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Effects of Laser Parameters on Solidification Cracks Formation during LSM Treatment for AA6061

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Abstract

Laser surface melting (LSM) is a material surface modification process based on using high power laser beam as a heat source in order to enhance the mechanical properties of the material surface. In this article, the effect of pulsed laser power during LSM process on the formation of solidification cracks within AA-6061 and degree of hardening will be studied. Four level of power is selected (4.5, 3.5, 2.5 and 1.5) kW with maintaining the same magnitude of energy through increasing the pulse duration. It is concluded that if the power level reduced the solidification crack is eliminated. Furthermore, the melted region becomes smaller. It also has been noticed that the hardness of the sample is inversely proportional with laser pulse duration.

Keyword: Laser surface melting, solidification crack, laser power, AA6061

INTRODUCTION

Laser with high power has become intensively used as a tool for large number of manufacturing and surface modifications processes for its flexibility, its accuracy and it's considered to be easy automated energy source. The mechanical properties enhancement of the material surface can be obtained through changing either the microstructure or the chemical composition of surface. Laser can be used to achieve such surface modification. These modifications processes may applied in order to increase surface hardness, increase wear resistance, or enhance fatigue life through including residual stress (compressive) in the surface layers (Kannatey-Asibu, 2009). One of laser surfaces modification which has attracted interest in last years is laser surface melting (LSM). This process involves melting the surface layers and due to self-quenching rapid solidification occur, This laser treatment cause microstructure changes in the treated region as a result metal properties changed also such as hardness, wear resistance and corrosion resistance (WANG, 1983). This type of surface modification is suitable with aluminum alloys. Recently aluminum alloys is widely used in engineering applications due to its excellent strength to weight ratio. A large number of engineering applications requires special properties near the surface region such as hardness, wear resistance, corrosion resistance and enhancing fatigue properties, as mentioned before these properties can obtained from LSM for aluminum alloys. In the related literature, it can be found many research investigated the laser treatment of aluminum alloys. **Sušnik et al., 2012**, studied the effect of laser surface melting on Al-Si alloy and investigated the changes in micro-hardness and microstructure of the treated area. Laser surface melting was carried out using different energy value. A fine-grained microstructure is obtained after solidification. The fine-grained microstructure causes micro-hardness increment of Al-Si alloy up to 80%. It was concluded that the variation of mainly tensile residual stresses in melted layer depends on laser pulse duration i.e. the cooling rates. Reduction of residual stresses is obtained from Precipitation annealing after laser surface melting process. **Tillová and Chalupová, 2014**, used an Nd: YAG laser (BLS 720) to treat cast alloy AlZn10Si8Mg. Two levels of laser power were applied (50 and 80) W. microstructure changes in the treated surface of the AlZn10Si8Mg are acquired. Melting region is α_phase with fine columnar dendrites morphology without the presence of Si-particles and intermetallic phases. In the transition area, grain refinement of eutectic Si was obtained. Micro-hardness of the surface treated layer was increased from 94 $HV_{0.01}$ to 140 $HV_{0.01}$ after the laser treatment process. In the surface layer (laser power 80 W), cracks were observed due to uneven heat transfer. **Nassar et al., 2015**, used a pulsed Neodymium Yttrium Aluminum Garnet (Nd:YAG) laser with wavelength 532 nm and 5 min time of irradiation. They applied different powers ranging from 250 to 2100 mW with pulse width of 8 ns to treat the hypereutectic Al-18wt%Si. The microstructure and micro-hardness (HV) were studied after the laser treatment. The results showed that the laser-treated samples had positively affected eutectic silicon morphology according to the enhancement in the measured mechanical properties. On the other hand, increasing laser power led to the formation of precipitates which can be considered dendrite boundaries that divided the material in the same way that the grain boundaries do. It was concluded that increasing the laser power values led to the formation of precipitates and dislocations. This is contributed to the increased micro-hardness. **Pakieła et al., 2016,** studied the effect of laser surface treatment on the properties and structure of aluminum alloy ENAC-ALMg9 by using a high power diode. The treatment parameters were (1.8, 2.0 and 2.2)kW laser power and the scan rate of the laser beam was set 0.5 cm/s. argon was used In order to protect the liquid metal. To improve the wear and surface mechanical properties of the aluminum alloy, biphasic tungsten carbide WC/W2C was used. It was concluded that the highest properties of the treated surface were obtained at the lowest laser power of 1.8kW. The laser treatment with 1.8kW power a treated layer was achieved with a hardness of about 15HRF higher compared to the substrate. Also, a significant increase in the friction coefficient for the aluminum samples with the composite layer. The resulting layers were characterized by a friction coefficient reaching from 2.55 (1.8 kW) to 1.92 (2.2 kW). **Ansari et al., 2016,** studied Laser surface re-melting and alloying of AA 6061-T6 with pre-placed chrome powder utilizing Nd: YAG pulsed laser. As-alloyed layer demonstrated heterogeneous microstructure contained Cr-rich islands in α-Al matrix. The Re-melted layer showed microstructures consist of dense and homogeneous network of Al–Cr. the hardness of treated region was three to six times higher than that of the AA 6061-T6 substrate for the as alloyed and re-melted layers, respectively that of the base material. Due to aluminum thermal properties, solidification cracks may appear during LSM process which can cause inferior properties if it's not processed .these cracks can be avoided either by reducing the cooling rate, reducing the power level or adding alloying element that move the melted metal composition and freezing range away from the crack-sensitive range. In this article effect of power level on AA6061 tendency to form solidification cracks will investigated.

EXPERIMENTAL WORK

LSM process is done on the AA6061 annealed aluminum alloy samples to study the effect of laser power on crack formation. The metal was supplied from the local market. Chemical composition of material was analysis in (State Company for Inspection and Engineering Rehabilitation) the result which is compared with ASTM standard is shown in table (1). LSM experiments were done in (university of Baghdad-Institute of Laser for Postgraduate Studies) by using ND: YAG pulsed laser of 1064 nm wavelength (model PB80 manufactured by Han´s Laser Technology). The laser beam of this machine is characterized by (maximum power of 8 kW, pulse duration of 1-50 ms and frequency of 1-100 Hz). The used laser machine is shown in figure (1).Optimal treating parameters according to maximum obtained hardness were adopted from (Al-ashtari & Abdulsattar, 2018)which they are: power 4.5kW, pulse time (3+0.5)ms, frequency 1Hz and offset distance 12mm. The experiments were performed at ambient temperature equal to 20°C. In this enhancement process it was considered that high level of power and low level of pulse duration cause formation of solidification cracks. Therefore to enhance the melted region through reduce solidification cracks, the power level was reduce and the pulse duration increased with maintaining the same amount of energy (14.6 J). Table (2) shows power and pulse duration levels that used in this enhancement. After processing the aluminum samples with laser; theses samples were polished with SiC paper with different grades of roughness 200, 400 and 600 degree in order to remove the material and access the center of the treated area being processed then the cross section surface was polished using 800, 1000, 1500, 2000, 2500 and 3000 degree of SiC paper followed by using cloth paper with Alumina polishing solution, then the samples were washed with water and alcohol to prepare the samples for etching procedure. The etching was performed using etchant which consists of (1 ml HF and 200 ml water) according to (ASTM American Society for Testing and Materials Standards, 2002).. Optical examination was performed on all LSM samples to inspect the melted cross section and identified the depth of melted layer using (Optika OPIM-3METmetallurgical microscope). Vickers micro-hardness test was applied using (Adolph I.Buehler inc) micro-hardness device to measure Vickers hardness for the treated cross section of all treated samples to a depth of 1.2 mm below the sample surface (Vickers hardness carried out with load equal to 200g for 15 second holding time).

Table 1. Chemical Composition of 6061 Al-alloy wt. %

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. Levels of Enhancement Parameters

Power (kW)	Pulse duration (ms)	Energy (J)
4.5	3+0.5	14.6
3.5	3.95+0.5	14.6
2.5	5.6+0.5	14.6
1.5	9.5+05	14.6

Figure 1. Nd-YAG Machine, 'A' the power supply, 'B' robot controller, 'C' &'D' the robot arm

RESULTS AND DISCUSSION

From optical examination shown in figure (2) it can be observed that the depth of melted region is reduced and the solidification cracks becomes less intensity as the power levels reduced especially when the power is about 1.5 kW. Figure (3) shows the micro-hardness value in the cross section of the treated region. The average hardness in the cross section of the treated region was calculated and listed in Table (3). The micro-hardness of base metal is about (30.6 HV). When the power decrease to 3.5 kW and the pulse duration increase to 4.45 ms although the depth of the molten region has not changed; average micro-hardness decrease to 47.31 HV due to increasing the interaction time between laser and metal which effects on cooling rate. From figure (3) it can be noticed that the depth of hardening extends to the heat effected zone (HAZ) this is probably due to dense dislocation network that may appear in the HAZ resulted from high cooling rate and shrinkage occurred in the melted region. As the power decrease to 2.5 and 1.5 kW the melted region depth and the depth of hardening decrease also and that cause reduction of the average hardness.

Power =4.5 kW

Power =3.5 kW

Power=2.5 kw

Power=1.5 kW

Figures 2. Microscopic Examination for the Treated Region with Different Peak Power Values

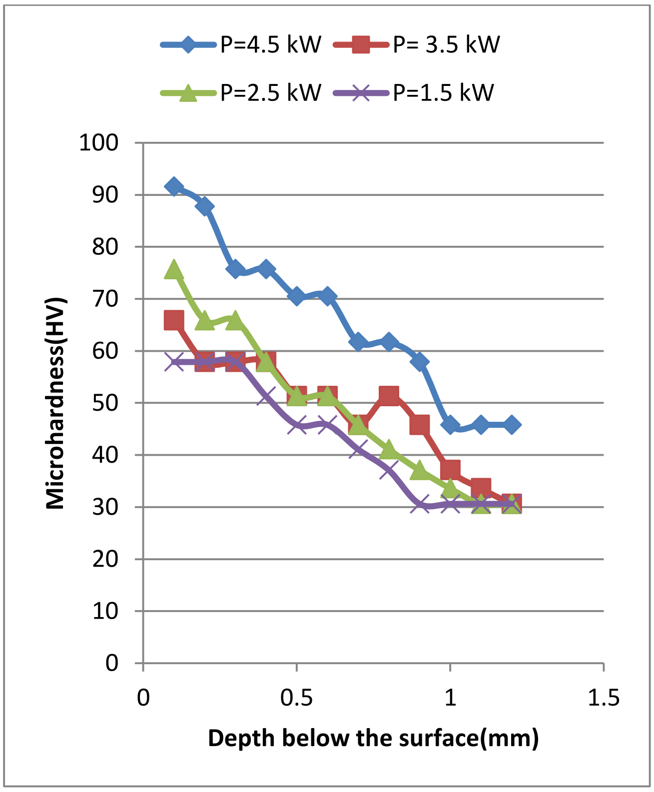

Figure 3. Micro-hardness Profiles Along Cross Section for Different Power and Pulse Duration Levels and Equal Energy Value

Table 3. Increment of Micro-hardness in The Treated Region

Peak Power (kW)	Pulse duration (ms)	Energy (J)	Depth of melted region (mm)	Average HV value for treated region	Increases by percentage
4.5	3.5	14.6	0.22	65.79	115%
3.5	4.45	14.6	0.22	47.31	54.6%
2.5	6.1	14.6	0.2	46.47	51.8%
1.5	10	14.6	0.18	41.75	36.4%

CONCLUSION

In this study, laser surface treatment was applied to samples of AA6061 alloy with different power levels in order to prevent the formation of the solidification cracks and enhance melted region. For each sample, optical examination and micro-hardness test were performed. The following points have been remarked from the present work

1) As the laser power level reduced, the solidification crack will eliminated
2) In spite of maintaining the same magnitude of energy, reducing the laser power level cause reduction in the depth of melted region
3) Increasing the pulse duration to maintain the power level, case hardness reduction due to increase the interaction time between laser and material.
4) The depth of treatment and the degree of hardening can be controlled from controlling the power level during LSM process

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