Experimental Investigation & Analytical Calculations of Lased Melting Gray Cast Iron

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Abstract

Laser melting of gray cast iron was carried out using a 600W continuous wave Yb-YAG fiber laser under different parameters of laser, processing, and material surface roughness, based on Taguchi L16B design of experiments. The variables are, laser power (80,230,380 and 530 W), beam diameter (1.5, 1.9, 2.4 and 3.3 mm), traverse speed (2.5, 5,10 and 20 mm/s), shrouding gas flow rate(0,5,10 and 20 SLPM), and surface roughness (0.203, 2.127,3.623 and 5.363 μm). The output of Taguchi design of experiments is described by volume of melt, also the relation between spot diameter and the melt width was investigated. Different equations were obtained that explain the relation between laser parameters and the geometrical dimensions, time to melt, peak temperature and normalized temperature of heat affected zone.

Introduction

Cast iron is the traditional engineering material used before many thousands years and still have numerous applications nowadays in different sectors due to its serviceability, availability and low cost compared with steels [1]. Surface engineering processes were used to generate parts with hybrid material properties to improve their system performance [2]. Several technologies were used began with flaming, induction hardening, electron beam and lasers. Laser also used in surface engineering as heating tool. Surface hardening by laser includes two categories of processes heat treating and melting Vicente, et al, had used laser heat treating cast iron surface to improve the tribological properties [3]. Grume had hardened cast iron surface by laser melting [4]. Laser heating of gray cast iron to the transformation temperature and rapid cooling by self-quenching, leads to improve matrix hardness with keeping existence of graphite. Using suitable laser power irradiance that maintains melting and dissolving of graphite; and increasing the solubility of the matrix. Then solid solution will be and metastable phases according to rapid solidification; which increase the hardness, without the existence of graphite.

The effective parameters and their values are to be accurately selected and designed. Using the software programs to design the experiments can help in saving time and make the work more economical. Finding the relations between the process parameters and the measured responses will be practically useful. In the present work comparing experimental results with theoretical information to well understand the cast iron behaviors under different parameters of laser irradiation.

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Methods and Materials

Yb: YAG fiber-diode laser was used in these experiments with 1080 nm is fixed into the head of CNC machine. The spot size of the laser beam is controlled by changing the distance between the work-piece and the focus point of focusing lens. Argon was used as shrouding gas. Gray cast iron samples with dimensions of (80, 40, 5) mm on were used with properties illustrated by Rehab [5]. Gray cast iron were used and their surfaces were prepared to be with different four surface roughness before firing the laser. 2. Table 1 includes the chemical composition of as received samples

Table 1 Chemical composition of as received gray cast iron.

Fe	C	Si	Mn	P	S	Cr	Ni	Mo
Base	4.02	1.91	0.666	0.034	0.28	0.124	0.047	0.005
Al	Co	Cu	V					
0.007	0.008	0.154	0.008					

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Theoretical and experimental analysis

The design of experiments follows Taguchi design L16b.The processing sets are listed in Table 2.

Table 2 Process parameters values.

Ex.No.	Power (W)	Traverse speed (mm/s)	Beam diameter (mm)	Surface roughness, Ra (µm)	Shrouding gas flow rate (SLPM)
1	80	2.5	1.5	0.203	0
2	80	5	1.9	5.363	5
3	80	10	2.4	3.623	10
4	80	20	3.3	2.127	20
5	230	2.5	1.9	3.623	20
6	230	5	1.5	2.127	10
7	230	10	3.3	0.203	5
8	230	20	2.4	5.363	0
9	380	2.5	2.4	2.127	5
10	380	5	3.3	3.623	0
11	380	10	1.5	5.363	20
12	380	20	1.9	0.203	10
13	530	2.5	3.3	5.363	10
14	530	5	2.4	0.203	20
15	530	10	1.9	2.127	0
16	530	20	1.5	3.623	5

- Calculation of melt volume:

$V_{the} = \frac{Q\,(1-R)}{\rho Cp\,[(Tm-To)+\frac{Lm}{Cp}]}$ (1) $V_{exp} = A_m.v$ (2)

- **Calculation of time to melt.**

- $t_m = \frac{\pi}{\alpha}\,\frac{kTm}{2Io}^{2}$ (3)

- **Calculation of peak temperature of HAZ.**

- $\frac{1}{Tp-Tt} = \frac{2\pi k\alpha\ EXP.}{Pv}\left[2+(\frac{vy}{2\alpha})^2\right]+\frac{1}{Tm-To}$ (4)

- **Calculation of normalized temperature**

$Tn = \frac{Tp-To}{Tm-To}$ (5)

Result and Discussion

Volume of melt

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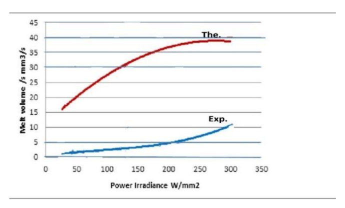

Fig. 1 Relation between the power irradiance and the volume of melt per unit time.

It is clear that the theoretical volume is more than experimental and both of them increase with increasing power irradiance. It means that there is high amount of heat lost, either to the ambient, consumed by the shrouding gas, dissipated by the inclusions or conducted to the bulk.

The relation between theoretical and experimental volumes of melt per unit time, and the traverse velocity is represented in Figure 2.

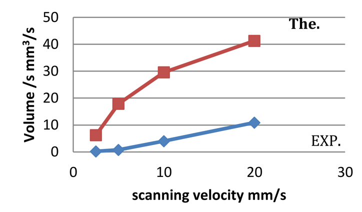

Fig. 2 Relation of theoretical and experimental volume of melt per second and the traverse velocity.

Figure 2. declares that the volume of melt increases as the travers velocity increases, because the delivered heat is consumed in melting and not allowed to be conducted to the bulk.

The relation of the surface average roughness with the theoretical and experimental volume of melt per unite time is represented in Figure 3.

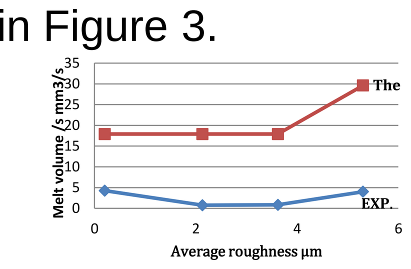

Fig. 3 Relation of surface average roughness with theoretical and experimental volume of melt.

Figure 4. shows that surface average roughness have little effect on the volume of melt, and there is no direct proportional relation between roughness and volume of melt. Reducing the volume of melt for increasing the roughness till 2μm and increasing it as the roughness increases more than 3.66 μm is may be due to the contributions of other parameters of laser. And it agree with Bergström [7].

Conclusions

-The experimental volume of melt is less than theoretical, and increases as laser power irradiance increases.
- There is no important effect of average surface roughness on the volume of melt.
- For irradiance more than melting threshold, increasing the time of melt increases volume of melt.

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