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Optimization of Process Parameter and Additive Simulation for Fatigue Strength Development by Selective Laser Melting of AlSi10Mg Alloy

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Abstract:

In this study optimization of process parameters is required to improve the fatigue strength with high density and also parts manufactured by selective laser melting (SLM) of AlSi10Mg alloy. Thermal analysis simulation was most important role in SLM printing process before such as save time, cost and material. After layer by layer additive simulation it was observed that thermal gradient, displacement and other stress was developed in SLM printing process on specimen. The AlSi10Mg alloy specimens were manufactured and conducted bending fatigue test for prediction of fatigue life for suitable process parameter. The Present research work obtained the metallurgical keyhole pores, cracks and overlap as thermal deviation produced at high laser power. The compared of overlap sample with other printed samples has a similar microstructure with little difference grain size and slight differences in fatigue strength. These metallurgical defects are how to effect on fatigue strength, density, and hardness are also discussed. Finally achieved high dense part at 99 % with good strength and less defects at laser power of 250 Watts, scan speed of 500 mm/s, hatch spacing of 80µm and laser energy density of 208.3 J/mm^3.

Keywords: Additive manufacturing (AM), Laser powder bed fusion (LPBF), Selective laser melting (SLM), AlSi10Mg alloy, Thermal analysis, Fatigue strength, Microstructure characterization, Density and hardness.

1. INTRODUCTION

Present situation, modern industry also requires manufacturing geometrically complex shape structures with reducing cost, time and light weight [1-2]. These results mainly possible in metal additive manufacturing (AM) using powder with a laser power source as selective laser melting (SLM) also called direct metal laser melting (DMLM) to build layer upon layer [3-4]. In this case SLM were builded printed specimens given process parameters i.e., scanning speed, laser power, traversing every layer as x-y plane [5-6]. After each layer, the piston was lowered to allow for the melted next layer of powder and this operation was repeated to several times until to the finished part [7-8]. When it is compared with other SLM produced materials, AlSi10Mg aluminium alloy powders have a low density, high reflectivity, poor flowability, and high thermal conductivity [9-10]. One of the main biggest challenges in manufacturing AlSi10Mg alloy parts by SLM is to minimize porosity and maximum researches have looked into how processing parameters affect porosity [11-12]. Although SLM is produce high density components near the nominal density, due to oxides, gas bubbles and particles may become stuck due to process instabilities [13-14]. The pores are unavoidable and can be act as nuclei in the cracks, which can lead to reduced of mechanical characteristics [15]. The unmolten power particles, on the other hand, are indicated by irregular elongated pores, which are often caused by a lack of energy (such as hatch pattern defects) [16-17].The main impartment process parameters considered in SLM printing process are layer thickness, scanning direction, build platform temperature, laser spot, scan speed, hatch distance and laser power [18-19].

In this paper, thermal simulation is presented and affected the part by using a different laser power and scanning speeds [20]. Optimized the suitable process parameter on fatigue strength, hardness and density without defects (porosity pores and cracks), which can able the thermal warping of components made using the SLM AM technique [21]. Some of the researcher are evaluated by the mainly focus on mechanical properties (UTS, YS, and E %), microstructural characterization and defects due to building orientation [22].

2. EXPERIMENTAL PROCEDURE

2.1. Material

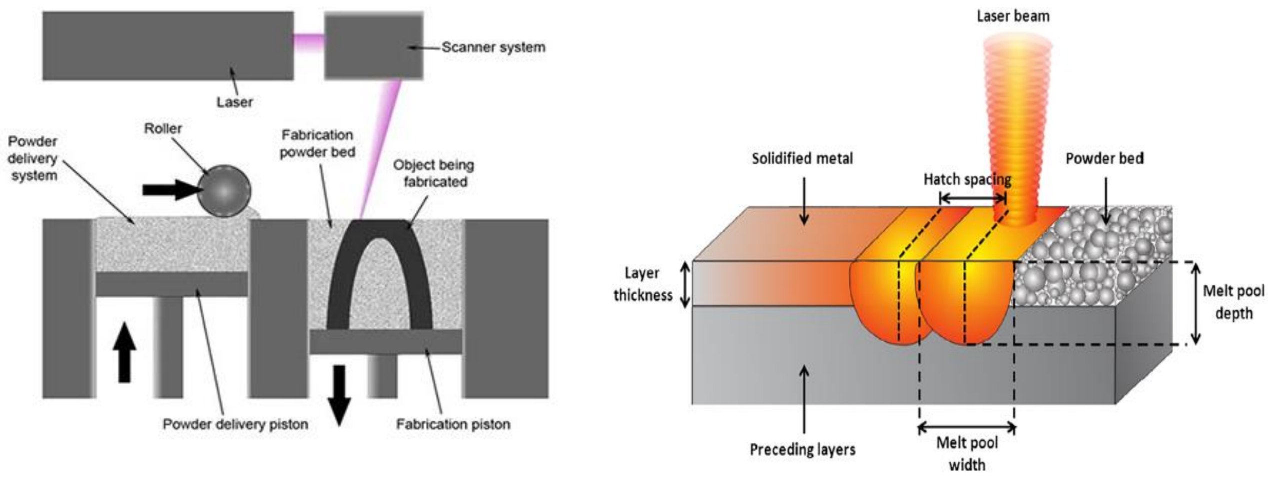
The AlSi10Mg alloy used for SLM printing process of chemical composition as shown in table 1, it was supplied by SLM solution group AG germany and in SLM printing process distribution of powder particle size ranges from 20 to 63 µm.

Table 1. Chemical composition of AlSi10Mg alloy.

Al	Su	Fe	Cu	Mn	Mg	Zn	Ti	Ni	Pb	Sn	Other total
Balance	9.00 – 11.00	0.55	0.05	0.45	0.20 – 0.45	0.10	0.15	0.05	0.05	0.05	0.15

2.1. L-PBF of SLM Process

The AlSi10Mg alloy sample was printed by SLM solution M280 2.0 L-PBF system (Germany). The SLM specification was laser power of 400 Watts continuous Yb-fiber laser in argon gas atmosphere and build platform volume of 280×280×365 with various important key process parameters involved in printing process as shown in figure 1.



(a) (b)

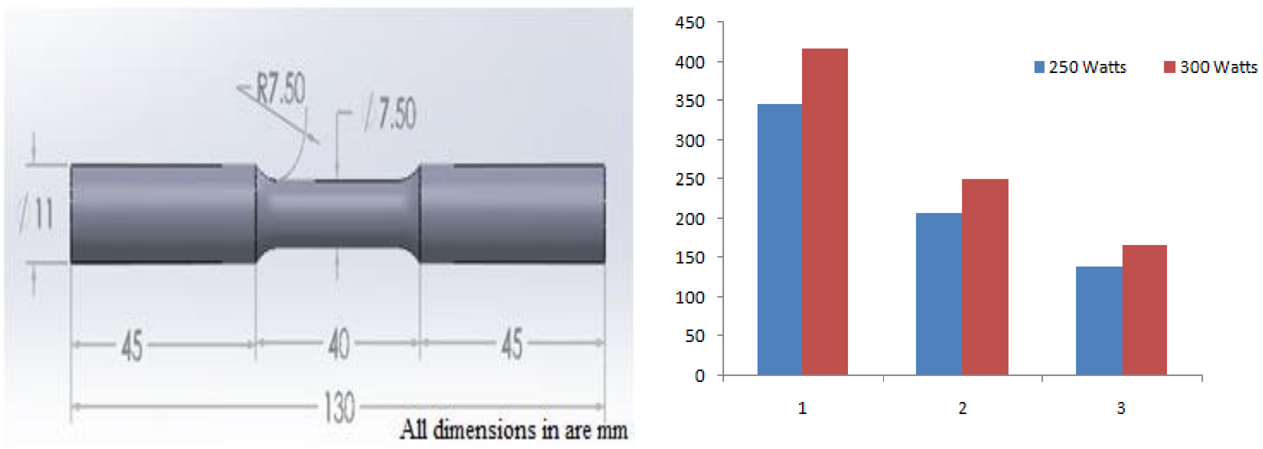
Figure 1. SLM printing process diagram and process parameter.

The considered of SLM input process parameters considered as laser power (two levels), scan speed (three levels) and hatch distance (three levels) mentioned in table 2, other parameter kept constant like build platform temperature of 150^0C, laser spot diameter of 75 µm, layer thickness of 30 µm, scanning direction and build orientation was horizontal .

Table 2: Consider process parameter for SLM printing of AlSi10Mg alloy

Laser Power in Watts	Scan speed in mm/s	Hatch distance in µm	Specimen trails
250	400,500 and 600	60,80 and 100	T1, T2 and T3
300	400,500 and 600	60,80 and 100	T4, T5 and T6

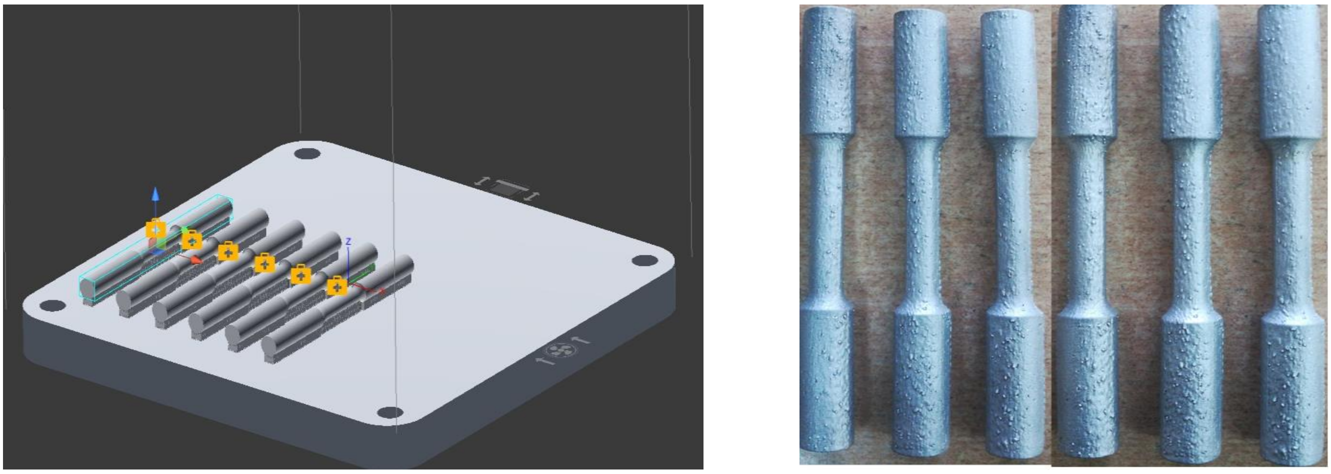
The SLM manufactured part as per ASTM standard E2948 for cyclic bending fatigue test. The laser energy density was calculated by the equation of $\frac{P}{v \times h \times t}$ ...(eq.1), used this for above process parameter and calculated by the energy density was 347.2, 208.3, 138.8, 416.6, 250, 166.66 j/mm^3 as in figure 2.



(a) (b)

Figure 2. Fatigue test specimen its dimensions and energy density graph.

After given the individual process parameter to specimens (such as; T1, T2, T3, T4, T5 and T6) in SLM inbuilt software then generate the printing process to start machine as shown in figure 3. The printing process is given two levels i.e., considered first level as 250 watts and second level as 300 watts with same scan speed range of (400,500, 600 mm/s) and hatching distance (60, 80 and 100μm).



(a) (b)

Figure 3: specimens on SLM build platform and after printed parts.

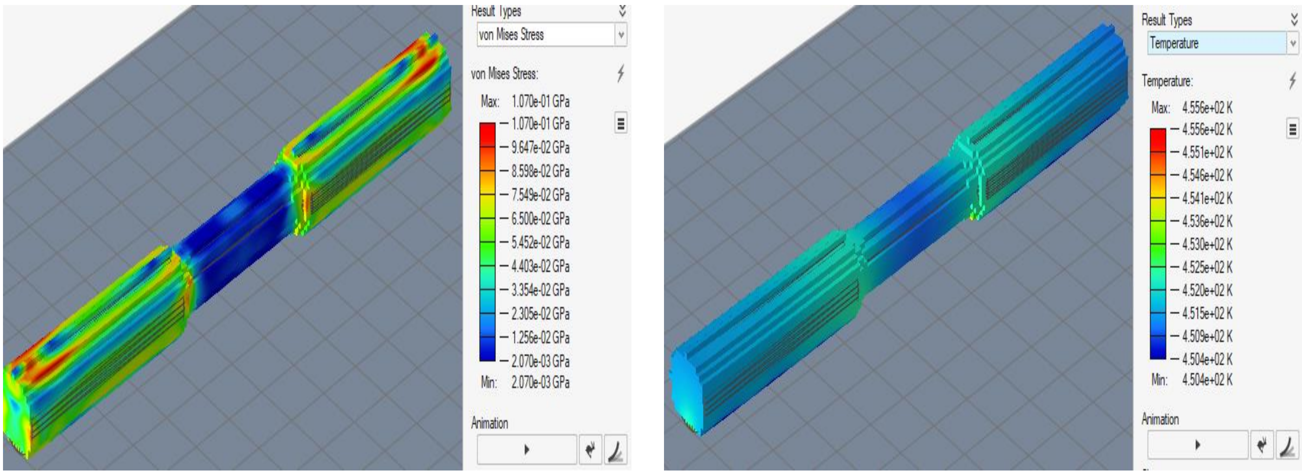
3. RESULTS AND DISCUSSION

In this work determined the effect of porosity influence on fatigue behaviour with horizontal building orientation conducted by bending fatigue test and also observed microhardness and density parts of AlSi10Mg alloy produced by SLM. The experimental procedure conducted by following steps.

- Identified the SLM printing process of key parameters.
- Developed the thermal simulation before printing process.
- Considered the laser power upper 300 and lower 250 watts.
- The output performance as considered as fatigue strength, microhardness and density.
- Developing the Design of experiment for optimal process parameter.
- Conducting the experiments as per given process parameter on fatigue test.

3.1 Thermal behaviour for optimal process parameter

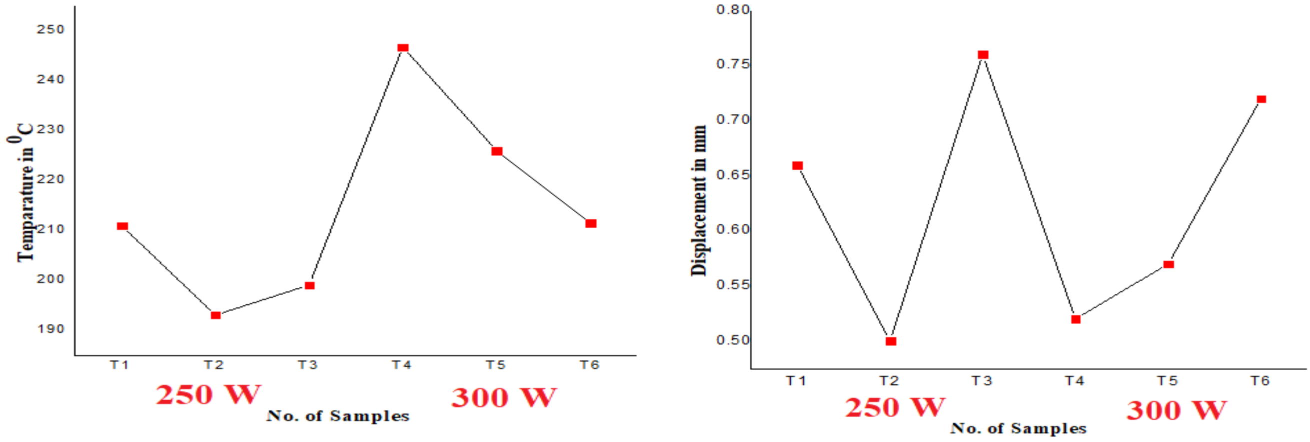
Before SLM printing process to conducted the thermal analysis simulation as per given process parameter means saving the material, cost and time. In that thermal simulation stresses was developed such as displacement, temperature, plastic strain, von mises stress and other stress. The thermal analysis simulations were conducted at individual specimens with a different process parameters used as laser power in watts (250 and 300), scan speed in mm/s (400, 500 and 600) and hatch distance in μm (60, 80 and 100) as mentioned above table 2. The predicted of maximum printing temperature in SLM of 246.6 ^{0}C at T4 and also maximum displacement at T3 due to increased the laser power with scan speed as shown in figure 4.



(a) (b)

Figure 4.Thermal simulation as per given process parameter

The highest von mises stress operated of 95.73 MPa at T5 (when increasing the scan speed) and the lowest plastic strain was developed of 0.33 at T3 (when increasing the hatch distance). During the optimization in this object purpose was reduce the porosity and improve the strength, finally the simulation results obtained of optimal process parameter with less displacement and minimum operating temperature at T2 (laser power of 250 W, scan speed of 500 mm/s and hatch distance 80 µm) as shown in figure 5.

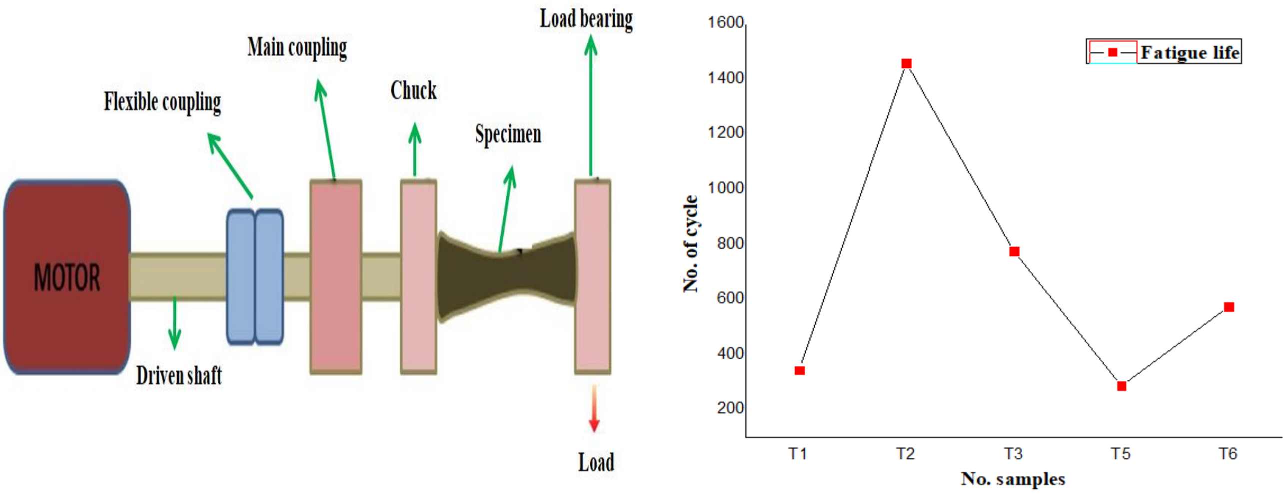


(a) (b)

Figure 5: Thermal analysis simulation results and displacement values

3.3 Fatigue Performance

The fatigue test as indicated as shown in figure 6, it is used and found of horizontal building orientation specimen fatigue strength of SLM manufactured by AlSi10Mg alloy. The SLM-AM part building directions is the most important role in fatigue strength. The fatigue failure data, it can be observed that when used high laser power with low scan rate. The specimen's defects, pores and porosity were observed that after test crack on part surfaces and defects have give harmful impact on fatigue strength.



(a) (b)

Figure 6: Fatigue testing and plotted vales at each specimen.

The samples were tested at a constant load was applied to determine suitable process parameter based on the fatigue strength (such as fatigue life). The motor speed was calculated by the time at sample was broken and the number of cycles in time, as shown in table 3.

The fatigue strength calculation:

- The motor rpm is 2880,

1 minute = 2880 rev (i.e., 1 second = $\frac{2880}{60}$ = 48 revolution per second),

- The number of life cycles = time taken in second (s) × 48 revolution per second and
- Length of the shaft is 190 mm,
- Diameter of the shaft (D) is 15 mm,
- Weight (W) = 10 × 9.81 = 98.1 N, (applied load for fatigue test is 10 kg),
- Bending moment (M) = L × W… (eq.2) = 48069 N-mm and

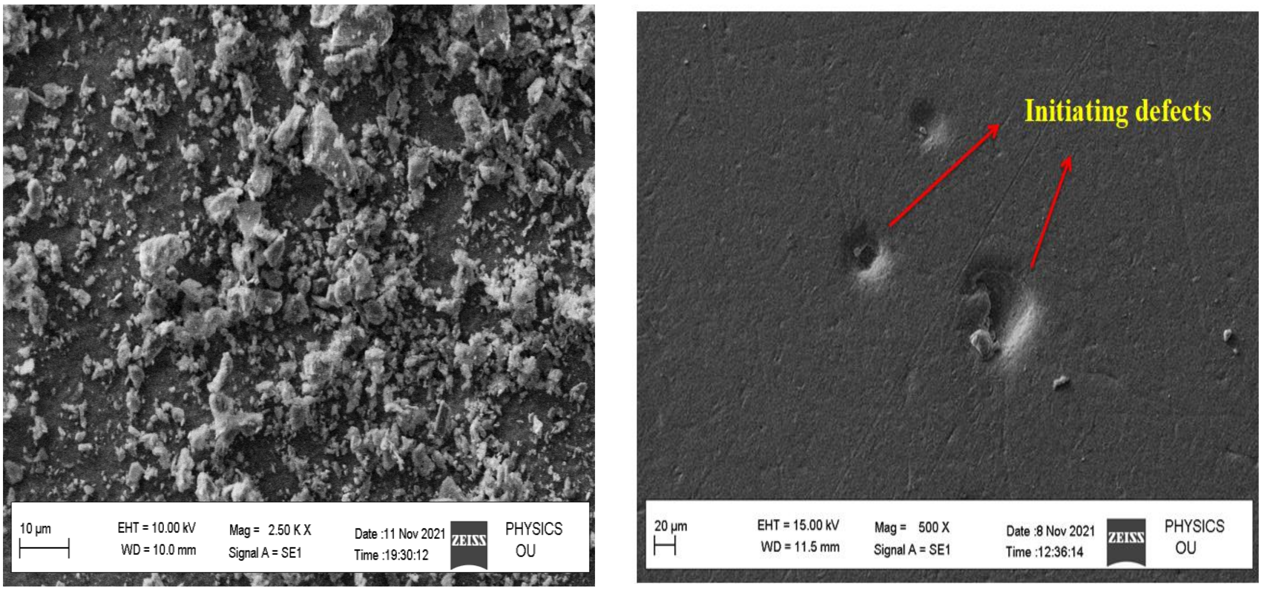
- Bending stress (σ_b) = $\frac{32M}{\pi d^3}$ ... $(eq. 3)$ = 145.14 MPa.

Table 3: After experimental test conducted of fatigue test results

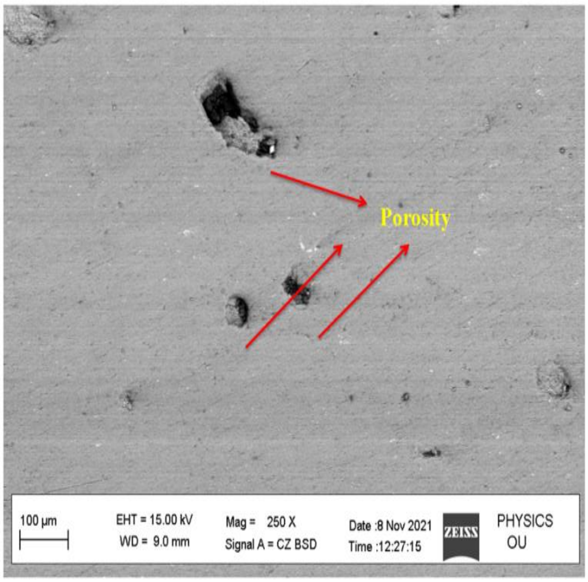
Trail No.	Time taken in sec	No. of cycle
T1	7.2	3.45×10^2
T2	30.6	1.46×10^3
T3	16.2	7.77×10^2
T4	Not printed specimen due to overlapping (high laser power of 300 Watts and low scan speed of 400 mm/s)	
T5	6	2.88×10^2
T6	12	5.76×10^2

3.4 Microstructure, hardness and density

From the figure 7 as shows that scanning electron microscopy (SEM) image of AlSi10Mg alloy powder particle distribution and it can be observed that powder particles are not spherical. The powder particles morphology is a very uneven shapes, with many little irregular satellite particles connected to the large powder particles and other places have seen these irregular structures with little satellite particles. All samples are produced in a melt pool with good metallurgical bonds. Used the high energy (E) input then created large pores with low scan speed. The overlapping between molten pools is expected to affect defect formation, irregularly shaped pores were apparent with more thermal distortion by the high laser of 300 Watts and lower scan of 400 mm/s. The majority of the burring layer was current in the cross section at a high laser with 600 mm/s scan speed. From this completed that burring phenomenon is mainly metallurgical porosity defects on specimen at high power laser with fast scan rate. The SLM samples manufactured at T2 is shown a better microstructure with no any visible like pores, the laser power energy density defined as the optimal parameter for obtaining minimum defects, porosity, pores, cracks for a range of 250 Watts, 500 mm/s, 80 µm, and 30 µm of layer thickness for SLM of AlSi10Mg alloy to achieve defect-free component.



(a) (b)

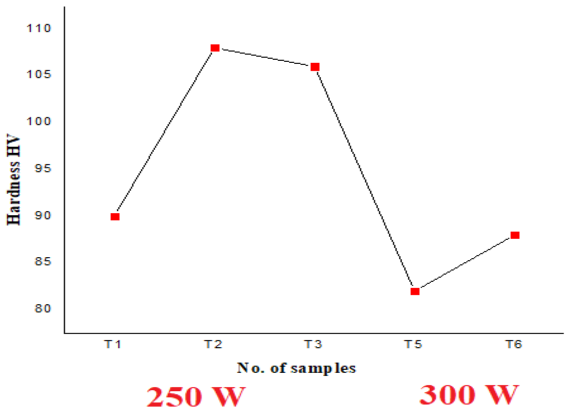


(c)

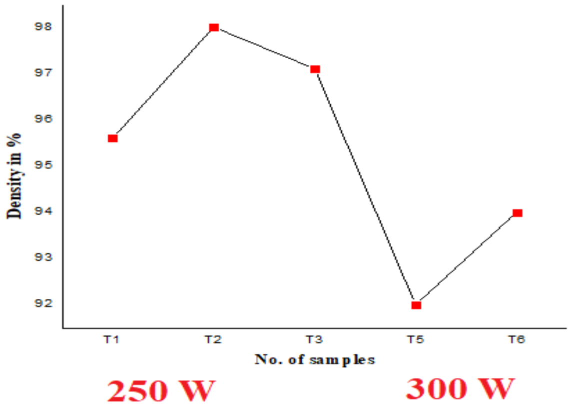
(d)

Figure 7. The microstructure profile: a) overlap with high 300 watts laser power b) initiating defect at 300 watts with 600 mm/s c) porosity at 250 watts with 400 mm/s and d) fine structure at 250 watts with 500 mm/s.

For as built condition were tested all samples, the microhardness higher at T2 is 108.3 HV, lower at T6 watts is 82 HV due to high laser with overlap samples. Finally the hardness and density values are as shown in figure 8 with achieved the highest hardness and density is 108 HV, 98 %.



(a)



(b)

Figure 8: . a) Hardness and b) Density values.

4. Conclusions

The metallurgical pores, fractures, and isolated areas with overlap of thermal gradient created at high laser power and low scan speed, i.e., keyhole, are presented in this work, and their effects on fatigue strength, density, and hardness of AlSi10Mg alloy are discussed.

- The pores in overlap boundary are expected to cause early fracture in the samples during fatigue testing.
- The pores overlap and defects was achieved at increasing the hatch distance from 80 to 100 µm (i.e., heat buildup with cool slowly).
- The overlap and isolated samples has a similar microstructure with little difference of grain sizes. The energy density (E) has an important influence factor on mechanical properties and defects are formed when the laser energy density is too high or too low (such as defects, porosity, and micro crack). When balling is occurs at scan speed is increase, promotes the capture of powder that hasn't entirely melted by the laser beam scanning the next layer, resulting in the formation of a keyhole pores.
- To avoid the defects (pores, cracks) and achieve full dense part should be selected low laser power and scan speed, for that best process parameter was obtained as scan speed is 500 mm/s, hatch spacing is 80µm, and lower power is 250 W with layer

thickness is 30 µm at fatigue strength is 1.46×10^3, hardness is 108.3 HV and density is 98% with laser energy desity is 208.3 j/mm^3.

Future work will be mainly focus on how to eliminate pores, crack with optimisation of process parameter and further improve the fatigue strength, especially full dense part.

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