Dry Sliding Wear Characteristics of EN 24 Steel Hardened by ND: YAG Laser

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Abstract

The aims of this investigation is to survey influence of ND:YAG Laser surface treatment of dry sliding wear features of EN 24 steel, which is medium carbon low alloy steel. Many parts of automotive, railways, marine and electric power generators are made from this alloy with distinctive properties as high strength and good wear resistance. According to ASTM G99 standards, length and diameter of the samples were (2 and 1) cm prepared by lathe machining. The prepared specimens were heat treated by using pulse ND: YAG Laser of 1064 nm wavelength and 6 Hz frequency with different energies as 500, 750 and 1000 mJ for 10 pulses. Whilst, wear inspect with dry slipping was carried out in pin–on–disc mechanism through changing loads and times from 5, to 25 N and 5 to 30 min in 5 intervals respectively. In addition, roughness and microhardness examinations were performed for the samples as received and after wear test. Photomicrographs were taken for the samples before, after surface Laser treatment, before, and after wear test. Results obtained increasing in hardness with improving in wear resistance. Surface roughness of treated specimens with 1000 mJ was more than with 500 and 750 mJ energies.

Keywords: ND: YAG Laser, Surface Treatment, EN 24 Steel, Dry Sliding Wear, Roughness

1. Introduction

Laser surface hardening is one of the most important processes that can be used to enhance the surface characteristics of engineering metals [1]. EN 24 steel is extensively used in many parts of automotive, railways, marine and electric power generators, which is possess high strength and good wear resistance [2, 3]. Laser surface treatment occurs at austenizing temperature and then self-quenching takes place, this treatment makes the surface harder than the core [4]. There are two major types of laser surface treatment [5]; thermal process without changing in chemical constituents as hardening treatment and melting, welding and cutting. The second type is thermo-chemical process which includes the changes in chemical constituents of the treated surface such as laser alloying and laser cladding. This process results in a new surface with different metallurgical structure. However, there are many advantages of treatment by laser for instance: laser energy can be focused and used to treat a small region. Moreover, it is clean and considered as a flexible tool for the engineers [6].

There are many investigations published in laser surface treatment for ferrous alloys. Radziszewska and Kusinski [7] studied the effect of tantalum (Ta) as an alloying element for coating the steel alloy at 0.17% C by using laser CW CO2 at 2.5 kW power. This study revealed that the thickness of Ta coating by laser was 0.16 mm and this improved the wear resistance and increased the microhardness of thin layer coating, and the microstructure of coating layer which composed of Ta2C and γ eutectic. Gazaliyev and et al. [8] investigated the wear behavior of different steel alloy with different percentages of carbon after ND: YAG laser treatment by using different power density. They obtained that the changing in laser power density changed the surface structure simultaneously with the mechanical properties. In addition, the investigators calculated the temperature for the pulse of laser, the diameter of the pulse, the depth of hardening and the microhardness of surface layer because of hardening by pulse ND: YAG laser. Khansaa and Muhannad [9] made comparative study by using ND: YAG laser surface hardening with conventional treatment. The treatment performed using a laser pulse ND: YAG with 1000 mJ of energy, then quenching at 840℃ in oil and tempering at 200℃ for 2 hr. followed by cooling in air. Mechanical properties was improved for laser-treated specimen including: yield strength, tensile strength, Vickers hardness and elongation about 670 MPa, 810 MPa, 675 kgf/mm2 and 15.2% respectively comparing with the values obtained from the conventional heat treatment as 558 MPa, 750 MPa, 438 kgf/mm2 and 13.8%.

This experimental investigation aims to find wear characteristics after surface heat treatment of EN 24 steel hardened by ND: YAG laser. Pin –on –disc technique with varying loads and times is used to evaluate the wear of prepared specimens before and after surface heat treatment. This investigation also aims to study the microhardness and roughness of treated specimens related to the microstructural change.

2. Experimental Procedure

2.1 Materials

EN 24 (AISI 4340) was a choice of selected material from medium carbon low alloy steel group. **Table 1** demonstrates the chemical composition of standard EN 24 steel as compared with steel, which was supplied from the local market and was used in this work. The used steel was analyzed by spectrum analysis in the lab of Commercial Company for Examination and Rehabilitation Engineering.

2.2 Specimens Preparation

Two different groups of the specimens were prepared; the first group was for microstructure examination and hardness test, while the second group was for wear test. All specimens were machined by the lathe machine. Then, they were grinding by emery papers (500 and 1000 µm) Standard ANSI. The specimens were washed by water for each step of changing the finer paper. Then they were washed by alcohol. After grinding process, they were polished by alumina solution at 1 µm in size with a suitable cloth, and then they were washed by water and alcohol. After that, the specimens were etched by using Nital (2% HNO3 + 98% alcohol) as an etching solution.

The specimen's dimensions of hardness test were 1 cm in length as well as in diameter, whilst the length and diameter for samples of wear tests were 2 cm and 1 cm respectively.

2.3 Surface Treatment by Laser

ND: YAG laser with 10 pulses, 1064 nm wavelength, and the frequency about 6 Hz of this system was performed for heat treatment of the surface. Three different energies were applied as 500, 750 and 1000 mJ of specimens that were used for hardness test and wear test. This heat treatment process was carried out in Laser Engineering Department at University of Technology.

2.4 Microstructure Examination

Photomicrographs were taken by using light optical microscope (LOM) at 250x magnification for specimens before and after laser surface heat treatment to analyze the microstructure, and the specimens after wear test to evaluate the surface topography.

2.5 Microhardness Testing

Vickers microhardness testing was carried out to measure the microhardness of the specimens after heat treatment by pulse ND: YAG laser with load of 500 g for 15 s, while the magnification was 400x. It was performed using digital microhardness HV 1000 instrument. At least four readings were taken for each sample, and then the averages of these readings were recorded. Vickers hardness number of each treated sample by pulse ND: YAG laser was determined by using following equation [10].

$$V.H.N = 1.854 \times \frac{F}{d^2{}_{avg}} \quad (kg_f/mm^2) \tag{1}$$

Where:

F: Applied Load in kg_f

d_{avg}: Average length of the diagonal left by the indenter in mm

2.6 Wear Test

Wear test was carried out with variable loads and time. At the first stage, the load was increased (5 – 25) N with step of 5 N, and then time of sliding was changed as 5, 10, 15, 20, 25 and 30 min respectively. This test was done by using pin–on–disc mechanism with rotating disc at 720 rpm; this disc was made of hardened tool steel with hardness equal to 60 HRC. Before and after wear test the specimens were weighed by using sensitive electronic balance type Metter AE-60. The wear rate of all the specimens as-received and that treated by pulse ND: YAG laser was determined by using the following formula:

$$\dot{W} = \frac{\Delta\, w}{2\pi rnt} \quad (2)$$

$$\Delta\, w = w_1 - w_2 \quad (3)$$

where: $\dot{W}$: wear rate
$\Delta\, w$: Weight changing (g)
w_1, w_2: Specimen weight, before and after wear test (g)
r: distance from disc center to specimen center
n: rotation of the disc (rpm)
t: testing time (min)

2.7 Surface Roughness Examination

Surface roughness examination was performed by setup the Talysurf-4 instrument made by Taylor-Hobson Company for the samples after wear test. Then the roughness average (Ra) was calculated for at least three readings. Table .2 shows the reading of roughness average for the specimens treated by ND: YAG laser with three different energies before and after wear test.

3. Results and Discussion

3.1 Microstructure Evaluation

Microstructure of the samples were treated by using pulse ND: YAG laser with three different energies 500, 750, and 1000 mJ. Laser surface treatment occurred at austenizing temperature and then self-quenching took place with very short time for cooling, therefore led to form martensite phase with little amount of retained austenite. The laser treated samples comparing with conventionally heat-treated samples contain undissolved carbides and more retained austenite. Increasing the energy of treatments led to finer grains of martensite and to an increase in the hardness and wear resistance [11]. Fig. 1 shows the photomicrographs of microstructure for the as-received samples and after surface treatment by pulse ND: YAG laser with three different energies at 500, 750, and 1000 mJ respectively.

3.2 Effect of Laser Surface Treatment on Hardness

The depth of hardening can be defined as the distribution of hardness through the depth of the treated layer by laser. Specimens with surface laser treatment had a thickness layer about 0.5 mm. The hardness gradually decreased faraway the surface, the hardness of surface treated by energy of 1000 mJ was more than that of surface treated by energies of 500 and 750 mJ. This is attributed to the forming of un dissolved carbides as a result of rapidly cooling of the self-quenching, which in turn causes the grains treated by 1000 mJ energy to be more refined than those treated by other energies (500 and 750) mJ [12]. Fig. 2 reveals that an increase in laser energy leads to an increase in hardness.

3.3 Effect of Laser Surface Treatment on Wear Rate

Laser surface treatment leads to form a martensite phase with a little amount of austenite and then improve the wear resistance. However, it is obvious that the wear resistance of the specimens treated by leaser energy at 1000 mJ is more than that of the other specimens, which are treated by laser energies at 500 and 750 mJ. Since the laser heat treatment was used with three different energies, the cooling rates were also different, and the wear rates were different also.

The increase of the applied load with changing the time leads to the increase of the wear rate even with untreated specimens. This attributed to the galling of surfaces at which the specimens touch the rotating disc. However, for the treated samples by using different laser energies, the galling of the surface layer is reduced because an oxidation takes place between the pin and rotating disc because of friction between them and increases heat transfer [13]. Heat transfer produced a welding condition, which prevents the galling of wear's debris. Thus, wear resistance of the specimens treated by energy of 1000 mJ is more than that of the specimens treated by energies 500 and 750 mJ. Fig. 3 and Fig. 4 show obviously that an increase in load and time leads to an increase in the wear rate of the as-received specimens and those treated by pulse ND: YAG laser. This is obviously shown that the wear rate of the specimens treated by 1000 mJ is lower than that of other specimens and hence the wear resistance is high.

3.4 Influence of Laser Treatment on Surface Topography

Heat treatment by laser of ferrous alloys produced rough surfaces with many ripples. It is clearly noted that the roughness surface of specimens treated by energy of 1000 mJ is more than that of specimens treated by energies of 500 mJ and 750 mJ. Moreover, the laser surface treatment created grooves at the surface because of the galling of the surface and it produced wear debris [14]. Fig. 5 and Fig. 6 show that the grooves for untreated specimens are deeper than those of the treated specimens because the galling occurred easily. As for the specimens treated by laser, it can be seen that the grooves for the specimens treated by energy of 1000 mJ are finer than those of specimens treated by energy of (500 and 750) mJ, this notion can be attributed to the same reasons mention previously.

4. Conclusions

The following conclusions can be summed up from this investigation:

1- Grains at the surface of the sample were finer due to increasing of the laser energy.
2- Increasing the energy of laser leads to increase Vickers hardness number.
3- Laser surface treatment leads to the increase of wear resistance.
4- Increasing the energy of laser leads to the increase of the roughness of the worn surface of the specimens.

Conflicts of Interest

The author declares that they have no conflicts of interest.

5. References

[1] Monteategre, M. A., Castra, G., Rey, P., Arias, J. L., Vazquez, P., and Gonzalez, M., *Surface treatments by laser technology.* AIMEN Technology Center, Relva 27A, Torneinas, 36410 Porrina, Pontevedra, Spain, pp. 19-30, 2010.

[2] Kursum, T., *Effect of the GMAW and the GMAW-P welding processes on microstructure, hardness, tensile, and impact strain of AISI 1030 steel joints fabricated by ASP 316L austenitic stainless steel filter metal.* Archives of Metallurgy and Materials, Vol. 56, pp. 955-963, 2011.

[3] Babu, P. D., Buvanashekaran, G., and Balasubramanian, R., *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, 2012.

[4] Seifert, M., Anhalt, k., Baltrachat, C., Bonss, S., and brenner, B., *Pecise temperature calibration for laser heat treatment.* Journal of Sensors and sensors Systems, pp. 47-54, 2014.

[5] Schuocker, D., Handbook of Euro Laser Academy, Ed. Chapmann Hall, 1998.

[6] Steen, W. M., *Laser material processing. Springer*, 2003.

[7] Radziszewska, A., and Kusinski, I., *Laser alloying of plain carbon steel surface layer*. Archive of Foundry Engineering, Vol. 8, pp. 175-179, 2008.

[8] Gazaliyev, A. M., Meluikov, A. G., Labankova, O. V., Zykov, I. Y., Kvon, S. V. S., and Filippova, T. S., *Studying laser radiation effect on steel structure and properties.* Metalurgija, Vol. 55, No. 3, pp. 411-413, 2016.

[9] Khansaa, D. S. Muhannad, Z. K., *Improving the mechanical properties of CK35 steel using ND: YAC laser surface hardening.* Journal of Engineering and Development, Vol. 20, No. 2, pp. 250-258, 2016.

[10] Bolton, w., Engineering Materials Technology. Butter worth Heinemann Oxford, 1988.

[11] El-Batahgy, A., Ramadan, R. A., and Moussa, A., *Laser surface hardening of tool steel - experimental and numerical analysis.* Journal of Surface Engineering materials and Advanced Technology, Vol. 3, pp. 146-153, 2013.

[12] Lu, Z. J., and Lao, I. Z., *Tribological behaviors of laser shock processing AISI 8620 steel.* Chiness Journal of Laser, pp. 1-3, 2012.

[13] Visschers, H., Rooi, M. B., Vroegop, P. H., and Schipper, D. J., *The influence of laser line hardening of carbon steel AISI 1045 on the lubricated wear against steel AISI 5210.* pp. 638-647, 1995.

[14] Radmanesh. M., and Kiani, A., *ND: YAG laser pulses ablation threshold of stainless steel 304*. Material Science and Applictions, Vol. 6, pp. 634-645, 2015.

Table 1. Chemical Composition of EN 24 Steel Alloy (wt. %) [9]

Metals	**C**	**Ni**	**Cr**	**Mn**	**Si**	**Mo**	**S**	**P**	**Fe**
Standard	0.4	1.85	0.8	0.7	0.25	0.25	0.035	0.030	Rem.
Actual	0.37	1.84	1.0	0.68	0.31	0.21	0.030	0.025	Rem.

Table 2. The Values of the Roughness Average for the Specimens

The specimen	Load (N)	Values of Ra before wear (μm)	Values of Ra after wear (μm)
Treated by 500 mJ	5	0.090	0.100
	10	0.103	0.112
	15	0.115	0.129
	20	0.200	0.138
	25	0.297	0.141
Treated by 750 mJ	5	0.104	0.101
	10	0.118	0.113
	15	0.217	0.198
	20	0.229	0.217
	25	0.238	0.225
Treated by 1000 mJ	5	0.112	0.108
	10	0.125	0.119
	15	0.241	0.201
	20	0.275	0.235
	25	0.321	0.314

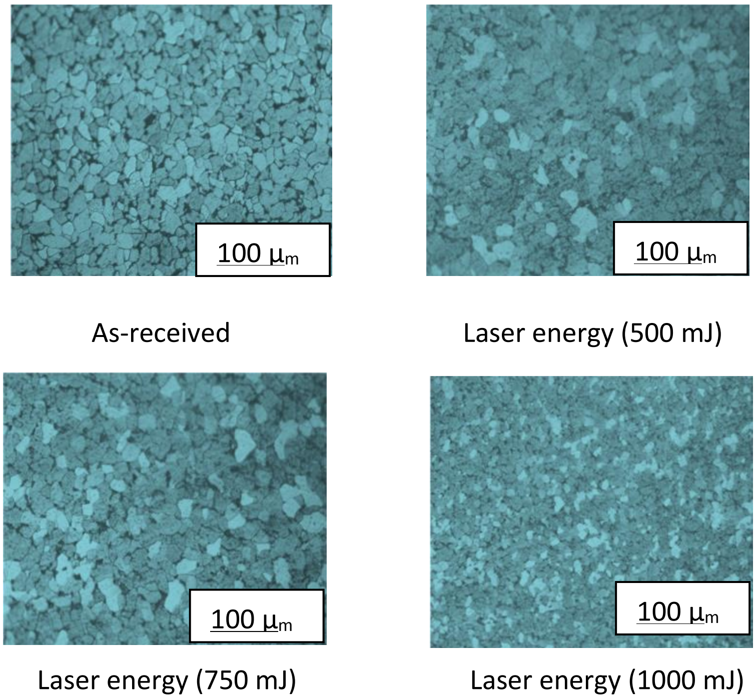


Figure 1. Microstructure of Specimens Treated by Different Laser Energy

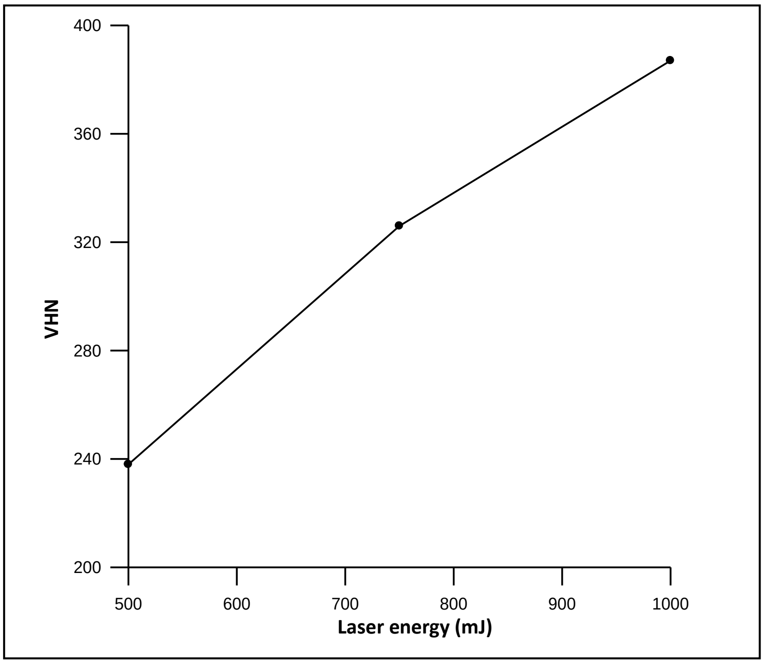


Figure 2. Relationship between Hardness and Laser Energies

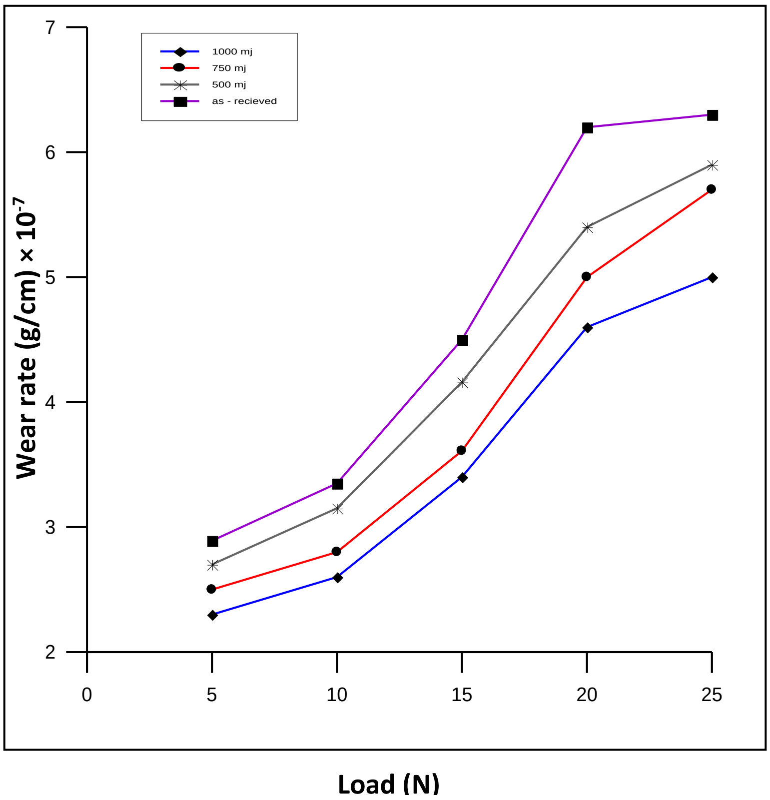


Figure 3. Relationship between Wear Rate and Load for all Laser Energies

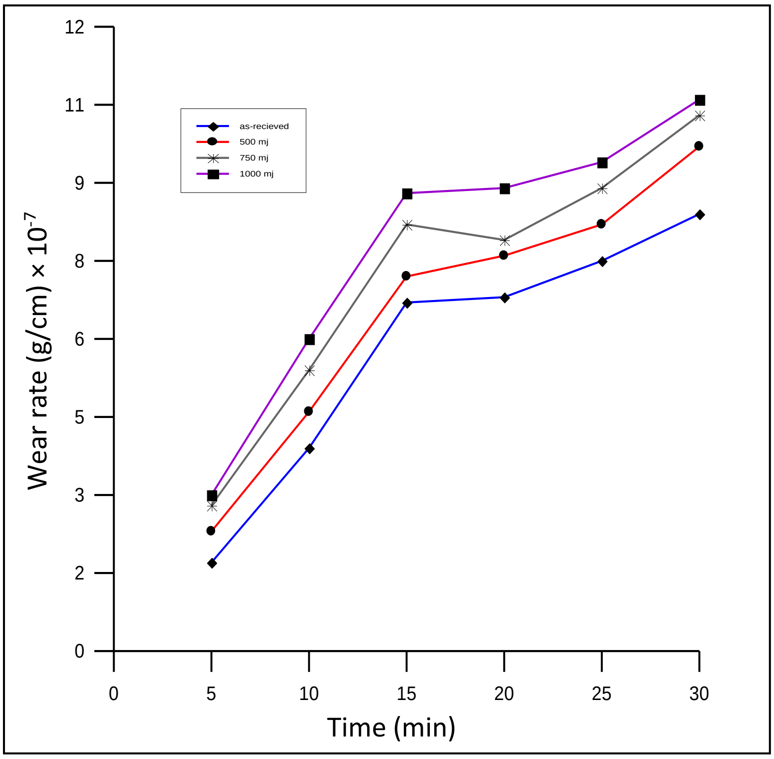
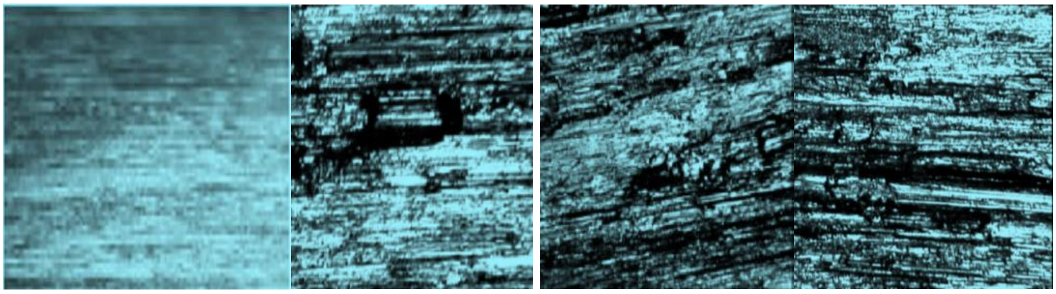
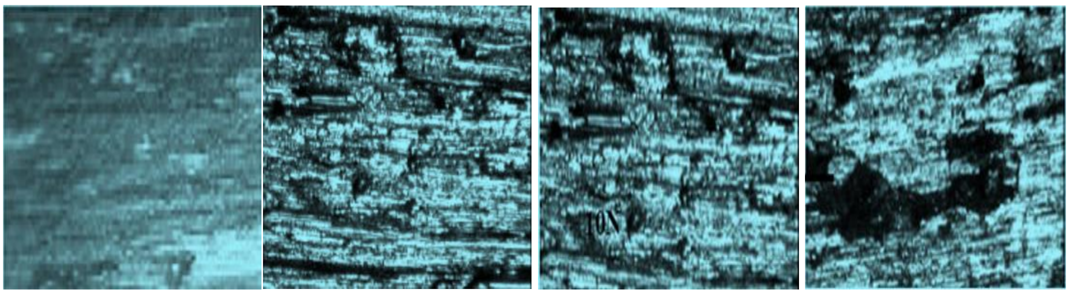


Figure 4. Relationship between Wear Rate and Time for all Laser Energies



As –received treated by laser (500 mJ) treated by laser (750 mJ) treated by laser (1000 mJ)

Figure 5. Worn Surfaces of the Specimens at 15 N for Constant Time 15 min



As –received treated by laser (500 mJ) treated by laser (750 mJ) treated by laser (1000 mJ)

Figure 6. Worn Surfaces of the Specimens at 15 min for Constant Load 15 N

خصائص البلى الانزلاقي الجاف لسبيكة فولاذ EN 24 المصلد بالليزر نيديميوم – ياك

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الخلاصة

أهداف هذا البحث هي دراسة تأثير المعاملة السطحية بالليزر نيديميوم – ياك على خصائص البلى الانزلاقي الجاف للفولاذ EN 24 الذي هو عبارة عن سبيكة فولاذ متوسط الكربون منخفض السبائكية. وهي تستخدم في العديد من التطبيقات التي تتطلب مقاومة عالية ومقاومة بلى مثل بعض أجزاء المركبات، ســـكك الحديد، مجالات البحرية ومولدات الطاقة الكهربائية. تم تحضير العينات بالتشـــــغيل علـــى المخرطة لقياس ٢ سم طول و١ سم قطر بموجب المواصفة القياسية ASTM G99. تمت معاملة العينات المحضرة حرارياً باستخدام الليزر نيديوم – ياك النبضي بطول موجي ١٠٦٤ نانومتر، وبتردد لمنظومة الليزر ٦ هيرتز مع طاقات مختلفة ٥٠٠، ٧٥٠، و١٠٠٠ ملي جول لعشر نبضات. بينما أجري اختبار البلى الانزلاقي الجاف باستخدام تقنية المسمار– على– القرص بتغيير الأحمال والزمن بمقدار ٥ إلى ٢٥ نيوتن و٥ إلى ٣٠ دقيقة على التوالي وبخمسة فترات. كذلك أجريت اختبارات الصلادة الدقيقة وفحص الخشونة للعينات قبل وبعد اختبار البلى. وتم أخذ صور مجهرية للعينات قبل وبعد المعاملة السطحية بالليزر وأيضا قبل وبعد اختبار البلى. أظهرت نتائج هذا البحث تحسن مقاومة البلى وزيادة الصلادة. خشونة السطح للعينات المعاملة بـــ ١٠٠٠ ملي جول هي أكثر مما هو عليه للطاقات ٥٠٠ و٧٥٠ ملي جول.

الكلمات الدالة: ليزر نيديوم – ياك، المعاملة السطحية، الفولاذ EN 24، البلى الانزلاقي الجاف، الخشونة.