Microstructure and Hardness of Nd-YAG Laser Surface Melted low Carbon Steel

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ABSTRACT

The unique characteristics of the laser beam compared to the normal light i.e. its directionality, monochromatcity, and brightness make it a very important tool in the surface engineering. The concentrated heat in the laser beam can precisely directed toward the processed region on the surface. The laser beam power, 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 resolidification 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.

Key words:Laser surface Melting, Carbon steel, Microstructure, Microhardness

الملخص

يمتاز شعاع الليزر بعدة ميزات مقارنة بالضوء العادي و التي من أهمها أحادية اللون ،التماسك ،اتجاهية و شدة إضاءة عالية، لذلك يمكن اعتباره أداة ذات أهمية في هندسة الأسطح. حرارة شعاع الليزر يمكن توجيهها بدقة نحو المنطقة المعالجة على السطح، كما يمكن التحكم في حجم و قدرة شعاع الليزر و سرعة المسح بسهولة عند استخدامه في معالجة الأسطح

بطرق مختلفة. تستخدم الليزر في معالجة أسطح المواد المعدنية بطرق مختلفة منها الصهر السطحي و التسبيك السطحي و التغليف لتحسين الخواص الميكانيكية و مقاومة التآكل.

لقد تم في هذا البحث اختبار مدى إمكانية الصلب الكربوني للتصلد السطحي عن طريق المعالجة السطحية بالليزر. عرضت عينات من الصلب الكربوني لأشعة ليزر Nd-YAG النبضي ذات الطول الموجي 1.06 ميكرومتر وبقدرات مختلفة أقصاها 90 وات، تحت متغيرات منها سرعة مسح العينة بالليزر. لوحظ تغير البنية الميتالوجرافية في منطقة الصهر LMP من أطوار فريتية برليتية إلى أطوار ناتجة عن التحولات السريعة للأوستنايت مثل الباينيت و المارتنسيت بالإضافة إلى تشبع البنية الجديدة بالعيوب النقطية نتيجة التبريد السريع جدًا. ولقد نتج عن ذلك تحسن الصلادة الميكرونية في المناطق المعالجة حيت تجاوزت 400 فيكرز.

Introduction

In laser surface treatment, energy is transmitted to the material's surface in order to create a hardened layer by metallurgical transformation [1]. Lasers used as a heat source rapidly raise the surface temperature of the processing material. Heat sinking of the surrounding area provides rapid self-quenching, thus producing a hardened transformation layer. Since lasers can be precisely controlled, dimensionally as well as directionally, it is most effective when it is used to selectively harden a specific area, rather than 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, surface coating is not required, and generally the power required is less than with the use of longer wavelength lasers[1]. Because of the concentrated laser beam a small spot of intense heat can be produced with numerous advantages. The high 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 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 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 carbon steel to transformation.

1. 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 table 1.

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

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

Standard procedures were used to prepare, metallographic specimens in the following manner. Grinding using emery paper started from 100 up to 600 grades, this process was followed by fine polishing using alumina (Al_2O_3). The laser treated surfaces were etched by Nital 3%. Microstructure on the transverse sections of the processed material, were analyzed by optical microscopy. Mechanical features of the microstructure developed were evaluated by Vickers microhardness tester.

Table: 2 *Laser processing parameters*

Track N0.	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

2. Results and discussions:

Microstructure of the as received material is presented on figure 1. It is consists of a matrix of ferrite grains containing islands of pearlite. The volume fraction of pearlite is around 30% and the rest is ferrite phase. In general the microstructures of the ferrite and pearlite grains have directionality towards the rolling direction. A general view of transverse section of the material after laser surface melting is shown in figure 2.

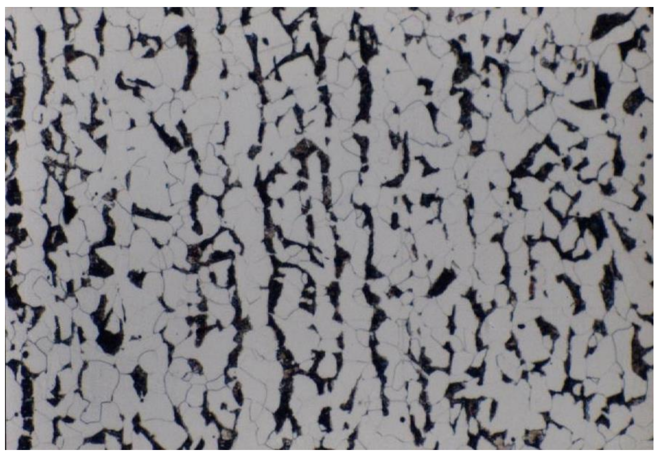


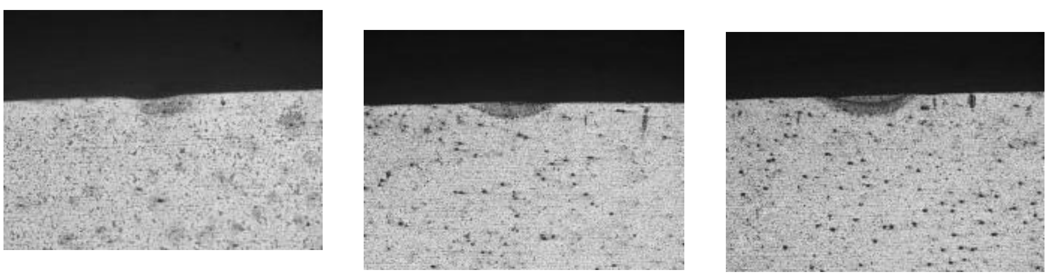
Figure1. Optical micrograph of microstructure of the carbon steel original starting material, 200X.

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 metallograhic 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 depth that can be achieved, when 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 micrographs of melted pool produce by laser power 100X (a) 10W, (b) 30W, (c) 50W and scanning velocity v=1 mm/s

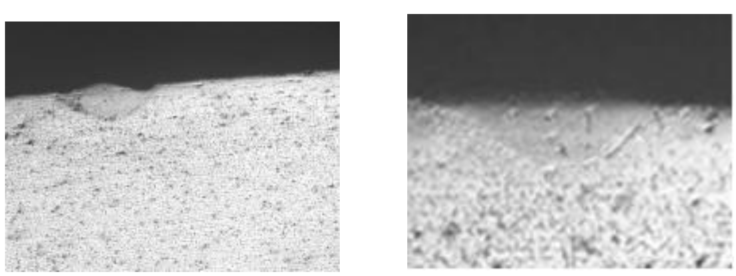


Figure 4. Optical micrographs of melted pool produced by laser power of 90W and scanning velocity 100X(a) 7 mm/s and (b) 1 mm/s

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.

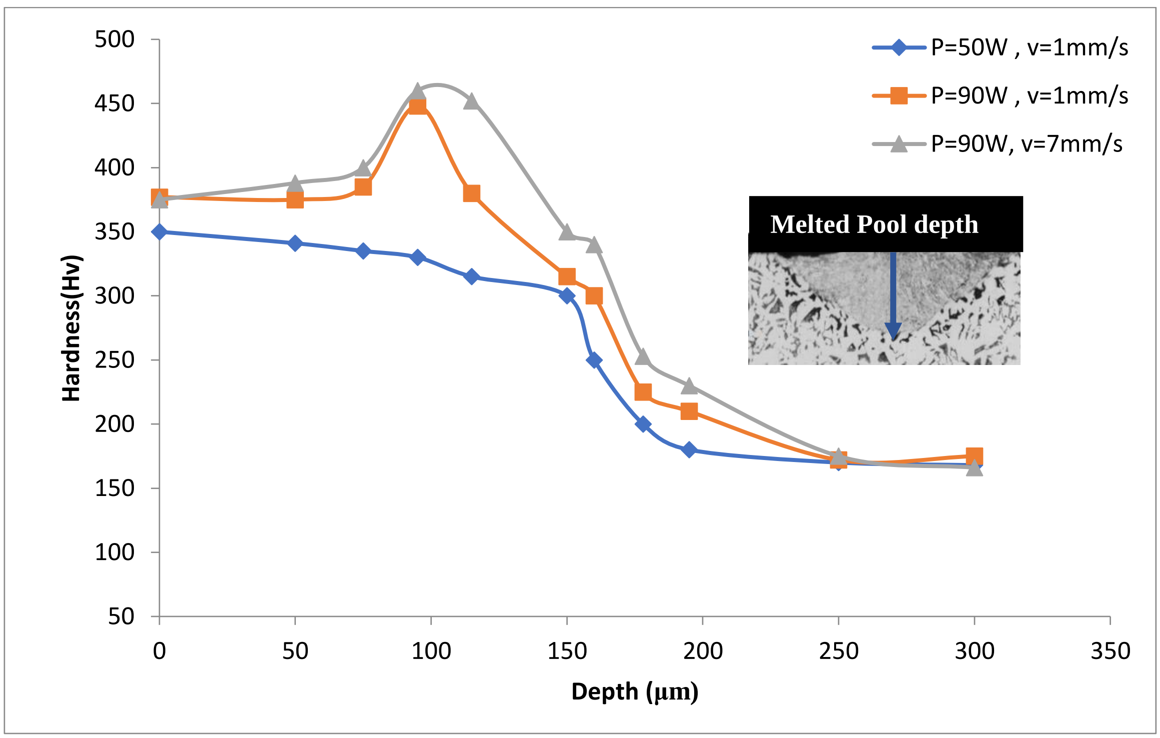


Figure 5. Microhadness profile of laser surface melted carbon steel
at different laser processing powers and scanning velocities

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 substrate (untreated base metal) region is in the range of 170-195HV. The high hardness values in the treated surface is 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 [4].

Figure 5 shows the hardness profile at different laser beam power and different scanning velocities. It is clearly shown that the scanning velocity affect the hardness. The values of the hardness are higher in the melted pool and heat affected zone at higher scanning velocities. It shows values between 460-375HV at 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 increases, the amount and size of martensite plates are decreased. This is due to the higher cooling rate of the higher scanning velocity in limited areas[2,4]. 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 shows 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 resolidification in the melted pool and increase the heat affected zone. consequently higher laser processed power produced areas with finer microstructure and higher hardness.

3. Conclusion

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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