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SURFACE TREATMENT OF NANO-STRUCTURED STEEL WITH PULSED LASER

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Abstract. In this paper, the laser surface treatment of $Fe_{52}Cr_{18}Mo_7B_{16}C_4Nb_3$ alloy has been investigated with the use of pulsed Nd:YAG laser, and the optimum pulse duration parameter for having finer microstructure, highest hardness and the most homogeneous surface has been studied. Melt profile and structure of laser processed samples were investigated by use of optical and field emission scanning electron microscopes and X-ray diffraction (XRD). Moreover, the mean crystallite size of laser treated zones was studied by the Scherrer formula. Hardness of the samples was measured by means of microhardness testing device. Results showed that by decreasing the laser pulse duration and power density in the surface of the laser treated zone the highest amount of the hardness can be achieved. Moreover, peak broadening phenomenon was observable in XRD patterns of samples with lower pulse duration. It is due to the increasing of thermal gradient in the surface as a result of decreasing power density.

1. Introduction

Over the past few years, the improvement of surface layers by different methods has attracted many investigators. Changing the microstructure contributes to many advantages such as corrosion, fatigue and wear resistance [1]. Surface melting and rapid solidification of surface layers by laser treatments can contribute to interesting properties and structures [2]. This technology allows us to convey large amount of energy in a very short time on the exact point of the surface [3]. It provides high power densities of 10^8 to 10^9 W/m^2 [4]. High energy laser beam can produce high rate unstable heat on the surface of bulk alloy and afford to fabrication of layers with appropriate properties and structures [5]. The cooling rates afforded by high power lasers are exactly in the bounds of the quench rates necessary for “amorphisation”, and therefore surface engineering by high power laser provides the chosen tool for this investigation into the fabrication of amorphous or nano-scale surface layers [6]. Depending on the thickness of the melt layer, a cooling rate in the order of 10^4 to 10^6 K/s can be achieved [7]. Because of precision of the process, short time and local effect of laser surface treatment, it can be also considered in precise industrial applications [8]. Fine crystalline materials obtained under the rapid cooling rate can exhibit high properties over micron-sized materials [1].

Laser surface treatment of steels [8, 9] and production of nano-crystalline structures on the surface of different alloys by laser beam have been investigated [2, 4, 6]. These layers exhibit attractive properties such as low friction, high hardness and good wear resistance [11].

Steels are suitable for all mechanical applications due to their high strength and ductility, good machining and low price. However, their composition and surface hardening has the major role in wear conditions [12]. Fe-based alloys that have good glass forming ability are proper for obtaining a uniform structure on the surface [13]. Their glass forming ability can be improved by adding some elements such as Nb, Mo, and Cr [14]. Due to high cooling rates in laser treatment, fabrication of layers with high hardness and wear resistance will be possible [15, 16].

In this study, fabrication of nano-structured layer on the surface of Fe-based alloy of $Fe_{52}Cr_{18}Mo_7B_{16}C_4Nb_3$ by pulsed Nd:YAG laser surface treatment was investigated. The effect of laser pulse duration on the microstructure and hardness of the surface has been studied.

2. Experimental

The investigated material is Fe-based alloy that has been casted in Shahverdi's investigation team of Tarbiat Modares University. The high purity materials (>99.5 mass %) was selected, and melted in VIM (Vacuum Induced Melting) furnace. The chemical composition of the alloy is given in Table 1. The plate of 30 mm × 60 mm × 2 mm size was cut from the bulk material. Before laser treatment the surface of the plate was ground and cleaned with acetone to remove impurities. Model IQL-10, a pulsed Nd:YAG laser with a maximum mean laser power of 400 W was used as laser source for the experiments. The laser beam with different scan pulse duration, from 1 ms to 2 ms, was irradiated on the surface of the alloy.

Table 1. The chemical composition of the investigated Fe-based alloy.

elements	Fe	Cr	Mo	B	C	Nb
wt%	57	19	14	3.5	2	4.5

According to Eq. (1) and (2), because of the constant peak power, the mean power changes by changing the pulse duration.

$$E_p = P_{av} / f \ , \tag{1}$$

$$P_p = E_p / (pulse\ duration) \, . \tag{2}$$

Here E_p stands for pulse energy, P_{av} is the average power, and P_p is the peak power.

During the test the surface was protected by pure Ar gas emerged coaxially with the laser beam. The laser parameters are shown in Table 2. More detail about the laser processing setup can be found elsewhere [17].

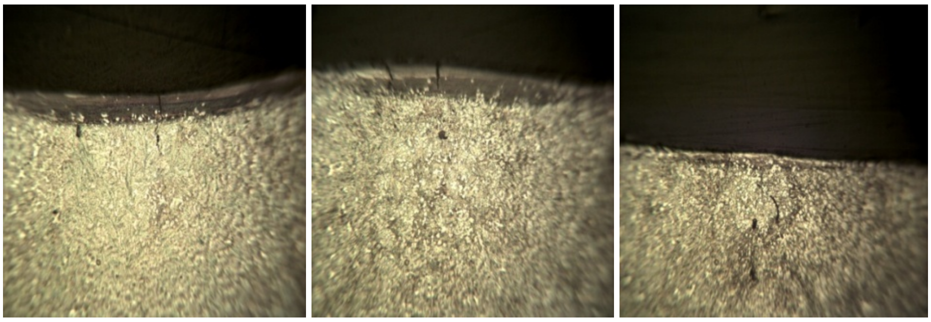
Table 2. Laser parameters.

Sample Name	Average power, W	Frequency, Hz	Pulse duration, ms	Beam diameter, mm	Laser scan speed, mm/s
A1	85	40	1	0.9	4
A2	127		1.5		
A3	170		2		

The microstructure of the surface was studied by optical and field emission scanning electron microscope (FESEM). X-ray diffractometery (XRD) operated with Co-K_α was used to identify phase structure. The Vickers microhardness profiles were extracted from cross-sections of the processed samples by applying a 200 g load for 15 s.

3. Results and discussion

Variations of the melt pool depth of samples A1 to A3 are presented in Fig. 1. It is shown that by increasing the pulse duration, the depth of the processed zone increases. Hence, when the pulse duration increases, the volume of the processed area increases and it results to more depth of laser processed region. In addition, by increasing the pulse duration, the mean power of the processed area increases and contributes to more penetration of the melted zone. Exact amounts of penetration depths are shown in Fig. 2.



(a) (b) (c)

Fig. 1. Optical micrographs of samples A1 to A3.

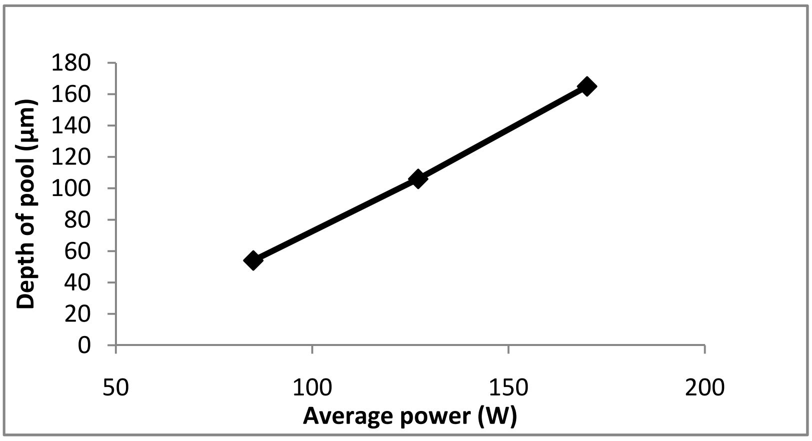


Fig. 2. Variation of the depth of the melt pool versus pulse average power.

Figure 3 shows the FESEM micrographs of the processed zone. It can be shown that by applying laser on the surface of the alloy, the microstructure becomes more uniform and tends to form a finer microstructure.

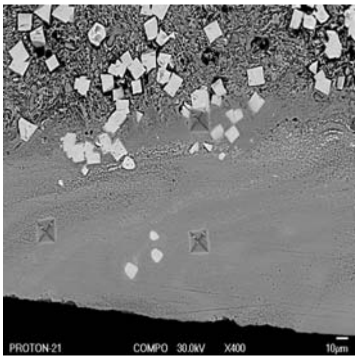


Fig. 3. FESEM microghraph of the processed zone.

It is due to the fact that applying laser on the surface contributes to high thermal gradient. Whereas the processed alloy tends to form glassy or nano-size microstructure with high thermal gradient, the processed zone has uniform and finer microstructure. As it can be seen, all the precipitations are solved in this area.

Figure 4 demonstrates the X-ray patterns of bulk alloy, samples A1 and A3. It shows that by applying laser on the surface of the alloy, some peaks that belong to some crystalline precipitation such as peaks of Cr_2C and Cr_2Nb disappear showing that the microstructure tends to become homogeneous. The main peak that belongs to α-Fe phase becomes wider, and signal to noise ratio decreases that overall means that the laser processed region tends to exhibit ultra-fine microstructure properties. Also, it is seen that by decreasing the average energy, the main peak becomes broader to somehow, and its FWHM improves. Also, some peaks that belong to Fe_2B or Fe_3B become wider. As it is explained in previous section, peak broadening is resulted from higher thermal gradient and finer microstructure. Crystallite sizes measured by the Scherrer formula confirm these pretensions. Table 3 shows the approximate amount of crystallite size on the surface of the alloy measured by the Scherrer formula. It demonstrates that by increasing the average energy, the crystallite size decreases.

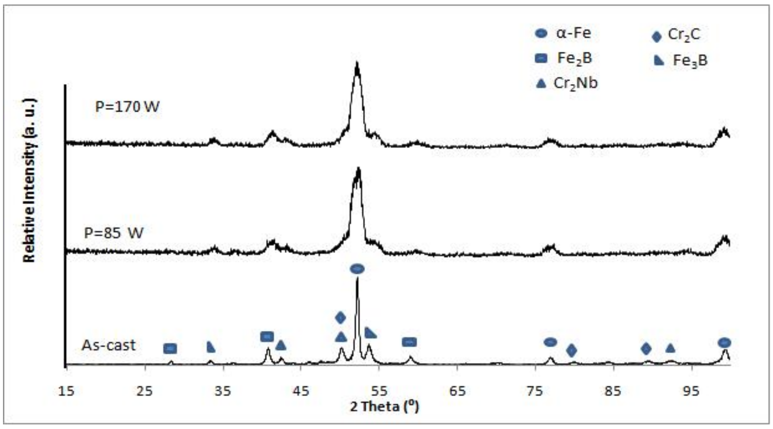


Fig. 4. XRD patterns of as-cast alloy, samples A1 and A3.

Table 3: Crystallite size of samples A1 and A3.

Sample	A1	A3
Mean crystallite size, nm	30	50

Figure 5 shows the average hardness of the surface of the samples. Since the microhardness of the as-cast alloy is about 600 HV, it is seen that laser processing will improve the surface microhardness.

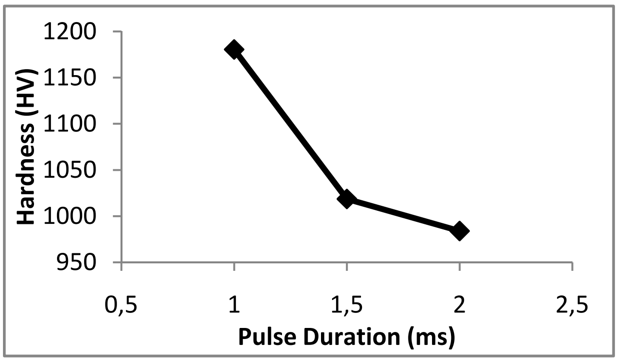


Fig. 5. Average hardness of all samples with different pulse durations.

It is shown that by increasing the pulse duration, the hardness of the treated surface decreases that is a direct result of the grain growth. As it is known, by increasing the pulse duration (in constant peak power) the average power increases and results to lower thermal gradient, so the microstructure becomes coarser. As a result wherever there is higher thermal gradient in the surface, microstructure becomes finer and contributes to higher hardness that occurs in lower pulse duration.

4. Conclusions

1. The uniformity of the microstructure improves by applying laser on the surface of the as-cast alloy.
2. By radiating lower pulse duration on the surface of the alloy, finer microstructure forms.
3. XRD analysis shows that lower pulse duration contributes to peak broadening, and it results to nano-scale microstructure.
4. By increasing the average energy, the hardness decreases, that is a direct result of grain growth.

Acknowledgments

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