International Science and Technology Journal
المجلة الدولية للعلوم والتقنية

Volume 34 العدد
Part 1 المجلد
April 2024 ابريل

المجلة الدولية للعلوم والتقنية
International Science and Technology Journal
ISTJ

تم استلام الورقة بتاريخ: 3/ 2024/4م    وتم نشرها على الموقع بتاريخ: 30/ 2024/4م

# Effect of Nd-YAG Laser Parameters on the Surface Hardness of AISI D2 Tool Steel at Different degree of Roughness

www.doi.org/10.62341/hehs3430

**Hussein A. Masrub, Hanan S. Habishi**

Libyan Advanced Center of Technology
www.act1.ly

Husseinmasrub@yahoo.co.uk, Hanan_habishi@act1.ly

**Abstract:**

This research study focuses on the experimental analysis of surface hardening with laser rays for a sample of tool steel 1.2379 at different surface roughness's and laser parameters.The sample was received in an annealed condition with hardness value of 220 HV. The purpose of the experiment was to determine the effect of surface roughness and laser scanning speed on the surface hardness of the sample and the depth of the molten layer. The results showed that the surface roughness and laser scanning speed influenced the depth and hardness of the provided surface. It was observed that at slower scanning speed and a higher surface roughness, a higher hardness and a deeper cured layer thickness were achieved. A maximum surface hardness of 662 HV was achieved using a laser power of 75 W, a laser spot diameter of 0.5 mm, a pulse rate of 80 kHz, a laser processing speed of 1 mm/s, and at the higher surface roughness.

**Keywords:** Tool Steel, Laser Surface Hardening, Surface Roughness, Microhardness, Scanning Speed.

تم استلام الورقة بتاريخ: 3/ 2024/4م وتم نشرها على الموقع بتاريخ: 30/ 2024/4م

# تأثير مدخلات الليزر (Nd-YAG) على الصلادة لصلب العدة عند درجات مختلفة من الخشونة السطحية

**حسين احمد المصروب، حنان سالم الحبيشي**
Hanan_habishi@act1.ly, Husseinmasrub@yahoo.co.uk

المركز الليبي المتقدم للتقنيـــــــــــــــــــــــة
www.act1.ly

**الملخص:**

تركز هذه الدراسة البحثية على التحليل التجريبي للتصلد السطحي بأشعة الليزر لعينة من صلب العدة عند (AISI D2 Tool Steel) خشونة سطح مختلفة ومتغيرات ليزر . العينة تم استلامها في حالة ملدنة بقيمة صلادة 220 فيكرز. الغرض من التجربة هو تحديد تأثير خشونة السطح و سرعة مسح الليزر على صلادة سطح العينة وعمق الطبقة المنصهرة، أظهرت النتائج أن خشونة السطح وسرعة مسح الليزر له تأثير علي عمق وصلادة السطح المعالج. لوحظ أن عند سرعة المسح الأبطأ وخشونة السطح الأعلى تحققت صلادة اعلى وسمك الطبقة المعالجة الأعمق. تم تحقيق أقصى صلادة سطحية تصل إلى 662 بمقياس فيكرز باستخدام طاقة ليزر تبلغ 75 واط وقطر بقعة ليزر 0.5 مم ومعدل نبض يبلغ 80 كيلو هرتز وسرعة معالجة بالليزر تبلغ 1 مم/ثانية وعند سطح الخشونة الأعلى.

**الكلمات المفتاحية:**صلب العدة، تصلب السطح بالليزر، خشونة السطح، الصلادة المجهرية، سرعة المسح.

تم استلام الورقة بتاريخ: 3/ 4/2024م وتم نشرها على الموقع بتاريخ: 30/ 4/2024م

## 1. Introduction

Surface hardening of tool steels is being recognized as an important factor in the face of increasing mechanization and automation of manufacturing processes. As a result, improvements to the surface layer of tool steels must take into consideration the predicted tool service circumstances. When the problem of tool steel wear is taken care of, the surface hardness of the tool steels becomes a major factor, where the surface of the tool steels must be robust enough to resist friction forces given to it across the operation while remaining hard enough to resist wear. However, many applications require that tool steels be robust enough to sustain impact without fracturing [1-4]. The cold work steel 1.2379 is widely used in the field of cutting and punching tools as well as in solid forming. The tool steel 1.2379 is a 12% ledeburitic chromium steel, which combines toughness, very high wear resistance, compressive strength, and dimensional stability; particularly for the cold extrusion of aluminum [5].

Due to several benefits over conventional heating methods, laser surface hardening is one of the greatest approaches for hardening a surface without compromising interior toughness. In other words, laser surface hardening is a successful approach for improving tribological properties and increasing tool steel service life. In contrast to traditional surface heat treatment, laser beam surface heat treatment is based on the features of self-quenching, which cools fast into the inner of materials without the need of a cooling media [6-8].

Laser beams provide focused heat input, limited distortion, the ability to treat certain areas, access to restricted locations, and fast cycle durations. The laser surface hardening produces wear resistance and a highly hardened surface layer due to very fine dendrites with dissolved carbides [9]. Laser surface treatment has contributed to increasing the life span of tools and products, for example in the automobile industry, a noticeable increase of up to 10-30%, at a lower cost of up to 3-10% of the cost of new tools [10]. Laser hardening of cutting tools also showed that less material was lost compared to induction hardening [11].

The wear resistance of a laser surface treated specimen is 30% greater than that of a conventionally heat-treated specimen.
The impact of different energy densities on the specimen and hardening process demonstrates that the depth of the melted and hardened layers of the laser-treated, quenched H13 steel increased significantly with increasing laser energy density [12].
For the reason of the partial dissolution of hard carbides, low powers typically result in melted zones with a higher hardness than higher powers [13].
Nowadays, laser surface hardening is a hot topic since it appears to provide the opportunity to conserve essential materials while also allowing for superior alloys with idealized surfaces and bulk engineering applications. Both Nd-YAG lasers and CO2 lasers have recently been used for targeted hardening of tool steel alloys, and so have prospective applications in machine tool industries. Many studies have been conducted to determine the influence of the independent factors of the laser hardening process, such as laser power scanning speed, laser spot size, pulse repetition rate and thermal characteristics of the work material [14,15]. This study has been planned to investigate the Nd-YAG Laser beam Parameters on Surface Hardness for AISI D2 tool steel at different degrees of roughness.

## 2. Experimental Work:

The sample used was Tool Steel 1.2379 according to DIN standard and equivalent to AISI D2 specification. The cold work tool steel 1.2379 is high chromium tool steel specifically designed to provide a high abrasive wear resistance and a high hardenability. The main applications are stamping tools, punches and dies, forming dies, shear blades and cutters and ceramic molds. It was received in an annealed condition with hardness value of 220 HV and a chemical composition shown in Table 1. A sample with dimensions of L25×W25×H20 $mm^3$ was cut from the as-received base metal. Two side surfaces of the test specimen were prepared using one side grit of #120 Grit ($1.32x10^{-6}$ surface roughness) and other side grit of #180 Grit ($0.76x10^{-6}$ surface roughness) sandpapers and manually

تم استلام الورقة بتاريخ: 3/ 4/2024م وتم نشرها على الموقع بتاريخ: 30/ 4/2024م

polishing the specimen to the desired state, prepared for laser surface hardening experiments. The surface of the sample 25x25 was divided into 5x5 areas for laser treatment under different conditions as shown in Figure 1.

**Table 1. Chemical composition (wt%) of used tool steel (1.2379).**

| C | Si | Mn | Cr | Mo | Ni | Cu | Al | V |
|---|---|---|---|---|---|---|---|---|
| 1.633 | 0.414 | 0.212 | 11.852 | 0.733 | 0.156 | 0.13 | 0.073 | 1.039 |

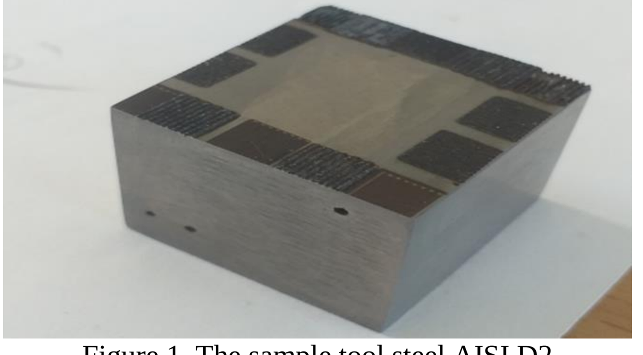


Figure 1. The sample tool steel AISI D2

The laser system employed is Nd-YAG laser with a maximum output power of 75 W, which emits radiation at a wavelength of 1064 nm. Figure 2 shows the schematic diagram of ND-YAG laser surface treatment system. The laser head is integrated with a galvanometer-based optical scanner. The laser beam was focused on the target through a 185.5-mm focal length F-Theta lens. The laser system is equipped with a CNC driven XYZ table where the sample is placed and moved for treatment. Nd-YAG Laser Machine parameters employed are indicated in Table 2.

**Table 2. Nd-YAG Laser processing parameters.**

| Power (Watt) | Scanning Speed(mm/s) | Fq(KHz) | Spot size(mm) |
|---|---|---|---|
| 75 | 1,2,3,4,5,6 | 80 | 0.5 |

تم استلام الورقة بتاريخ: 3/ 2024/4م وتم نشرها على الموقع بتاريخ: 30/ 2024/4م

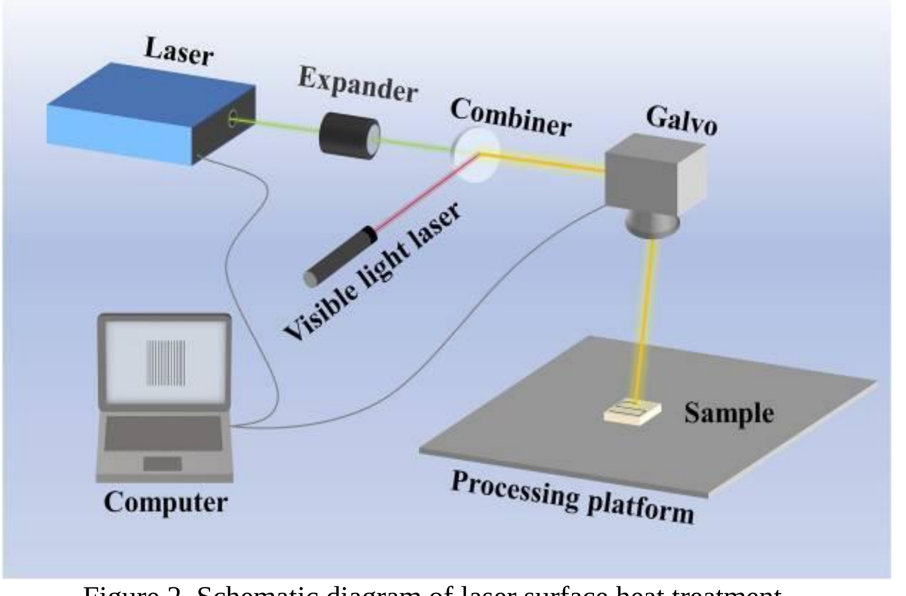


Figure 2. Schematic diagram of laser surface heat treatment

The microstructures of the treated zone and base metal were investigated using optical microscope. The microhardness of treated zone and subsurface layers was evaluated using Vickers Microhardness test. A cross-sectional sample was sanded with 600 and 1200 grit sandpaper and polished with colloidal silica to reduce its roughness, thereby preventing roughness that could interfere with the results of HV measurements. Microhardness was measured on the laser-treated sample surface, which was cleaned only with water to prevent that it could be modified. Vickers Hardness Tests were performed using a Leica VMHT MOT Microhardness tester operating with a load of 0.2 kg at 15 seconds. The tester was applied in the cross-sectional area of treated specimen until it reached the base material. Penetration depths of the tester from the surface of specimen to the treated material region were approximately 50 to 300 µm in the base material region, as shown in Table 3. At each of these depths, 15 micro-indentations were made in lines parallel to surface.

تم استلام الورقة بتاريخ: 3/ 2024/4م وتم نشرها على الموقع بتاريخ: 30/ 2024/4م

## 3. Results and Discussion:

### 3.1 Effect of Surface roughness on Laser Beam Speed:

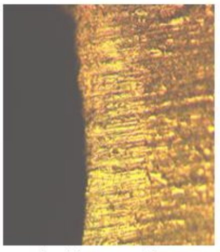
**Table 3: Laser Treatment Parameters with Grit Sandpapers (120,180)**

| No. | Scanning speed [mm/s] | Sand paper grit | Average depth [μm] | Max. Microhardness [VH] |
|---|---|---|---|---|
| 1 | 1 | #120 | 621 | 662 |
| 2 | 2 | | 143 | 590 |
| 3 | 3 | | 82 | 590 |
| 4 | 4 | | 92 | 613 |
| 5 | 5 | | 83 | 495 |
| 6 | 6 | | 86 | 563 |
| 7 | 1 | #180 | 484 | 299 |
| 8 | 2 | | 150 | 271 |
| 9 | 3 | | 100 | 326 |
| 10 | 4 | | 62 | 415 |
| 11 | 5 | | 107 | 375 |
| 12 | 6 | | 90 | 477 |

The effect of Surface roughness is noticeable. The values of microhardness were good indicator as the radiation absorptivity of the surface with high roughness was greater than the radiation absorptivity of the surface with less roughness. Consequently, the scanning speed on the surface with the higher roughness became obviously slower.

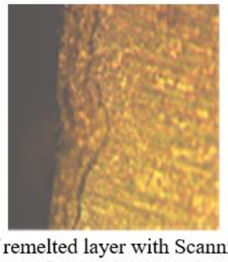
Increasing the scanning speed of the laser beam leads to a decrease in the thickness of the remelted zone formed on the surface of the sample as shown in Figure 3.

تم استلام الورقة بتاريخ: 3/ 4/2024م    وتم نشرها على الموقع بتاريخ: 30/ 4/2024م

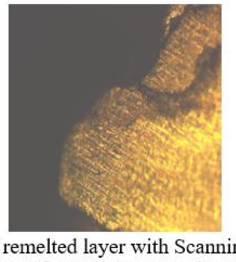


Depth of remelted layer with Scanning speed [1mm/s] &Sand paper grit#180

Depth of remelted layer with Scanning speed [1mm/s] & Sand paper grit#120



Depth of remelted layer with Scanning speed [6mm/s] &Sand paper grit#180



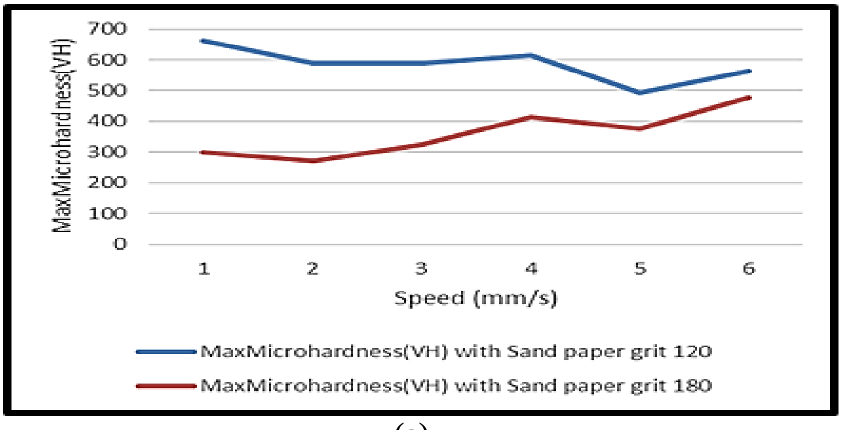
Depth of remelted layer with Scanning speed [6mm/s] & Sand paper grit#120

Figure 3. Hardened zones With Magnification [400X] of tool steel AISI D2 after Laser Processing.

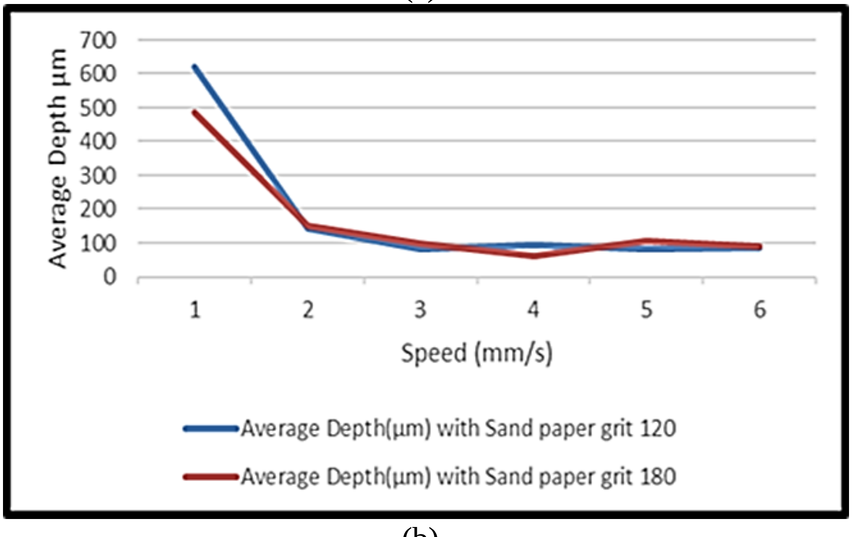
## 3.2 Effect of Laser Beam Speed on the Microhardness and Depth:

The principle of surface hardening with laser rays is based on heating to a temperature higher than the melting temperature of the steel to be hardened, thus melting and cooling the surface immediately, which leads to recrystallization of the surface and the formation of thin surface layers with a stable structure that leads to raising some of the mechanical properties of the surface layer of the steel [16] .Figure (4-a) shows that the higher of the scanning speed, which causes a decrease in hardness, and the decrease continues until it reaches a value equal to the hardness of the material as received.

تم استلام الورقة بتاريخ: 3/ 4/2024م وتم نشرها على الموقع بتاريخ: 30/ 4/2024م




(a)




(b)

Figure 4. Effect of laser beam speed on (a) the max Microhardness(VH) & (b) average depth(µm)

The most effective parameter used in laser surface treatment by pulsed YAG-Nd was scanning speed, however when this speed is high (5,6 mm/s) the both average depth and the microhardness were low than that in the beginning of the process .That because the first layer was in a molten state, and when it freezes ,it becomes

تم استلام الورقة بتاريخ: 3/ 4/2024م وتم نشرها على الموقع بتاريخ: 30/ 4/2024م

homogeneous, and the laser effect continues to heat the second layer.

At high speed, this layer does not have enough time to complete the transformation as the layer above it, resulting in a decrease in its depth, which continues to decrease as the speed increases ,Figure 4(a ,b) [17].

**4. Conclusions:**

- This study investigated the effect of laser surface solidifying of apparatus steel 1.2379 (AISI D2) utilizing laser power = 75 W, laser spot size = 0.5 mm, six different scanning speeds and for two different surface roughness. It was concluded that that the best results (max. Microhardness and deepest hardened layer) was achieved with the lowest scanning velocity (vscan = 1 mm/s) and using the roughest surface (1.32 x 10-6 m).
- The Surface Roughness of the used samples before being processed by laser beam has great effect on increasing Microhardness as it was observed that the Microhardness recorded:

- 662 VH at Surface Roughness of ( 1.32 x 10-6 m ).

  AND
- 299 VH at Surface Roughness of (0.76 x 10-6 m).

  Where the scanning Velocity was ( 1 mm/s )

- The average depth of the hardened surface layer was increased from 484 to 621µm after they had been treated by Laser beam.
- The degree of Surface Roughness and the Scanning Velocity of a Laser Beam are important factors that contributed to improving the Surface Hardness.
  - In general, with controlled laser beam parameters, the results could be used for many industrial applications such as: (metalworking processes, increasing service life of punch and die).

**ACKNOWLEDGMENT:**

The authors would like to thank all those who supported them during their work at the Libyan Advanced Technology Centre and the Libyan Center for Plasma Research in Tripoli, Libya.

تم استلام الورقة بتاريخ: 3/ 4/2024م وتم نشرها على الموقع بتاريخ: 30/ 4/2024م

**References**

[1] R. Wilson, "Metallurgy and Heat Treatment of Tool Steels," McGraw-Hill Book Company Limited, London, UK, 1975.

[2] D. N. Collins, "Deep Cryogenic Treatment of Tool Steels: A Review," Heat Treatment of Metals, No. 2, 1996, pp. 40-42.

[3] A. Molinari, M. Pellizzari, S. Gialanella, G. Straffelini and K. H. Stiasny, "Effect of Deep Cryogenic Treatment on the Mechanical Properties of Tool Steels," Journal of Materials Processing Technology, Vol. 118, No. 1, 2001, pp. 350-355.

[4] Y. Lakhtin, "Engineering Physical Metallurgy," Mir Pub- lishers, Moscow, 1971.

[5] A. El-Batahgy1, R. Ramadan, A. Moussa," Laser Surface Hardening of Tool Steels—Experimental and Numerical Analysis", Journal of Surface Engineered Materials and Advanced Technology, 2013, 3, 146-153.

[6] C. T. Kwok, et al., "Microstructural and Corrosion Char- acteristics of Laser Surface-Melted Plastics Mold Steels," Materials Science and Engineering: A, Vol. 357, No. 1-2, 2003, pp. 94-103. doi:10.1016/S0921-5093(03)00228-4

[7] H. J. Shina, et al., "Microstructural and Hardness Inves- tigation of Hot-Work Tool Steels by Laser Surface Treat- ment," Journal of Materials Processing Technology, Vol. 201, No. 1-3, 2008, pp. 342-347. doi:10.1016/j.jmatprotec.2007.11.232

[8] K. Obergfell, V. Schulze and O. Vohringer, "Classification of Microstructural Changes in Laser Hardened Steel Surfaces," Materials Science and Engineering: A, Vol. 355, No. 1-2, 2003. pp. 348-356. doi:10.1016/S0921-5093(03)00099-6

[9] H. Pantsar, et al., "Effect of Processing Parameters on the Microstructure and Hardness of Laser Transformation Hardened Tool Steel," Proceedings of the 23rd Interna- tional Congress on Applications of Laser and Electro- Optics

تم استلام الورقة بتاريخ: 3/ 4/2024م وتم نشرها على الموقع بتاريخ: 30/ 4/2024م

(ICALEO 2004), San Francisco, California, USA, 4-7 October 2004, pp. 565-573.

[10] A. Rozsnyai, ”Laser hardening of deep drawing tools for industrial usage Fundamentals, geometrical considerations and guidelines for successful hardening”, Master thises, technical university of Wien, Austria 2018.

[11] M. Miralles, “Laser hardening of cutting tools” PhD Thesis, Luleå University of Technology, Luleå, Sweden, (2003).

[12] P. Mali1, H. Deore,“ A Review on Laser Hardening Process for AISI H13 Tool Steel”, International Conference on Ideas, Impact and Innovation in Mechanical Engineering (ICIIIME 2017) ISSN: 2321-8169 Volume: 5 Issue: 6.

[13] T. Amine, cJ. W. Newkirk, H. F. El-Sheikh, F. Liou,’’ Microstructural and hardness investigation of tool steel D2processed by laser surface melting and alloying’’, Int J Adv Manuf Technol (2014) 73:1427–1435, DOI 10.1007/s00170-014-5882-8.

[14] G. H. Shehata, “Development of Hard Cutting Tools by Laser Processing,” Ph.D. Dissertation, Helwan University, Cairo, Egypt, 1992.

[15] M. S. Elnewishy, “Study on Laser Surface Treatment of Different Tool Steels,” M.Sc. Dissertation, Cairo Univer- sity, Egypt, 2006.

[16] Postnikov VS. Belova SA. “Effect of heat treatment on properties of the surface layer after laser “. Met. Sci. Heat Treat. 40(5-6):219-221, 1998 May-Jun. USA

[17] K. Azima. Effect of scanning speed of laser beam on the characteristics of tempering zone in carbon steel. Journal of engineering science, Vol. 2, No. 1, 2006 pp: 43-55.