using computerized optical microscopy. The results of this work showed that obviously improvement in mechanical properties for the specimen treated by laser more than the specimen treated conventionally as the following: From tensile test it showed that increasing in yield strength, ultimate tensile strength , elongation percentage and plasticity constant (k). Also decreasing in young modulus (E) and the coefficient of strain hardening (n). Whilst the micro hardness results showed that the highest value was obtained by laser hardening at the surface of the specimen and deceased far from the surface with depth of hardening equal to 0.5 mm. Also metallographic examination of the specimens after heat treatments showed that refining in grain size of the specimen treated by laser treatment more than the specimen treated by conventional heat treatment.

Keywords: *Laser hardening; CK35 steel; Mechanical properties.*

تحسين الخواص الميكانيكيه للفولاذ CK35 بأستخدام التصليد بالليزر نيديميوم-ياك

الخلاصة: في هذا البحث تمت معاملة الفولاذ (CK35) بأستخدام المعاملة السطحية بالليزر ومقارنة ذلك مع المعاملة الحرارية التقليدية. تم التصليد بالليزر بأستخدام الليزر نيديميوم- ياك النبضي وبطاقة 1000mj, بينما أجريت المعاملة الحرارية التقليدية بالتقسية عند درجة حرارة840°C والتبريد بالزيت ثم المراجعة عند°C 200 ولمدة 2hr. أجريت أختبارات ميكانيكية لجميع العينات التي استخدمت في هذا البحث قبل وبعد المعاملات الحرارية مثل: أختبار الشد وأختبار الصلادة الدقيقة.كذلك تم قياس الحجم الحبيبي وتحديد البنية المجهرية وذلك بأستخدام المجهر الضوئي المزود بحاسوب. أظهرت نتائج هذا البحث بتحسن واضح في الخواص الميكانيكية للعينة المعاملة بالليزر اكثر من العينة المعاملة بمعاملة حرارية تقليدية وكما يلي: من أختبار الشد نلاحظ زيادة في مقاومة الخضوع, مقاومة الشد القصوى, النسبة المئوية للاستطالة وثابت اللدونةk. كذلك نقصان معامل يونكE ومعامل الاصلاد الانفعاليn. بينما أظهرت نتائج الصلادة الدقيقة بان أعلى قيمة يمكن الحصول عليها بالتصليد بالليزر عند سطح العينة ومن ثم تقل بالأبتعاد عن سطح العينة وبعمق تصليد 0.5mm. كذلك أظهر فحص البنية المجهرية للعينات بعد المعاملات الحرارية بتنعيم في الحجم الحبيبي للعينة المعاملة بالليزر اكثر مما هو عليه للعينة المعاملة بمعاملة حرارية تقليدية.

1. Introduction

Medium carbon steels are used extensively in machining and tools. Often these steels are selected for their wear resistance rather high strength, and their parts

**Corresponding Author*: KhansaaDawood@yahoo.com

frequently must be heat treated to meet in –service strength requirements [1, 2]. There is a need in different industry sectors to improve the performance of material surface under wear and corrosion environments, which cannot be fulfilled by the conventional surface modifications. One way to improve the surface properties of materials is the laser surface engineering [3]. Because of the high power density of the laser heat sources and the high processing temperatures often desired to be closed to the melting temperature of the materials, precise temperature measurement and control is essential for keeping the process stable and ensuring reproducible quality of the parts[4].

The steady development of high power lasers and their suitability to be introduced in production lines has encouraged the industrial application of laser surface treatment. The methods of laser surface treatment of materials have been classified in to two types [5]. Thermal processes: with no change of composition (no material additions), like laser cutting, welding, tempering, annealing, melting and transformation hardening. Thermo-chemical process: with change in composition of surface (material addition, like laser cladding, alloying, where the process differ in the metallurgical structure. Furthermore, the advantages of these surface treatments include flexibility and the possibility of treating small areas, leaving the others parts unaffected [6].

Some literature survey about laser hardening for ferrous alloys has been made. M. Gowshikan, S. Balasubramanian [7] during 2014 have given an experimental investigation made with ND: YAG laser system on the study of effects of laser surface hardening process parameters on the high carbon steel components. It comprises the analysis on microstructure, wear resistance and hardness after laser hardening process. While H. Visscher, M.B. de Rooij, P.H. Vroegop, and D. J. Schipper [8] made an investigation about the influence of laser hardening of carbon steel AISI 1045 on the lubricated wear against steel AISI 52100. It is shown that the wear resistance of carbon steel AISI 1045 can be improved considerably by hardening the surface

The aim of this investigation is to improve the mechanical properties of CK35 steel specimens treated by laser treatment and compare the results with those of conventionally quenched and tempered.

2. Materials and Methods

The chemical composition of CK35 steel specimens used for this investigation is given in Table 1, while the mechanical properties of this alloy are given in Table 2.

Table 1. Chemical Composition of CK35 Steel (wt. %) [9].

Element	C	Si	Mn	P	S	Cr	Mo	Ni
Standard values	0.31-0.38	Max 0.40	0.60-0.90	Max 0.03	Max 0.035	Max 0.40	Max 0.10	Max 0.40
Actual values	0.34	0.38	0.62	_	0.028	0.42	0.07	0.37

Note: Actual values are obtained by an examination in General Company for Examination and Rehabilitation Engineering.

Table 2. Mechanical properties of CK35 steel [9].

Yield strength (MPa)	Ultimate strength (MPa)	Elastic strength (GPa)	Elongation (%)	Hardness (Hv)
370	585	190-210	30	190

2.1 *Specimen preparation*

A set of specimens was prepared for hardness tests and microstructural analyses. Tensile test specimens were also produced from the as-received CK35 steel of the same composition. The specimens were prepared after series of machining operations following the grinding by the emery paper (180, 320, 500, and 1000μ_m) and then polished by alumina solution (1μ_m).

2.2 *Heat Treatments*

2.2.1 *Conventional heat treatment*

The prepared tensile test specimens and other specimens were firstly treated with laser and the conventional heat treatment respectively.

Conventional heat treatment for the specimens of CK35 steel was carried out as follows: 840℃quenched in mechanical oil and tempered at 200℃ for 2 hours.

2.2.2 Laser surface heat treatment

The laser surface heat treatment was performed by using pulse Nd:YAG with 10 pulses and1064nm wave length, while the frequency of laser system 1-6Hz. In this investigation the applied laser energy is 1000mj. The same conditions were done for the specimens for micro hardness test, tensile test and micro structural examination. Laser beam was applied from distance 30 Cm for, by using beam splitter (4 Cm length, 1.5 Cm width) for tensile specimen, whilst for micro hardness specimen we used converge lens to avoid the dispersion in the output power because the diameter of micro hardness specimen 10 mm. This treatment is carried out in laser engineering department.

2.3 Mechanical tests

2.3.1 Tensile test

Tensile tests were carried out on the as-received, conventional and laser treated specimens using Instron Universal Tester (type Instron 1195 machine with full capacity 2.5 ton). Specimens for this test were manufactured according to ASTM E8N standard [10].

Each of the specimens was loaded till fractured, and the fracture load for each specimen was recorded as well as the diameter at the point of fracture and the final gauge length.

The initial diameter and initial gauge length for each specimen were noted before the application of the uniaxial load. The elongation percentage and reduction of each specimen were determined; also the ultimate tensile strength and yield strength were obtained from the following equations [11]:

$\sigma_y = \frac{F_y}{A} (\frac{N}{mm^2})$ (1)

$\sigma_{U.T.S} = \frac{Fmax}{A} (\frac{N}{mm^2})$ (2)

$$\varepsilon = \ln\frac{L}{L_O} \quad (3)$$

Whilst the strain hardening coefficient and plasticity constant for each treated specimens were obtained by using the following formula [11]:

$\sigma = k(\varepsilon)^n$ (4)

Where:
n: the strain hardening exponent.
k: the strength coefficient.

Log σ =Log $k + n$ Log σ (5)

2.3.2 *Hardness Test*

Vickers pyramid method was used for the determination of the hardness of the treated specimens. Macro hardness test was used for the specimens treated by conventional method, whilst micro hardness test was used for the specimens treated by Nd:YAGlaser. Micro hardness test was carried out by using (Digital Micro hardness HV 1000 apparatus). The magnification used was 400X with 500gm load for 15 second. Many reading were taken for each specimen, and the average was taken finally.
Vickers hardness number for each specimen treated by conventional heat treatment and laser surface treatment was calculated by using the following equation [12]:

$V.H.N = 1.8544 \times \frac{F}{d_{ave.}^2} \left(\frac{kgf}{mm^2}\right)$(6)

2.4 Grain size measurement

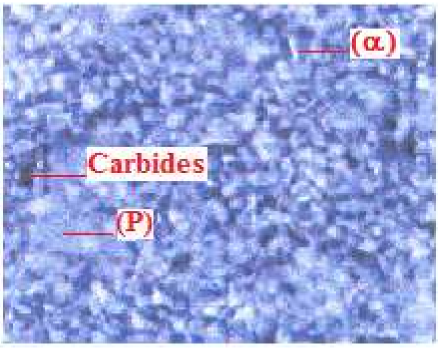
Particle size or grain size refers to the diameter of a grain of granular material.
Grain intercepts and plan metric methods are always applicable for determining average grain size [13].
In this investigation we used intercept diameter method to calculate the grain diameter by using straight line with length (L) intercept number of the grains (n) and then the grain diameter equal to $\frac{L}{n}$. Laser surface hardening lead to refining the grains sizes as shown in Table 3, [13].

Table 3. Shows the grain size of the phases all the specimens which were used in the investigation.

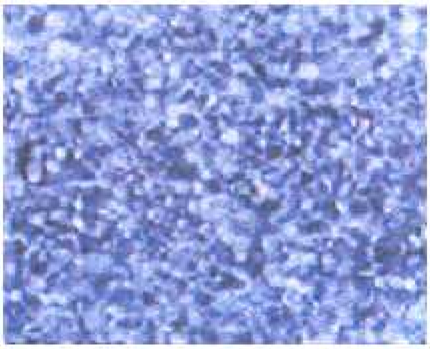
No.	Specimen	Grain size (μm)	
		Ferrite	Pearlite
1	As-received	15.1	15.3
2	Conventional heat treatment	14.5	14.9
3	Laser surface heat treatment	13.3	14.0

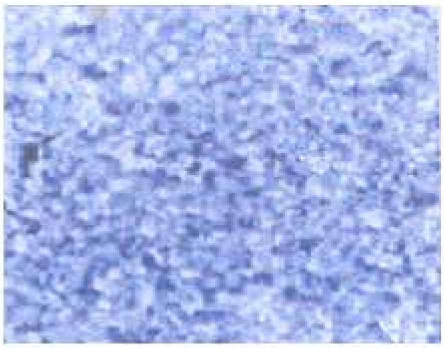
2.5 Microstructure examination

A computerized optical microscopy was used to examine the microstructure of all the specimens which were used in this investigation before and after heat treatment by conventionally heat treatment and laser surface heat treatment as shown in "Fig. 1",



A-As-received (100x)





B-Conventionally heat treatment (100x) C-Laser surface heat treatment (100x)

Figure 1. Micrographs of surface microstructure of CK35 steel

12

3. Results and Discussion

3.1 *Micro structural analysis*

Compared with conventionally heat treated specimens, the laser treated specimens contain more retained austenite and undissolved carbides. The conventionally treated specimen contains mainly with tempered martensite and dissolved carbides plus little retained ausenite [14].

Because of the very short time involved in the austenization during laser surface treatment, the finer austenite grain size resulting in the formation of unusually fine martensitic structures was obtained, it means that increasing in micro hardness and then improving the mechanical properties.

The hardness distribution along the depth of the laser treated layer is shown in "Fig. 2", The hardness of the quenched layer by laser is substantially greater than that of conventionally quenched and tempered.

The hardened layer of laser treated specimen has a thickness of 0.5mm. In the hardened layer the hardness gradient showing a gradual decrease in hardness is attributed to the reduction of dissolution of carbides due to the temperature gradient in the depth direction, therefore improving the mechanical properties.

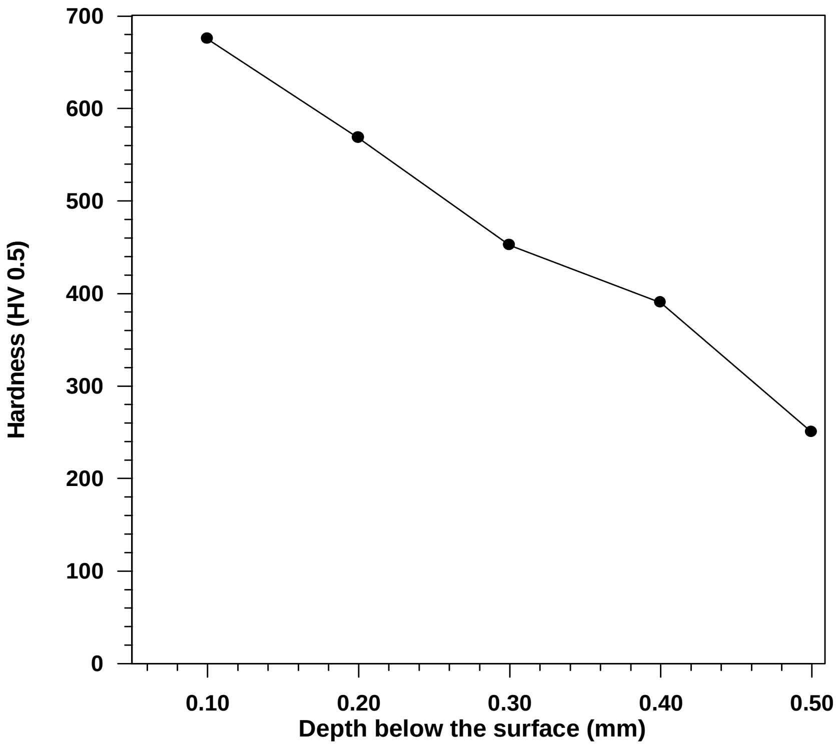


Figure 2. Hardness distribution curve along hardening depth of laser treated specimen

3.2 *Effect of heat treatment on mechanical properties*

Table 4 shows the mechanical properties of the as-received specimen with the specimens at different heat treatment Conventional heat treatment and laser surface heat treatment).

Table 4. Effect of heat treatment on mechanical properties

No.	Specimen	Yield strength (MPa)	Tensile strength (MPa)	V.H.N (Kgf/mm^2)	Elongation (%)	K	n
1	As-received	475	723	243	13	780	0.5
2	Conventional heat treatment	558	750	438	13.8	810	0.312
3	Laser surface heat treatment	670	810	675	15.2	832	0.2851

The hardness measurements presented in Table 4show that the laser surface treated specimens had higher Vickers hardness number compared with conventionally treated specimens. This may be due to faster cooling rate of laser treatment resulting in highest free carbon in martensite. Furthermore, the presence of fine dispersion of small particles in ferrite and pearlite, which will hinder the dislocation movement, may have also contributed to the higher Vickers hardness number of the laser surface treated specimens [15], and then improving the mechanical properties.

As shown in "Fig. 4", the yield strength and tensile strength of both conventionally heat treatment and laser surface treatment increases with the increase in the heat treatment temperature. The increase in the yield strength and tensile strength of the treated specimen conventionally as compared with that of un-treated specimens (as-received) specimen showed that the heat treatment by quenching and tempering operations influenced the strength of the steel specimens. However, may be due to the formation of fine pearlite as a result of fast cooling.

Whilst in laser surface treatment, it is well known that the yield strength and tensile strength of the materials could be higher than that of conventional heat treatment related to the hardness of the surface. Although martensite is hard, the presence of retained austenite has been reported to enhance the toughness, which implies that a proper combination of these phases would result in higher yield strength and tensile strength. It shows that the laser quenched layer is better than the specimens with conventional heat treatment, because the surface strength and hardness of the specimens are significantly enhanced by the laser [16].

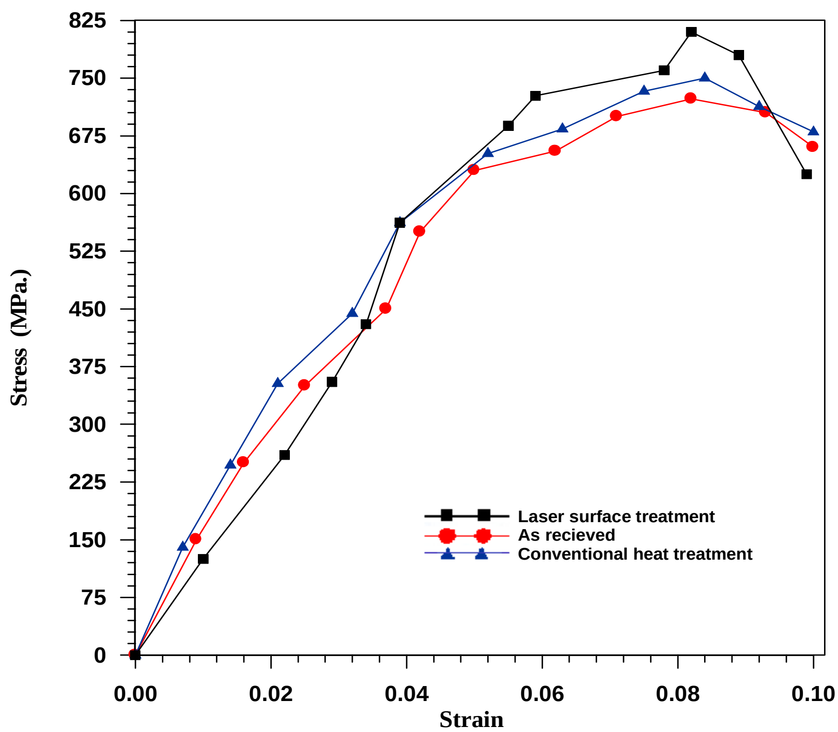


Figure 4. Relationship between stress and strain for specimens: as-received, conventional heat treatment and laser surface treatment

"Fig. 5", shows that laser surface treatment give higher value of the strength coefficient (k) than the values of the specimen as-received and the specimen treated conventionally, whilst the value of the strain-hardening exponent (n) for the specimen treated by laser smaller than the specimen as-received and the specimen treated conventionally. It is perhaps attributed to that the hardness for the specimen treated by laser more than the hardness of the specimen treated conventionally and the specimen as-received [17]. Also laser surface treatment lead to self-quenching which in turn lead to form martensite phase with retained austenite phase which were these phases lead to increasing in value of (k) and decrease in value of (n) for the specimen treated by laser than the specimen as-received. Finally, the values of (k) and (n) were agreed with [11].

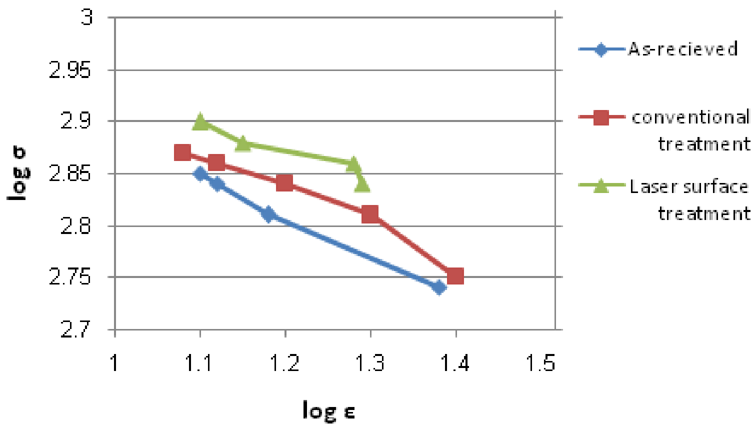


Figure 5. Relationship between log σ- log ε for all the specimens of this investigation

4. Conclusions

The following conclusions are made based on this investigation:

1. Laser surface treatment leads to improve mechanical properties such as the hardness, yield strength, ultimate tensile strength and the percentage of elongation.
2. Laser surface treatment leads to increasing the value of (k) and decreasing the value of (n).
3. Laser surface treatment leads to refining the grains at the surface of the specimen.

5. References

1. kursun,T. (2011).*"Effect of The GMAW and The GMAW-P Welding Processes on Microstructure, Hardness, Tensile And Impact Strength of AISI 1030 Steel Joints Fabricated by ASP 316L Austenitic Stainless Steel Filter Metal"*. Archives of Metallurgy and Materials, Vol.56, Issue 4, pp.955-963.
2. Purushothaman Dinesh Babu, Gengusamynaidu Buvanashekaran, Karupuudaiyar, BalasubramanianR. (2012).*"Experimental Studies on The Microstructure And Hardness of Laser Transformation Hardening of Low Alloy Steel"*.Transactions of the Canadian society of Mechanical Engineering, Vol.36, No.3,pp.241-257.

3. MontealegreM.A., Castro G., Rey P., Arias J.L., Vazquez P., Gonzalez M. (2010).*"Surface Treatments By Laser Technology"*. AIMEN Technology Centre, Relva 27 A, Torneinos, 36410 Porrino, Pontevedra, Spain, M.A.Montealegre et al, Surface Treatments by laser technology contemporary Materials, 1-1, PP. 19-30.
4. Seifert,M., Anhalt,K., Baltruschat,C., BonssS. and Brennner,B. (2014).*"Precise Temperature Calibration For Laser Heat Treatment"*, Journal of Sensors and Sensors Systems, 3, pp. 47-54.
5. D.Schuocker (1998).*"Handbook of the Euro Laser Academy"*. Ed. Chapman-Hall.
6. Steen W.M. (2003).*"Laser Material Processing"*.Springer.
7. Gowshikan,M., Balasubramanian,S. (2014).*"A Review On Laser Surface Modification Of High Carbon Steel Components"*, International Journal of Innovative Research and Studies, Vol.3, Issue 10, pp.187-197.
8. VisschersH., RooiM. B.de, VroegopP.H., SchipperD.J. (1995).*"The Influence of Laser Line Hardening of Carbon Steel AISI 1045 on The Lubricated Wear Against Steel AISI 52100"*. Wear, pp. 638-647.
9. AISI 1035 Carbon Steel (UNS G 1035) (2013), pp.1-3.
10. Annula(1988).*"Book of ASTM Standard"*.Vol. 3.01 and 3.02 Philadelphia USA.
11. Georg E-Dieter (1976).*"Mechanical Metallurgy"*. Second Edition.
12. Bolton W. (1988).*"Engineering Materials Technology"*. Butter Worth Heinemann Oxford.
13. ASTM Standard E112-12 (2004).*"Standard Methods for Estimating the Average Grain Size for Metals"*.
14. Radziszewska A. and KusinkiJ. (2008).*"Laser Alloying of The Plain Carbon Steel Surface Layer"*. Archives of Foundry Engineering, Vol.8, Issue,pp. 175-179.
15. ZhongJunweilu, JinZhong Lao (2012).*"Tibological Behaviors of Laser Shock Processing AISI 8620 Steel"*. Chines Journal of lasers,pp. 1-3.
16. MitraRadmanesh, AmirkianooshKiani (2015).*"ND: YAG Laser Pulses Ablation Threshold of Stainless Steel 304"*, Materials Science and Applications, Vol. 6, pp. 634-645.
17. Senthilkumar.T. and Ajiboye,T.K. (2012).*"Effect of Heat Treatment Processes on The Mechanical Properties of Medium Carbon Steel"*. Journal of Minerals and Materials Characterization and Engineering 11(2), pp.143-152.