International Science and Technology Journal
المجلة الدولية للعلوم والتقنية

Volume 35 العدد
Part 1 المجلد
October 2024 اكتوبر

المجلة الدولية للعلوم والتقنية
International Science and Technology Journal
ISTJ

تم استلام الورقة بتاريخ: 5 /9/2024م   وتم نشرها على الموقع بتاريخ: 2/ 10 /2024م

Effect of Applying Nd-YAG Laser on Microstructure and Hardness of AISI 1012 Steel Surface

www.doi.org/10.62341/nael2035

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Abstract

The unique characteristics of the laser beam such as directionality, monochromaticity, and brightness make it a very important tool in the surface treatment engineering. The concentrated heat in the laser beam can be precisely directed toward the processed region on the surface. The laser beam power, beam size, and scanning velocity are easily controlled during the different processing methods. Laser surface modifications of metallic materials, such as laser surface melting, laser surface alloying, and laser cladding are some of the most important methods to improve the mechanical properties of the processed layer on the surface. A pulsed Nd-YAG laser surface melted specimens of low carbon steel with a maximum power of 90W at different processing parameters. The rapid melt and solidification of the treated layer produced a refinement in the microstructure. The original microstructure of this steel (Ferrite + Pearlite) has been transformed to new phases of martensitic and bainitic structures. The melted layer consists of the melted pool, the heat affected zone, and the substrate. The maximum hardness of the laser melted layer is more than 400 HV. The effect of different lasers such as high power CW CO_2 laser on the mechanical properties and corrosion resistance of steel alloys will be carried out in future studies.

Keywords: Nd-Yag Laser, Laser surface treatment, Microstructure and hardness of AISI1012 steel

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تأثير استعمال ليزر النيوديميوم ياك (Nd–YAG) على البنية الدقيقة وصلابة سطح الفولاذ AISI1012

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الملخص

تم في هذا البحث اختبار مدى استجابة سطح الفولاذ AIS1012 للتصلد السطحي عن طريق المعالجة السطحية بالليزر، فقد تم تعريض عينات من سبيكة الصلب AISI1012 لأشعة ليزر Nd-YAG النبضي ذات الطول ألموجي $1.06\mu m$ ميكرومتر و بقدرات مختلفة أقصاها 90 وات، تحت متغيرات مختلفة منها سرعة مسح العينات بالليزر. لوحظ تغير البنية الميتالوجرافية في منطقة الصهر من أطوار فرياتية برليتية إلى أطوار ناتجة عن التحولات السريعة للأوستنايت مثل الباينيتو المارتنسيت بالإضافة إلى تشبع البنية الجديدة بالعيوب النقطية نتيجة التبريد السريع جدًا. نتج عن ذلك أيضا تحسن الصلادة في المناطق المعالجة حيت تجاوزت 400 بمقياس فيكرز. نسعى مستقبلاً لاستعمال أجهزة ليزر ذات قدرة عالية في المعالجة و دراسة تأثيرها على الخواص الميكانيكية و مقاومة التآكل.

الكلمات المفتاحية : ليزر Nd-YAG ، المعالجة السطحية باستخدام الليزر، الصلادة و البنية المجهريه لصلب AISI1012.

Introduction

In laser surface heat treatment, lasers used as a heat source which rapidly raises temperature of the material, then the acquired heat starts sinking until it is completely cooled down to room temperature. The processes happens in a very short time provides rapid heating and cooling, which allows phases transformations to be taking place in the surface of the material. The processes of Laser surface treatment can be precisely controlled, dimensionally as well as directionally because the concentrated beam possesses a small spot of intense heat and can be produced with numerous advantages [1].The processes is most effective heat treatment when to harden specific area, rather than the bulk heating of an entire part [2,3]. The Nd-YAG laser's 1.06 µm wavelength is strongly absorbed by most heat treatable metals, the power required is less than with those laser types of longer wavelength [1, 4]. The power density of the laser source, leads to quick transformation with low heat input to the part. This reduces distortion in heat-affected zone [5]. Since the high energy is concentrated, laser surface treatment can be carried out with great precision. As for flexibility the heat-treated area can be projected within a small diameter bore through the use of directing mirror. Since energy comes from light, nothing physically touching the work piece and no force be exerted on the part. In addition, magnetism and air do not affect the laser beam, and thus it is normally considered as an open-air processing with no contact [3-5]. This paper describes the susceptibility of low carbon steel to be hardened by Nd-YAG Laser surface treatment, and the effect of different processing parameters (such as, laser beam power, scanning velocity of the working piece, beam defocusing, frequency of the applied laser beam) on the ability of low carbon steel to be transformed into hard steel.

Experimental Procedure

Low carbon steel, AISI 1012, sample of 25mm diameter and 20mm thickness, in a normalized condition, was submitted to laser surface melting after a normalizing treatment for 30min at 950ºC. Chemical composition of the as received material is presented on table1.

Table 1. Chemical composition of the as received AISI 1012 low carbon steel

Element	C	Si	Mn	P	S	Cr	Ni	Cu
Wt. %	0.142	0.146	0.483	0.007	0.023	0.051	0.049	0.037

The laser used for the surface treatment was pulsed Nd-YAG with maximum power of 100 W. The surface of steel was melted by

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overlapping parallel tracks. Laser processing parameters are listed in table 2.

TABLE.2 Laser processing parameters

Track No.	Power (W)	Frequency (cycle/s)	Pulse width (ms)	Scanning rate (mm/s)	Spot size Φ(mm)
1	10	50	0.3	1	0.3
2	30	50	0.3	1	0.3
3	50	50	0.3	1	0.3
4	90	50	0.3	1	0.3
5	90	50	0.3	7	0.3

Standard procedures were used to prepare, metallographic specimens in the following manner. Grinding the cross section (perpendicular to the treated surface) of the specimens using emery paper started from 100 up to 600 grades. the process was followed by fine polishing using alumina (Al_2O_3). The surfaces were etched by Nital 3%., and magnified using optical microscope. The hardness of the specimens was evaluated by Vickers micro hardness tester.

Results and Discussions:

Microstructure of the base metal (as received) is presented in figure 1, which demonstrates a matrix of ferrite grains containing islands of pearlite.

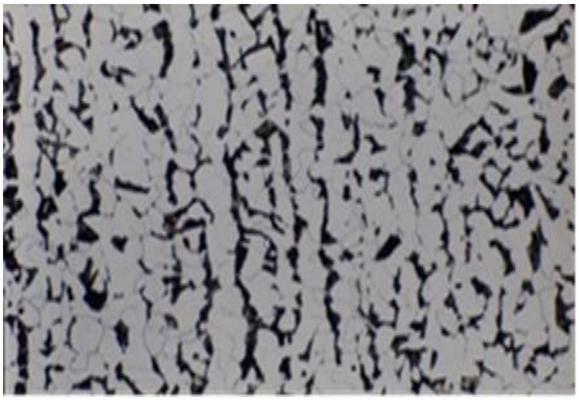

Figure1. Optical micrograph of microstructure of the carbon steel original starting material, 200X.

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The volume fraction of pearlite is around 30% and the rest is ferrite phase. In general, the microstructures of the ferrirte and pearlite grains have directionality toward the rolling direction. The microstructure of the treated surface is presented figure 2.

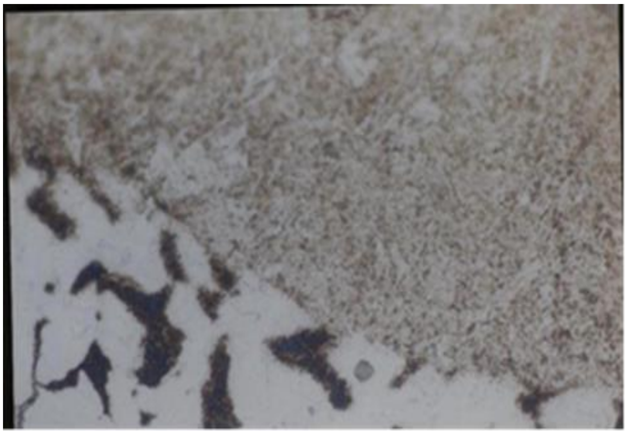
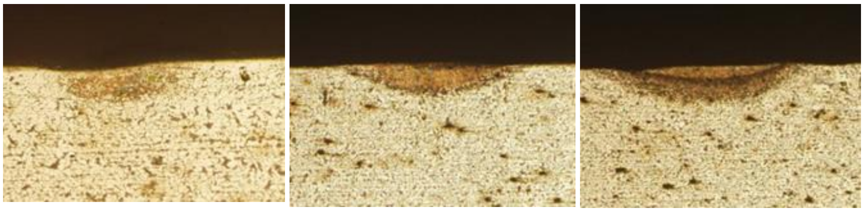


Figure2. General view of laser surface melted region of carbon steel, 500X. (Laser power 90W, Scanning velocity 1.00mm/s)

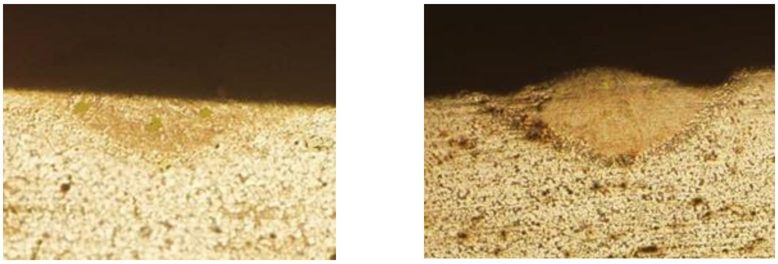
Detailed observation of the melted region, revealed a fine dendritic structure, typical of the fast solidification rates involved in the process. The first layer has a columnar-dendritic structure. The microscopic segregation is considerable due to a high crystallization rate. The structure inside melting pool is acicular ferrite and high cooling rate phases such as bainite and martensite. It was observed in figure 3 that the width as well as the depth of the melting pool increased with the input power of the Laser beam. According to the laser processing parameters in table 2, the metallographic has shown that the higher the power density the deeper is the case depth. However, if all other variables are fixed, there is a maximum that limit is exceeded, surface melting will occur. If scanning speed is increased, case depth will be decreased.

Figure 4 On the other hand decreased scanning speed causing significant surface melting and larger heat effected zone and more relieved structure with relatively lower hardness [4] .



(a) (b) (c)

Figure 3. Optical micrographs100X of melted pool produce by laser power (a)10W, (b) 30W, (c) 50W and scanning velocity v=1mm/s



(a) (b)

Figure 4. Optical micrographs100X of melted pool produced by laser power of 90W and scanning velocity (a) 7 mm/s and (b) 1 mm/s

Rapid cooling depresses the temperature at which the gamma (γ) to alpha (α) change takes place. As the transformation temperature falls, the distance over which carbon atoms can diffuse is reduced, and there is a tendency to form structures involving progressively shorter movements of atoms. With more rapid cooling carbides precipitate around or within the ferrite which now appears in the form of needles or plates rather than equiaxed grains, a structure known as bainite [4-6]. At even higher rates of cooling, the transformation is depressed to a temperature, where martensite Ms is formed, this transformation product is produced by shear movement of austenite lattice [7].

In general, the microstructure of the melted zone of this carbon steel is acicular ferrite. Between the ferrite grains higher-carbon transformation products such as fine perlite, bainite and martensite were observed and detected beside some localized areas, which contain retained austenite, figure 2. The microscopic observation doesn’t reveal any crack inside the melted pool or the heat effected zone.

The hardness of laser treated carbon steel layer is enhanced significantly as a result of laser surface melting, and subsequent self-quenching as shown in the microhardness profile figure 5. The maximum hardness of Laser surface melted layer is around 400-460HV where the hardness in the base metal (untreated) region is in the range of 170-195HV. The high hardness values in the treated surface are due to phase transformations which occurred due to dissolution of the original existed phases (ferrite and pearlite) forming bainite, martensite and amorphous regions beside high quenched in-vacancies produced by the high quenching rate.

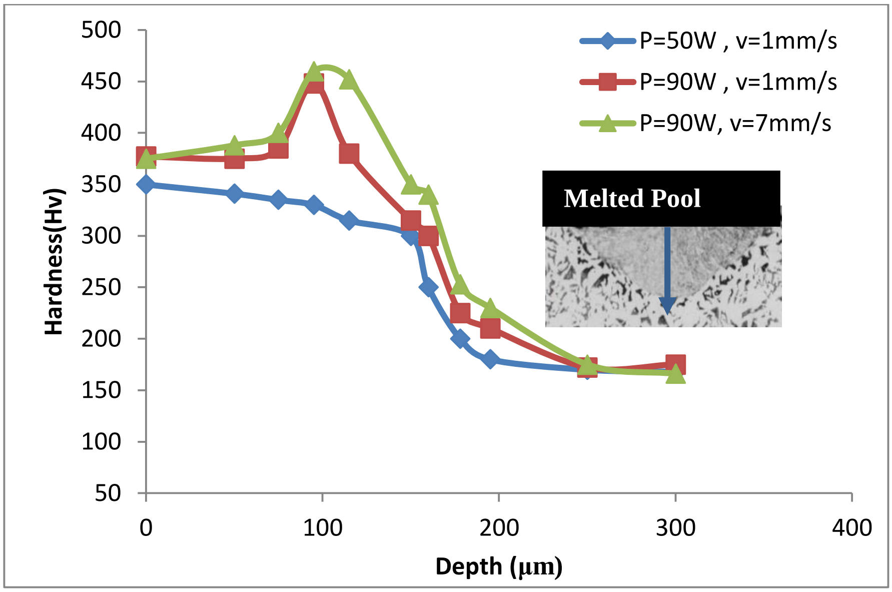


Figure 5. Microhadness profile of laser surface melted carbon steel at different laser processing powers and scanning velocities

Figure 5 shows the hardness resulted from applying different Laser beam power and different scanning velocities. It is clearly shown that the scanning velocity affected the hardness. The values of the hardness were higher in the melted pool and heat affected zone at

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higher scanning velocities. It shows values between 460-375HVat scanning velocity of 7.00 mm/s, while it is in the range of 450-350HV at scanning velocity of 1.00 mm/s. As the scanning velocity increased, the amount and size of martensite plates decreased. This is due to the higher cooling rate of the higher scanning velocity in limited areas. For lower scanning velocity, the martensite structure appeared in lower areas. Regarding the size of the acicular martensite, the scanning velocity has straight effect. It is also shown in figure 5 the decrease in the hardness values from 450-350HV to 350-300HV as laser processing power reduced from 90W to 50W. The high input heat at higher laser processing power led to a rapid melt and solidification in the melted pool and increase the heat-affected zone. Consequently, higher laser processed power produced areas with finer microstructure and higher hardness.

Conclusions

The common carbon structural steel has a good ability to be hardened by pulsed Nd-YAG Laser surface treatment. The most effective parameter used in laser surface treatment was the power of laser beam; however, when this power is high the depth of the affected metal surface is deeper. The second important parameter is the linear velocity of worked piece, the higher the linear velocity the narrower the width of the affected area. The improvement in hardness due to laser surface of low carbon steel exhibited clear dependence on laser processing power and scanning velocities.

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