OPTIMALLASER TREATMENT PARAMETERS OF AA 6061-O ALUMINUM ALLOY

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ABSTRACT

Laser surface melting (LSM) is a material treatment process based on using the laser beam as a heat source in order to modify the mechanical properties of the material surface. In this article, the optimal parameters of LSM process for AA 6061-O Aluminum is investigated using design of experiment approach. Experiments show that the most effective parameters on LSM process which give maximal hardening to the Aluminum are laser power and pulse duration. Different power magnitudes (4, 4.5 and 5) kW have been applied with different for pulse durations (3, 4 and 5) ms in order to identify the optimal parameters of the LSM. Minitab software was used to determine the optimal parameters of LSM process which they are found to be 4.5 kW laser power with 3ms pulse duration.

Keywords: laser surface melting, AA 6061, hardening, optimal parameters.

INTRODUCTION

Surface engineering treatments have been rapidly developed due to the demand to produce metal surfaces owning uniform mechanical properties without defects. Nowadays, conventional treatment techniques like carburizing and flame hardening have been replaced by modern techniques such as plasma, laser, ion, and electron. These modern techniques characterized by the simplicity in performing, modifying the surface efficiently with less time and keeping the surface with distortions due to the fine controlling on the applied heat on surface. Currently, high power lasers have become increasingly accepted as tools for many industrial applications required fine surface treatment(Steen & Mazumder, 2009). In many applications e.g. hardening, wear resistance, corrosion resistance and porosity reduction, the surface mechanical properties required to be modified without effecting on the bulk properties of the material. Laser surface melting (LSM) is one of the most promising techniques that is used to treating material surfaces. This process is based on applying laser of high power density with short interaction time in order to increase the hardening of the material surface(Quazi *et al.*, 2016).

Generally, aluminum alloys cannot be strengthening without melting their surfaces because they have no solid phase transformations. Therefore, the interesting on using LSM to modify the surface properties of such alloys is intensively increased(Razavi & Gordani, 2011). Because applying LSM ensures obtaining uniform mechanical properties along the alloy surface. The most important parameters effects on LSM treatment are the power of the applied laser beam and the duration of application. In this article, LSM is used to increase the hardness of the surface of AA 6061 aluminum alloy. This alloy hasa wide applications in industry, it is opportunity for medium and high strength application, has good toughness characteristic, and it is easily weld and joined(Alcoa, 2002).

In the related literature, it can be found many research investigated the laser treatment of aluminum alloys. For example, (Weinman *et al.*,1978)studies the effect of Nd- glass pulsed laser on Al-Fe 1-4 w/o, 2024 and 6061A transmission electron microscopy(TEM)and scanning electron microscopy (SEM)study showed that the dendrite spacing's were from 2500 A to 4000 A which corresponds to a cooling rate of over 1060C/sec. Melt depths obtained were in the range of 30-100 µm. No significant surface vaporization was observed at energy densities up to 440 J/cm^2. Fracture surfaces of the commercial alloys demonstrated elongated porosity in the melt areas, probably due to internal hydrogen.(Pinto *et al.*, 2003)studied microstructural and hardness variations throughout samples of an aluminium-copper alloy (Al-15 wt. % Cu) submitted to a laser surface re-melting treatment. The analysis procedure consisted of scanning electron microscopy (SEM) characterization and micro-hardness tests in the re-solidified and un-melted substrate regions, Mechanical Vickers hardness measurements have been carried out along the laser-treated cross sections, and it was found that values of about three times of those observed on the original substrate can be attained, confirming the effectiveness of the laser treatment. (Borowski & Bartkowiak, 2010), studied the effect of laser treatment on AlSi6Cu4 and 6082 alloy, it has been determined that the hardness of the AlSi6Cu4 alloy has increased from the level of 60-80 HV 0.1 to the level of 120 HV 0.5 due to laser treatment, while heat treatment dispersion hardening has resulted in further increase of the hardness of the laser treated zones up to the level of 160 HV. The even structure obtained allows us to propose such technology for increasing hardness and wear resistance of those alloys. In the 6082 alloy, containing less alloy elements, the hardness increase is smaller reaching the level of 120 HV0.5. This is related to obtaining zones with dispersion secretions. The suggested laser treatment parameters, 400W and 530 W with the traverse velocity of 2.8 to 5.33 mm/s do not cause significant increase of roughness, due to which such surface does not require further machining.(Sušnik *et al.*, 2012)treated Al-Si alloy, after laser surface re-melting by the changes in microstructure and micro-hardness of a modified surface layer. Laser re-melting of the thin surface layer was carried out with different energy inputs into the as-cast specimen surface. The re-melting conditions were varied by application of different laser beam pulse duration. After solidification of surface re-melted layer a fine-grained microstructure is formed. Such a microstructure increases micro-hardness of Al-Si alloy by about 60 to 80%. The variation and size of mainly tensile residual stresses in surface re-melted layer greatly depends on the cooling rates i.e. laser pulse duration.(Pakieła *et al.*, 2016)study the influence of a high power diode laser surface treatment on the structure and properties of aluminum alloy have been determined. The aim of this study was to improve the mechanical and tribological properties of the surface layer of the aluminum alloy by simultaneously melting and feeding tungsten carbide particles into the molten pool. During the process was used high-power diode laser HPDL of 1.8, 2.0 and 2.2 kW laser beam power has been used. The linear laser scan rate of the beam was set 0.5 cm/s. As a base material was used aluminium alloy ENAC -AlMg9. To improve the surface mechanical and wear properties of the applied aluminium alloy was used biphasic tungsten carbide WC/W2C. The size of alloying powder was in the range 110-210 µm,it was found that the highest properties of the obtained surface were achieved at the lowest laser power of 1.8kW a hardness of about 15HRF is achieved form this power.

In this article, the optimal parameters of LSM process for AA 6061-O Aluminum is investigated using design of experiment approach. Experiments show that the most effective parameters on LSM process which give maximal hardening to the Aluminum are laser power and pulse duration. Many experiments had been conducted with different laser power magnitudes and pulse durations in order to obtain the required data for applying the design of experiment approach which is based on full factorial design. Generally, factorial design is the very efficient for the experiments which involve the study of the effects of two or more factors. Factorial design means that all possible combinations of the levels of the factors are investigated in each complete trial or replicate of the experiment. Minitab software was used to analysis the experimental results. This software is widely available general-purpose statistical software package that have good data analysis capabilities and that handles the analysis of experiments with both fixed and random factors (including the mixed model).

Experimental work

From literature, it can be seen that there is four parameters affect the LSM process. Two parameters related to the laser characteristics: power and frequency. The other two parameters are the pulse duration of the laser and the offset distance between the laser head and sample. In the current work, these parameters had been experimentally investigated using Nd-YAG laser with 7.5 maximum output power, 50 ms pulse duration and 50 Hz frequency. In addition, using microstructure examination to determine the depth of treatment and performing micro-hardness test.

In this article, a plate from AA 6061-T6 Aluminum alloy with dimensions (6.5 mm x 750 mm x 750 mm) is used in the experimental work. The chemical composition of this alloy was identified in the SIER-Baghdad (State Company for Inspection and Engineering Rehabilitation). The composition can be seen in Table 1. Many samples were annealed to O- tamper according to ASTM slandered(Products, 2001). They were heated to about 400^{o}C, then they were kept inside the furnace to be cool to about 260^{o}C and finally they were brought out from the furnace in order to be cooled at air to reach room temperature. After that, these samples were cleaned and grinded using emery paper with grades of (120, 220 and 400) to enhance the absorption of aluminum to laser light. After treating the samples with laser they were polished and etched using etchant which consists of (1 ml HF and 200 ml water) according to Standard Practice for Micro etching Metals and Alloys(Practice, 1999) to study and investigate the cross section of the melted region

From conducting many experiments, it has been noticed that the laser power and pulse duration are considerably effect on the LSM process. Therefore, the effect of these parameters will be investigated deeply. The other two parameters (frequency and offset distance) will be fixed. The incoming experimental work was carried out at 18°C room temperature with offset distance is about 12 mm and frequency equal to 1 Hz.

The experiments have been carried out with varying the laser power and pulse duration according to the manner shown in Table-2.Microstructure examination was performed to investigate the treated section and identified the depth of treatment. Also, microhardness test was applied to calculate the HV for the treated section to a depth of 1 mm below the sample surface (Vickers hardness carried out with load equal to 200g). The design of experiment approach using factorial was applied to the obtained results. Minitab software is used to select the optimum parameters that give the maximum hardness to the treated sample.

Table-1. Chemical composition of the used AA 6061 aluminum alloy samples.

Composition	Per. (wt %)	Composition	Per. (wt %)
Si	0.6310	Ni	0.0115
Fe	0.7640	Zn	0.1590
Cu	0.3240	Pb	0.0160
Mn	0.1040	Ti	0.0500
Mg	1.0400	Al	Bal
Cr	0.188		

Table-2. Samples and variation of parameters.

Sample no.	**Power** (kW)	**Pulse duration**(ms)	**Energy**(J)
1	4.0	3+0.5	13.00
2	4.0	4+0.5	17.00
3	4.0	5+0.5	21.00
4	4.5	3+0.5	14.62
5	4.5	4+0.5	19.12
6	4.5	5+0.5	23.62
7	5.0	3+0.5	16.25
8	5.0	4+0.5	21.25
9	5.0	5+0.5	26.25

RESULT AND DISCUSSIONS

The metallographic investigations were performed on the cross section of the melted region. The results show that the depth of the melted layer depends on the energy of treatment which can be seen in Table-3.It is clear that when the energy is increased then the depth of treatment is also increased. Figures(1a) to (1i) show the obtained microstructure images for the treated regions with different parameters (according to Table-2).It can be noticed that the microstructure in the treated region becomes finest meanwhile thermal cracks are appeared within the melted zone. The thermal cracks are appeared due to applying high cooling rate, high level of laser energy. Thermal cracks can be avoided if some preheat is applied.

Figures (2),(3)and (4) show the microhardness variations versus the treated depth (up to 1 mm below the surface). The maximum values of microhardness were obtained when the power is about 4.5kW and the pulse duration is about 3ms.Design of experiment approach based in full factorial was applied on the experimental results (hardness) in order to calculate the optimal laser power and pulse duration.

Table-4 shows the factors levels and the response (hardness).These values were optimized using Minitab software. The level of confidence used in analysis of variance (ANOVA) is 95%. If p-value for the factor is less than 0.05 then it shows that the factor has significant effect on the process. From p- values listed in Table-5, it is found that the power has a significant effect on hardness. Figure-5 the effect of power and pulse duration on hardness. In this figure, when the power and pulse duration are increased then the hardness decreases. The increase in power and pulse duration means an increase in energy causing to increase the depth of the treated region as shown in Table-3.If the treated depth is increased then the cooling rate decrease which cause to decrease the hardness. Figure-6 shows the optimization plot which obtained from Minitab. The optimal levels of power and pulse duration which give maximum hardness are 4.5kW and 3ms.

Table-3. (Relation between energy and depth of treated region).

Sample no.	**Energy** (J)	**Depth** (mm)
1	13.00	0.19
2	17.00	0.21
3	21.00	0.24
4	14.62	0.22
5	19.12	0.25
6	23.62	0.26
7	16.25	0.23
8	21.25	0.30
9	26.25	0.29

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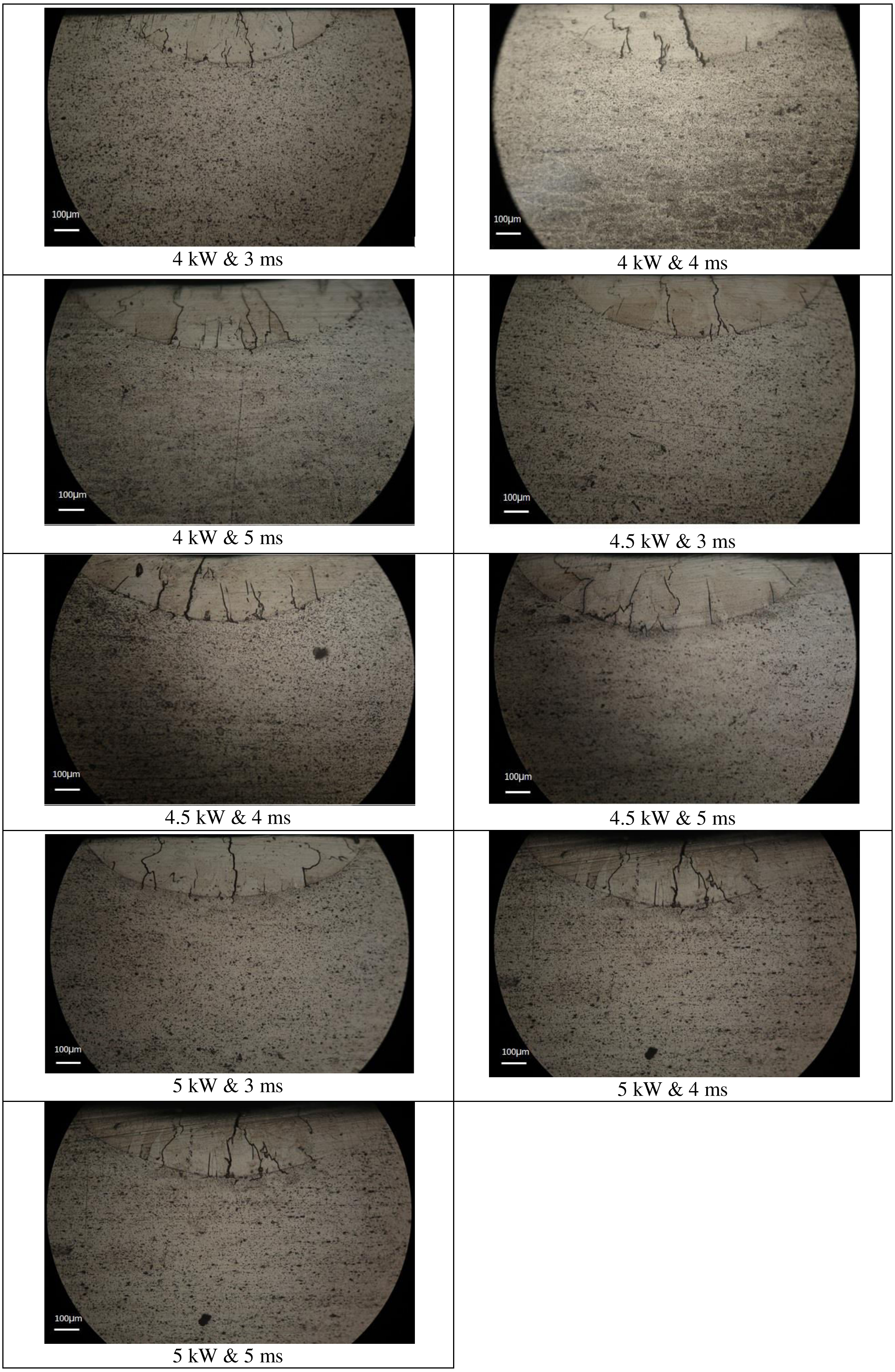

Figure-1. Microstructure images for the treated region for different laser powers and pulse durations.

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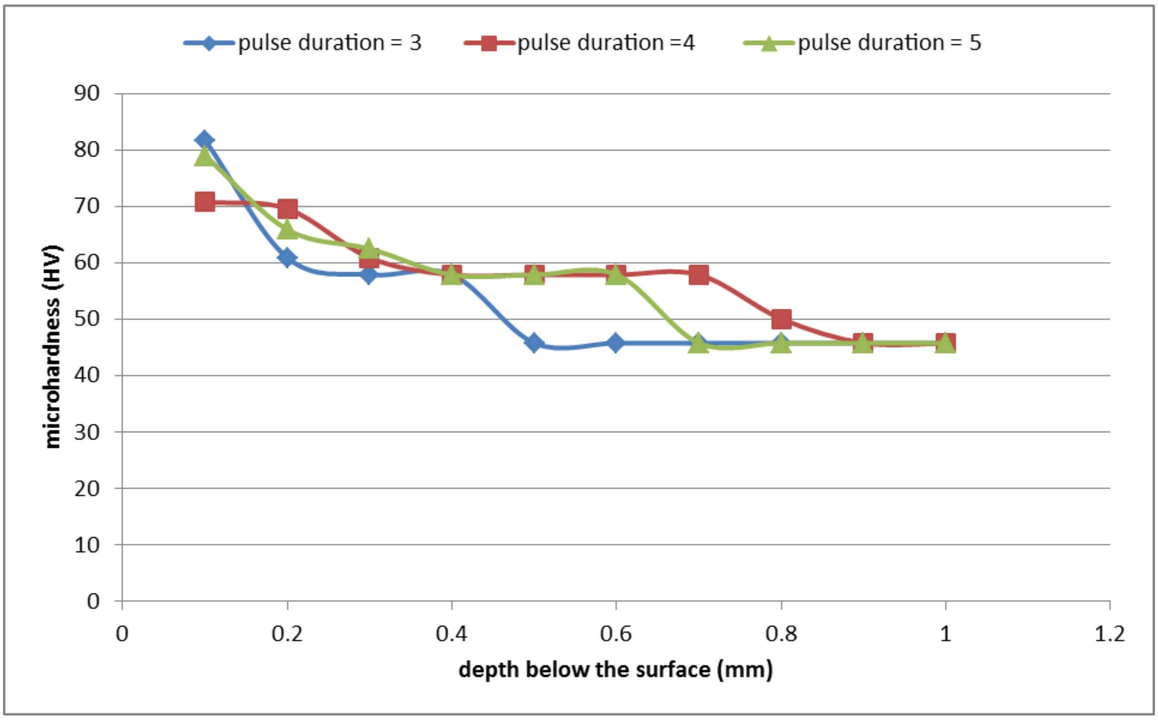

Figure-2. Microhardness versus depth of treatment 4 kW laser power and different pulse duration times.

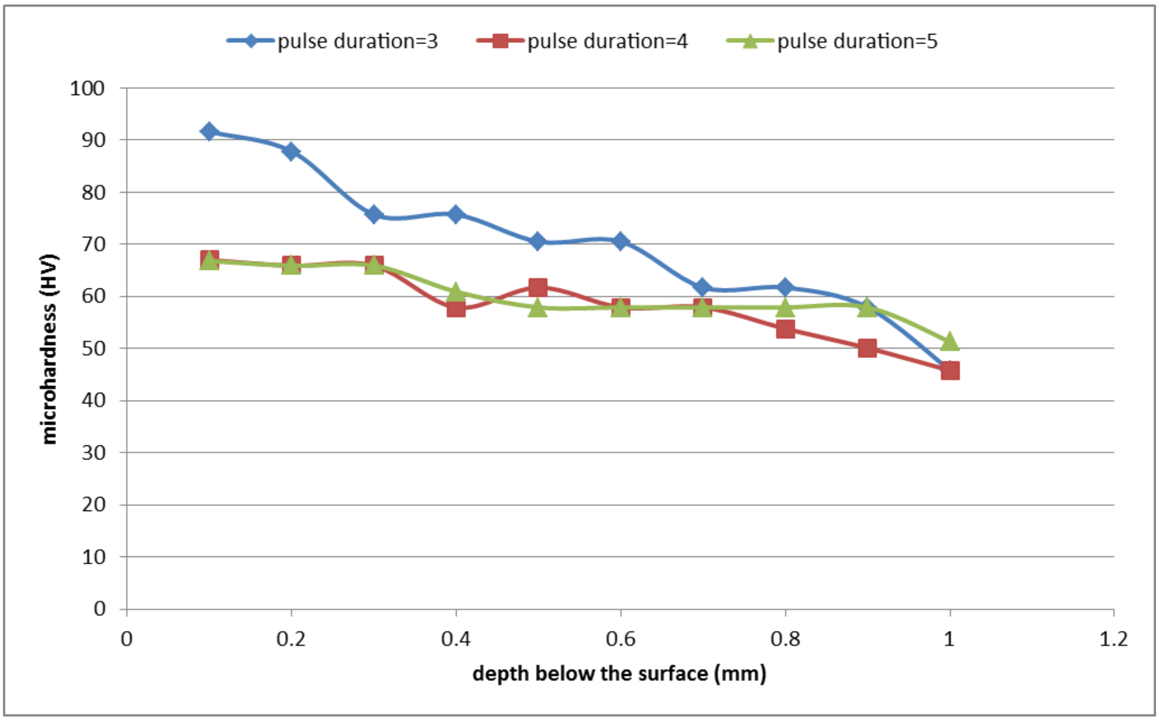

Figure-3. Microhardness versus depth of treatment with 4.5 kW laser power and different pulse duration times.

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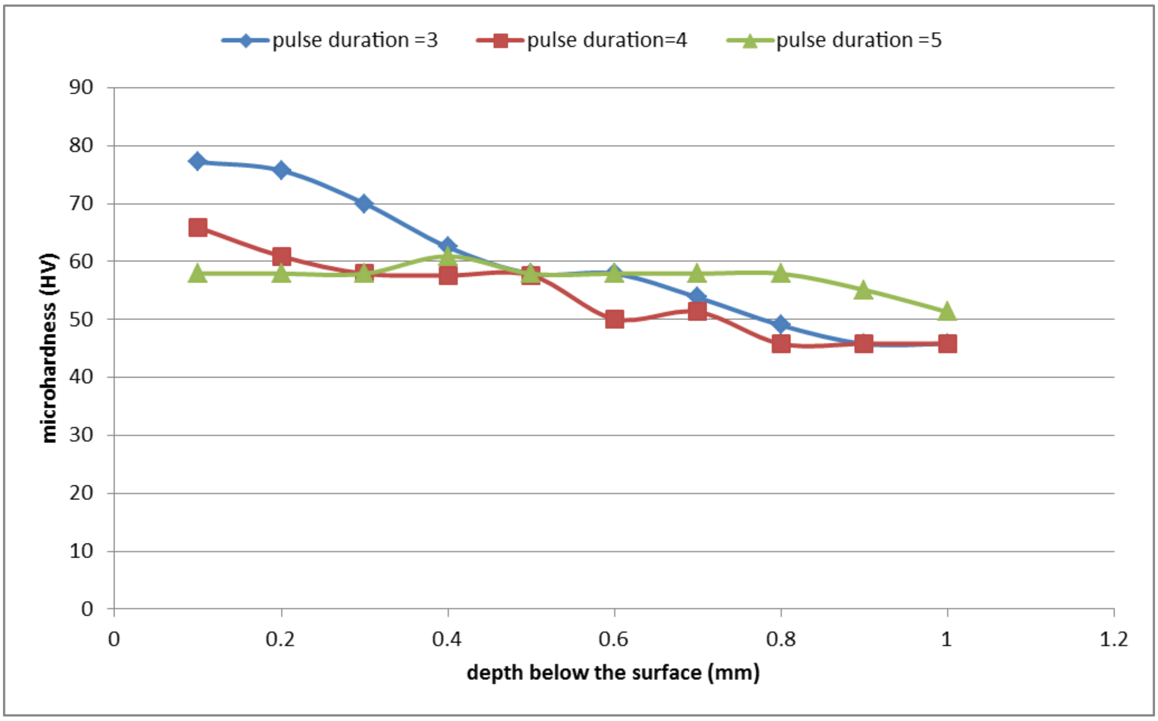

Figure-4. Microhardness versus depth of treatment with 5 kW laser power and different pulse duration times.

Table-4. Factors and response value for LSM process.

Power (kW)	**Pulse duration** (ms)	**Hardness** (HV)
4.0	3	81.85
4.0	4	70.80
4.0	5	79.65
4.5	3	91.60
4.5	4	67.00
4.5	5	66.8
5.0	3	58.00
5.0	4	69.75
5.0	5	54.00

Table-5. Analysis of variance for LSM process.

Source of variation	**Sum of square**	**Degrees of freedom**	**Mean square**	**F_0**	**P -value**	**Percentage contribution (SS/SS_{total})*100**
Power	999.3	2	499.64	5.69	0.025	33.25%
Pulse duration	349.3	2	174.63	1.99	0.192	11.62%
Interaction (power* pulse duration)	867.4	4	216.85	2.47	0.119	28.86%
Error	789.8	9	87.75			26.27%
Total	3005.7	17				

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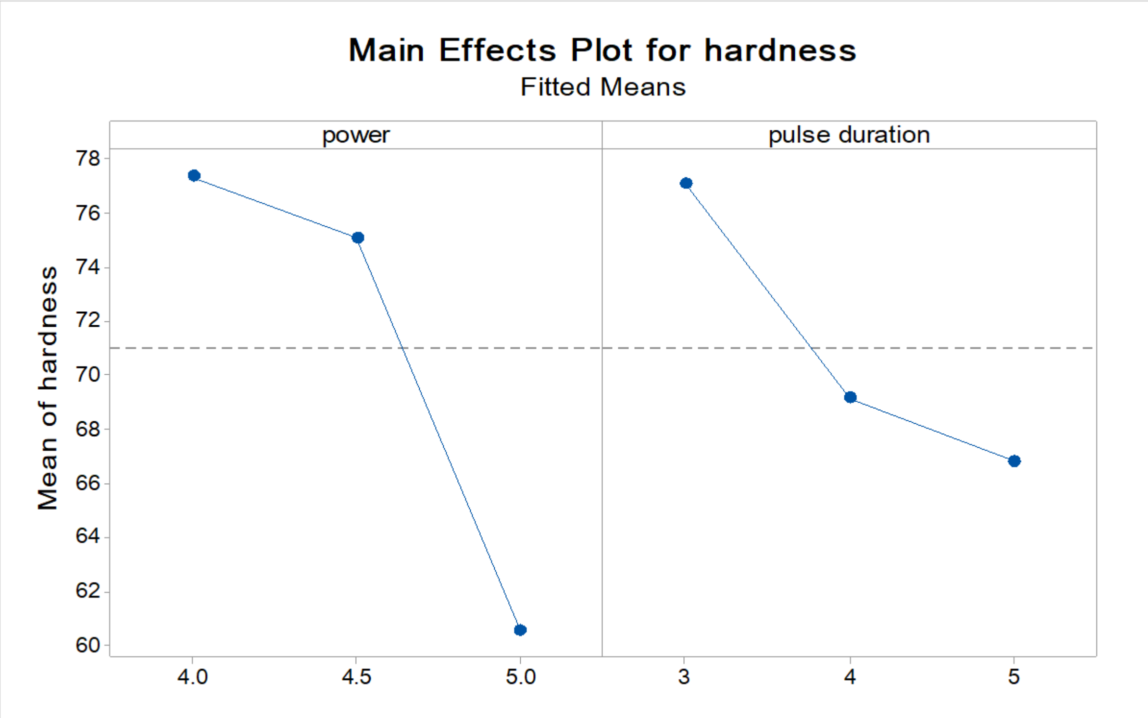

Figure-5. The effect of power and pulse duration on hardness (Minitab 17).

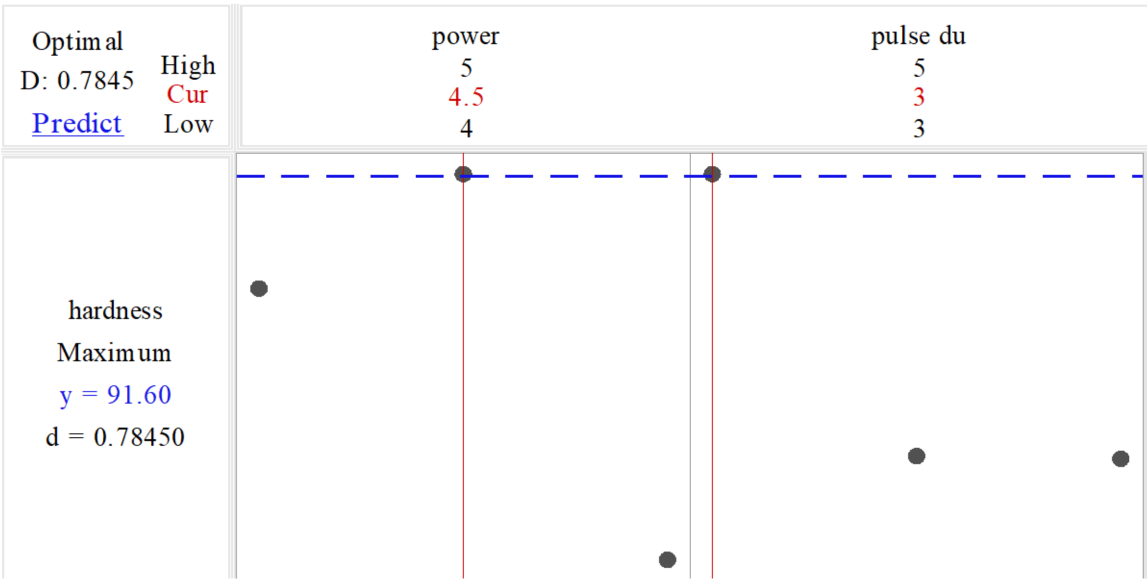

Figure-6. Optimization plot (Minitab17).

CONCLUSIONS

In this work, Laser Surface Melting (LSM) is applied to AA6061 in order to increase its surface hardness. Design of experiment approach with full factorial of three levels of power and pulse duration is used for selecting the optimal parameters. The following points have been remarked from the present work:

a) Depth of the melted layer depends on the energy of applied laser
b) Microstructure in the treated region becomes finest meanwhile thermal cracks are appeared within the melted zone due to high energy and high cooling rate
c) Maximum value of microhardness was obtained when the power is about 4.5kW with about 3mspulse duration. The hardness obtained at this case is about 91.6 HV
d) Increasing in power and pulse duration cause increasing in energy. This means increasing the depth of treated region. If the depth is increased then the cooling rate will decreases causing reduction in metal hardness.

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