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Abstract. In this study, experimental and numerical applied of heat distribution due to pulsed Nd: YAG laser surface melting. Experimental side was consists of laser parameters are, pulse duration1.3ms, wavelength 1064nm, laser energies 1.5, 2. 6 and 4.3 J, laser beam diameter is 0.6 mm and spot diameter 0.78 mm was applied a low carbon steel type St37 with a dimension 10, 10, 3 mm, length, width and thickness respectively. Numerical analysis side consist of a mathematical model and calculating a thermal cycle by using equation in the enthalpy method applied to determine the cooling rate in fusion zone. The simulation by using the enthalpy method, applied on conduction heat transfer to estimate the cooling rate model in fusion zone and heat affected zones. Cooling rates models are helping to estimate the microstructure and micro hardness distribution in fusion and heat affected zones. The complication of the heat transfer in laser surface melting process, because at in rapid solidification, therefore the enthalpy model is more appropriate for this case. The result shows that increases of laser energy lead to decrease cooling rates and increase width and penetration of fusion zone, also decrease micro hardness in fusion zone and we found an increase in the pool size of fusion and heat affected zones.

1. Introduction

There are many articles deal with simulation of laser interaction with materials surfaces. In this study the main techniques in numerical equation used enthalpy method in case at rapid cooling (solidification) processes. The important of this technique is appropriateness for solve problems where the phase transformation at a high temperature. A three– dimensional of enthalpy model is presented for both laser melting and laser cladding of material surfaces. It considers, in addition to the heat transfer and the deformation of the liquid- gas interface. Laser surface melting (LSM) is an additive industrial process through which parts are built by choice laser melting in order to obtain a good mechanical properties due to modify microstructure result from the LSM [2] and [1]. Naim et al [3] (2009), An studies of a Pulsed Nd:YAG laser welding, in this research   were studies the Nd:YAG laser pulsed applied in welding process and effects of different welding parameters of laser such as laser power, focal point   and welding speed. M. Moradi et al [4] (2012) , are studies the effect laser conditions on welding quality of stainless steel 1.441 , in this study, a lower power pulsed laser was used for joint of low carbon steel. The laser conditions were effects on the quality of weld design. C. Casavola et al [5] (2008) studied a numerical method of laser surface melting process was investigated to simulate the residual stresses.
 M. Sundar et al [6] (2007), they study the effect of fluid motion Analysis on the weld pool due to thermal distribution. Shahad et al [7] (2019) Studied the (Influence of Nd- YAG Laser Beam on Microstructure and Wear Characteristics of Gray Cast Iron), the purpose of this study is to study the

effect of pulsed Nd-YAG laser beam on the microstructure and wear resistance of surface gray cast iron of valve used in many agricultural machinery. They found that the microstructure of gray cast iron was affected by the laser energy, where increasing laser energy led to increase in the area of melted zone and heat affected zone which resulted the formation of martensite and irregular graphite. Abbas S.Alwan et al [8] (2019), were studied the "Improvement the surface properties of metal valves used in agriculture engine by using CO_2 laser beam". The aim of this work was to solve the problem on surface valve metal type ASTM A126 used in internal combustion engines of agricultural machines and improve the surface metal of valves by using CO_2 Laser Beam. The results shown that the microstructure of cast iron affected by the laser energy and it was observed that the increasing laser energy led to increase in the area of melted zone and heat affected zone which consists of martensite phase and irregular graphite. The aims of this work were study the experimental and numerical analysis of heat distributed due to laser surface melting by using techniques of enthalpy method which helped to determine the cooling rates models, width of fusion and heat affect zones, depth of penetration and micro hardness.

2. Experimental work

2.1 The Base Metal

Low carbon steel type St 37 is used in this work it is widely used in pipes and large storage tank structures and other engineering applications. The chemical composition of low carbon steel is shown in Table 1. The Plate preparation with dimensions of 10 mm, 10 mm and 3 mm, length, width and thickness respectively were used in laser surface melting process. The plates were prepared by milling machine from both surfaces.

Table1. Actual chemical composition of low carbon steel (ST 37)

Element	C%	Si%	Mn%	P%	S%	Cr%	Mo%	Ni%	Cu%	Ti%	V%	Fe%
wt%	.163	.252	.442	.018	.047	.081	.02	.02	.053	.006	.01	Rem

2.2 Laser Model

The experimentally of Laser Nd-YAG model was used in application of laser surface melting (LSM) as shown in Tables 2.

Table.2 Laser model Nd-YAG parameters

No	Parameters	Values	Character	Unit
1.	laser energy	(1.5 , 2. 6 , 4.3)	E	J
2.	pulse duration	1.3	τ	m s
3.	Beam diameter	0.6	D_b	Mm
4.	spot diameter	0.78	D_s	mm
5.	wavelength	1064	λ	nm
6.	spot area	0.4775	A	mm^2

3. Numerical method

In this present work, the numerical method is techniques of enthalpy energy (E) method which employed heat transfer in laser surface melting (LSM) process which help us to predict of phase change transformation. This method is depending on the energy equation of enthalpy method and conservation principle of energy balance. The numerical flow chart considers the numerical solution by enthalpy method program of laser treatment process as shown in Figure 1.

3.1 Assumptions

  In this work, a three - dimensional model for simulation of heat transfer in laser surface melting process by using enthalpy model. Following the assumptions as:

- All convection and radiation of heat transfer were neglected.

- Laser absorption energy is transmitted by conduction into the bulk of material.

- A uniform energy from the laser heat source.

- Insulated all the plate faces as shown Figure 2.

-The physical properties of plate metal data used in this studies were summarized in Table 3, dependent on the material type
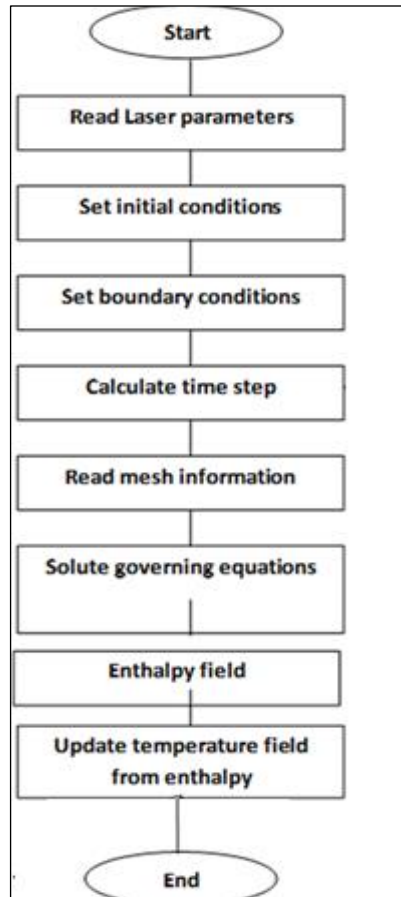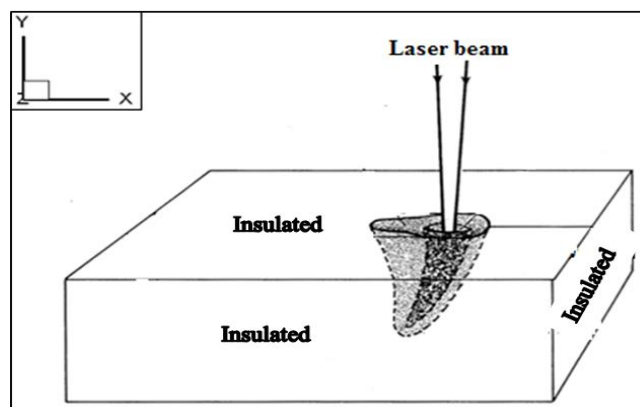
Figure 1. Numerical flow chart by enthalpy method

Figure 2. A schematic diagram of the boundary conditions assumed [6].

Table 3.   Physical properties of metal type (ST 37) [6].

Symbol	Property	Value	Unit
ρ_L	Liquid density	6980	kg /m³
ρ_S	Solid density	7860	kg /m³
k_L	L Liquid thermal conductivity	31	W/m. K
k_S	Solid thermal conductivity	45	W/m.K
Cp_L	Liquid specific heat	450	J/kg. K
Cp_S	solid specific heat	450	J/kg. K
T_L	Liquids temperature	1500	˚C
T_S	Solids temperature	27	˚C
H	Latent heat	2.7×10^5	J/kg
T_m	Melting temperature	1483	˚C

3.2 Initial and Boundary Conditions

   Initial conditions are required only when dealing with transient heat transfer in laser surface melting process which temperature of material changes with time. All the boundary conditions as illustrated in Figure 2 are:-
- Assumed all the side plate surfaces to be insulated.
- The laser speed component along the X- axis, and Z – axis equal to zero, while the speed of along Y- axis was different according to laser parameters.
- Initial temperature before melting is 25 °C.

3.3 Enthalpy Mathmetics

   The enthalpy (E) method is considered in term of energy instead of temperature [7]. The melting and evaporation cycles of heat conduction by enthalpy model is construction in the energy from model of Yiding Cao, Amir Faghrt and Won Soon [7]: as

$$\partial\,(\rho E)\,/\,\partial\,t = \partial\,2\,(\Gamma E\,/\,\partial\,x^2 + (\partial\,2\,(\Gamma E)\,/\,\partial\,y^2 + (\partial\,2\,(\Gamma E)\,/\,\partial\,z^2) + P \qquad (1)$$

   Where; $P = \partial 2s\,/\,\partial\,x2 + \partial 2s\,/\,\partial\,y^2 + \partial 2s\,/\,\partial\,z^2$

   $\Gamma = \Gamma\,(E)$ and $S = S\,(E)$

In the liquid region, equation (1) reduction to the linear energy equation: as

$$\partial\,(\rho L\,E)\,/\,\partial\,t = \partial\,/\partial x\,(kL\partial T\,/\,\partial\,x) + \partial\,/\partial y\,(kL\partial T\,/\,\partial y) + \partial\,/\partial z\,(kL\,\partial T\,/\,\partial\,z) \qquad (2)$$

The solid phase area equation (1) reduction to:

$$\partial\,(\rho s\,E)\,/\,\partial t = \partial\,/\partial x\,(ks\,\partial T\,/\,\partial x) + \partial\,/\partial y\,(ks\,\partial T\,/\,\partial\,y) + \partial\,/\partial z\,(ks\,\partial T\,/\,\partial\,z) \qquad (3)$$

4. Results and discussion
4.1 Experimental result

The experimentally parameters of laser surface melting (LSM) Process are shown in Tables 2. The wavelength of ND: YAG laser is (1064nm), and the three different energies were measured outside the laser system by using energy meter to fine the true value of the energy that affects the surface 1.5, 2. 6 and 4.3 J. The energy values of laser were affected on microstructures as shown in Figure 3. In this figure, it is clear that increasing laser energy led to increase in the area of fusion zone (FZ) and heat affected zone (HAZ) which matching with Table 4. The distribution of the electromagnetic field to a few energies for pattern Gaussian is characterized by a small divergence, hence, the heat generated increased with increasing the laser energy. These results are agreements with research [8]. The depth of fusion zone (penetration depth) measured from taking the average for three values and the depth of melted zone were 0.356mm,0.525mm and 0.628mm due to using different energies 1.5 J, 2.6 J and 4.3 J respectively, the micro hardness decreased in cross section because increased in energy, as shown in Table 5.

Table 4. Effect of energy in size of fusion zone

Sample	Energy (J)	Size of molted zone (mm)
S1	1.5	0.322
S2	2.6	0.543
S3	4.3	0.683

Table 5. Laser energy, micro hardness and depth of fusion zone

Sample	Laser energy (J)	Depth of molten zone (mm)	Micro-hardness (HV)
S1	1.5	0.356	854
S2	2.6	0.525	732
S3	4.3	0.628	495

In the work, variation of surface molted size due to laser conditions was study. An increase penetration shallow with increase laser energy as shown in Figure 4.
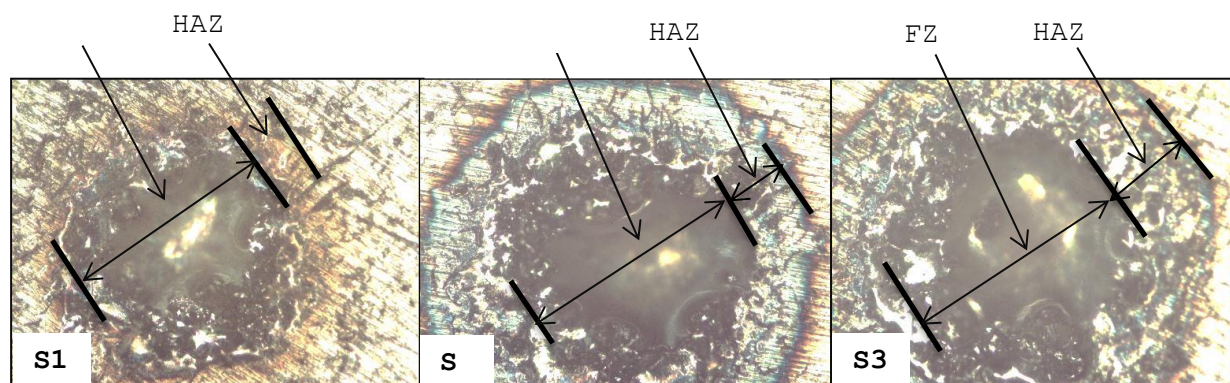

Figure 3. Effect of laser energies on Microstructure of fusion and heat affected zones.

Figure 4. Penetration of fusion zone with different energies S1, S2 and S3**.**

4.2 Numerical result

Figure 5, show the temperatures contours history with time for heat distribution of samples S1, S2, S3 with different laser energies 1.5 J, 2.6 J, 4.3 J in fusion zone respectively. The movement of the solidification front with the time, which is identical to controls by cooling rate. The high cooling rate was effecte to consist of a fine microstructure, which lead to improved mechanical properties. The results of cooling curves were evolution of pool laser microstructure, width of each of fusion and heat affected zone and micro hardness. Equations 4, 5 and 6 represent the model from cooling curve in fusion zone of laser surface melting energies 1.5, 2. 6 and 4.3 J respectively. This result was a good agreement with research [9,10].

$$R = 73.28 \times 10^{2} * t (-1.09) \tag{4}$$

$$R = 84.82 \times 10^{2} * t (-1.11) \tag{5}$$

$$R = 110.0 \times 10^{2} * t (-1.16) \tag{6}$$

Where; $R = dT/dt$,

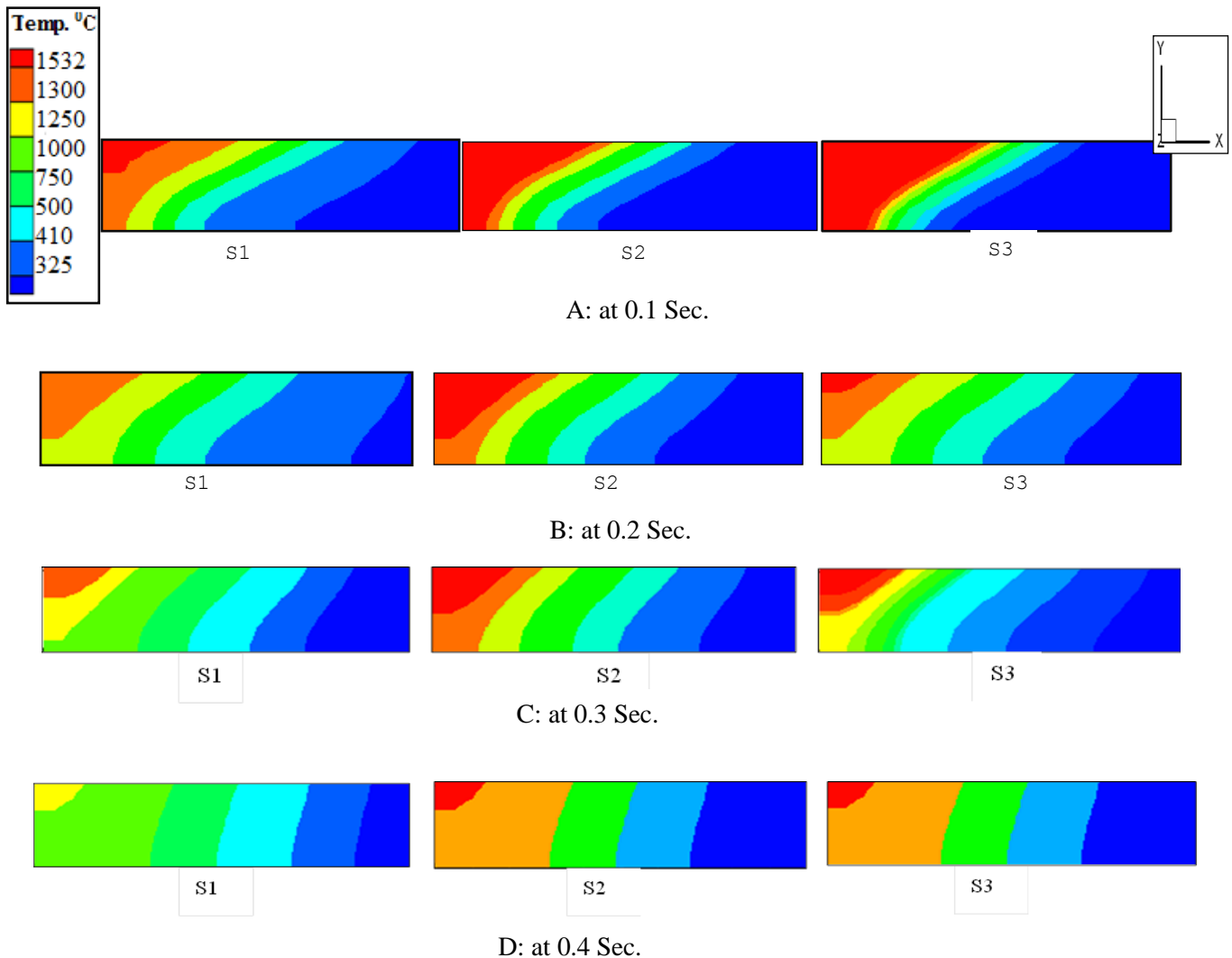R: Cooling rate and t: time (second).

Figure 5. Heat distribution of laser energies S1: 1.5 J, S2: 2.6 J and S3: 4.3 J in fusion zone at different Time, A; 0.1S, B; 0.2 S, C; 0.3 S and D; 0.4 S

Figure 6, show analysis of cooling curves at the Fusion Zone. The cooling curves are assumed independent of the position within the fusion zone of a given Laser spot. Enthalpy models helps of a recent model for calculation the cooling curve (Temperature-time) (T-t). The derivations of these equations determine the cooling rates its clear increasing laser energy leads to decrease cooling rates as described in the following equations4, 5 and 6. on the other hand, the cooling rates (R) was a mathematic model to predict the effect of heat distribution on the microstructure, and some of the mechanical properties (micro hardening) of the fusion zone, was agreement with results [11]. Increase laser energy leads to increase depth of fusion zone, width of molted zone and decrease in micro hardness values and cooling rates as summarize of matching experimental and numerical results in Table 6".
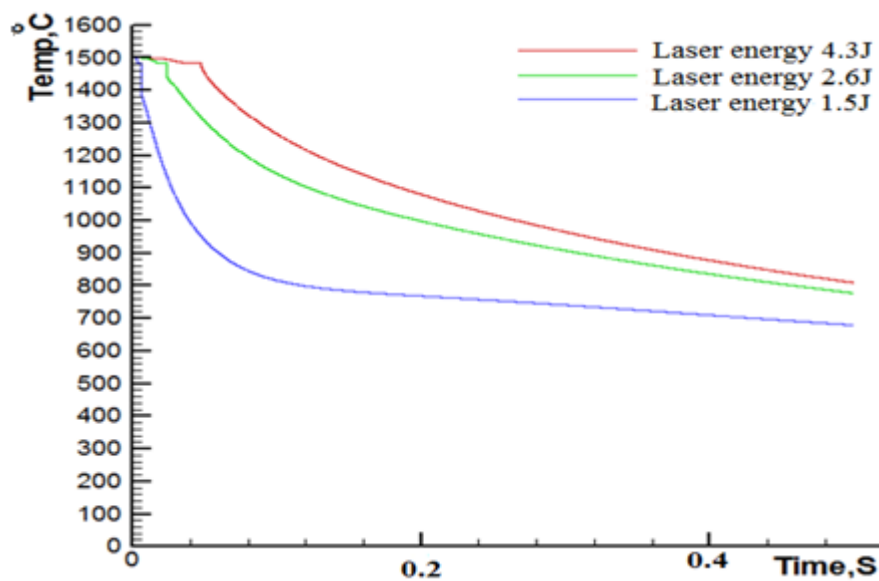
Figure 6: Computational of cooling curves in fusion zone with different laser energies.

Table 6. Summarize of numerical and experimental results.

Sample	Laser energy (J)	Cooling rate models	Depth of molten zone (mm)	Width of melted zone (mm)	Microhardness (HV) Kg/mm²
S1	1.5	$R = -73.28 * t^{(-1.09)}$	0.356	0.322	854
S2	2.6	$R = -84.82 * t^{(-1.11)}$	0.525	0.543	732
S3	4.3	$R = -110.0 * t^{(-1.16)}$	0.628	0.683	495

Conclusions

1. Numerical analysis of heat transfer by energy equation (enthalpy method) was help us to predict the mathematical models were used in melting pool of the laser conditions.
2. As increase laser energy effect to Increase width and depth (penetration) of fusion and heat affected zone.
3. An increase in laser energy, the cooling rates and micro hardness of fusion zone was decreases.
4. Increasing laser energy led to increase in the area size of fusion and heat affected zone.
5. Decrease in micro hardness values with increases in laser energy.

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Nomenclatures

T_m: Melting temperature**,** °C

T_L: Liquids temperature, °C

T_S: Soldidus temperature**,** °C

ρ: Density, kg/m^3

ρ_L: Liquid density, Kg/m³

ρ_S: Solid density, Kg/m³

R: Cooling rate, °C/S

C_{ρ}:   Specific heat**,** J/kg.K

K_L: Liquid Thermal conductivity**,** W/m.°K

K_S: Solid Thermal conductivity**,** W/m.°K

H: Latent heat**,** J/kg

E: Enthalpy**,** kJ/kg

ΔT: temperature difference, T_L- T_S (K)

T: time, s

x, y, z: coordinate directions

x: x- direction distance between two adjacent grid points δ

y: similar to Δx, $\delta x \delta \Delta y$,

Δz, δz: similar to Δx, δx

T*:   "Kirchhoff" temperature (W/mol)

Cp_L: Liquid specific heat,   J/kg. K

Cp_S: Solid specific heat J/kg. K

Γ and S: Coefficients in equation

FZ: Fusion zone

HAZ: Heat affect zone