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LASER SINTERING PROCESS OF ALUMINIUM POWDER FOR DIRECT METAL LASER FABRICATION PROCESS

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Abstract

This research reports on the results of an experimental study examining the potential of the selective laser sintering process to produce a layer of specimen by using AlSi10Mg powder. A 300W Nd: YAG laser machine was used in this laser sintering experiment in order to fabricate the AlSi10Mg specimen. The effect of the laser parameters such as laser power, scan speed, scan spacing, and pulse rate was considered in this research, in which, the research started by evaluating sintered samples on a single track and continued with multiple tracks which creating a single layer sintered specimen. The evaluation of specimen characteristics was concentrated on surface morphology, relative density and dimensional accuracy. There were a set of power range and pulse rate applied in the single track test which were 30W to 75W laser power and 100Hz, 150Hz, and 200Hz of pulse rate. Whereas, set of laser parameter range applied in the single layer test were 40W and 60W of laser power, 1mm/s, 3mm/s, 5mm/s of scan speed and 0.6mm, 0.7mm, 0.8mm of scan spacing. The result of the laser sintering experiment showed that laser power was inversely proportional to the porosity of the specimen, but directly proportional to the area percentage error of the specimen. While, the scan speed parameter was directly proportional to the porosity of the specimen, but inversely proportional to the area percentage error of the specimen. The purpose of the research was to find optimum laser parameter conditions and created a process map for laser sintering of AlSi10Mg powder material.

Keywords: *Selective laser sintering; Rapid prototyping; AlSi10Mg*

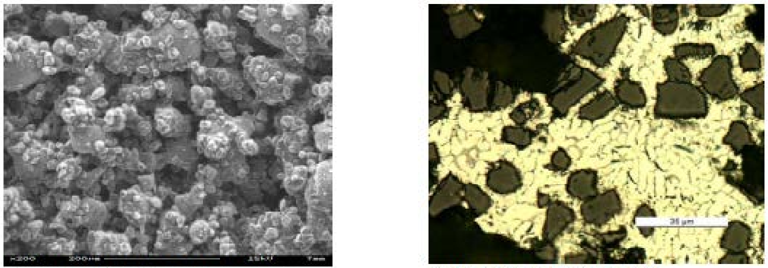
Introduction

The traditional method of fabricating a prototype part is machining, which can require significant lead times, depending on part complexity, difficulty in ordering materials, and scheduling production equipment. The development of rapid prototyping technique makes the fabrication of engineering prototypes faster and less expensive compared to conventional method [1]. Direct Metal Laser Sintering (DMLS) is one of the rapid prototyping technology that can produce parts directly from metal powders using the energy of a laser beam to promote sintering, in an inert and thermally controlled environment within a chamber. The incidence of the laser can promote the sintering of powder particles or its complete fusion, bonding them to the previous layer. After obtaining each layer, an additional

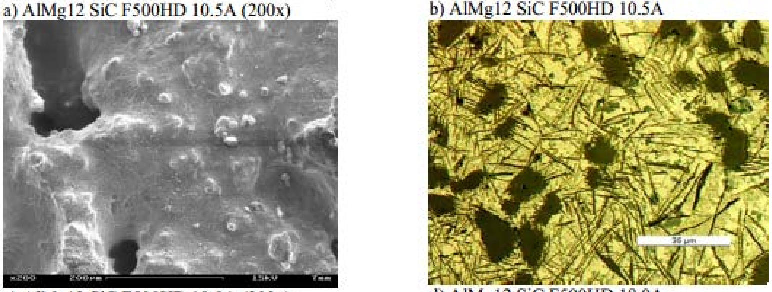
layer of powder is superimposed on the part, and the laser beam once again scans the desired areas, according to the virtual model, thereby obtaining a new layer, and subsequently, to complete construction of the part [1, 2].
Laser sintering is one of the leading commercial processes for rapid fabrication of functional prototypes and tools. The process creates solid three-dimensional objects by bonding powdered materials using laser energy. There are a few materials that are used such as engineering plastics, thermoplastic elastomers, metals, and ceramics. Laser sintering can fabricate many products including patterns for investment casting, metal moulds for injection moulding and die casting, and moulds and cores for sand casting. It has also fabricated prototype objects to enhance communication and testing of concepts during the design cycle. The process of laser sintering is very complex because it is accompanied by multiple modes of heat, mass and momentum transfer, and chemical reactions. The scientific and technical aspects of the production route such as sintering rate and the effects of processing parameters on the microstructural evolution during the layer manufacturing process have not been well understood. So, the method essentially relies on empirical and experimental knowledge [1, 3].

Aluminium AlSi10Mg is a master alloy Aluminium powder. AlSi10Mg is a typical casting alloy with good casting properties and is used for cast parts with thin walls and complex geometry [4]. The alloy combination silicon/magnesium results in a significant increase in the strength and hardness. It also features good dynamic properties and is therefore used for parts subject to high loads. Standard building parameters completely melt the powder in the entire part [5]. Parts made of Aluminium AlSi10Mg can be machined, wire eroded and electrical discharge machined, welded, micro-blasted, polished and coated. Unexposed powder can be re-used. Typical applications of Aluminium are direct manufacture of functional prototypes, small production runs, user-specific products or spare parts [4].

In Vaucher *et al.* study [6], a research about laser sintering of Al/SiC to investigate the influences of laser power and matrix composition on wettability, interfacial reactivity and porosity of the material. The SLS sintering station used was a specially designed set-up mounted with an Nd: YAG (1.06 µm) Q-switched laser, F-Θ lens galvanometric scanner. Laser parameters used were: nominal current: 8.4-18.2A, pulse frequency: 40 kHz, scanning speed: 40 mm/s. The sample geometry was 1 cm square made of a series of 0.2 mm parallel single lines spaced by 0.1mm (200% overlap). Static argon or nitrogen atmosphere was used after clearing of the chamber down to 5.10-2 mbar. Single layer were normally prepared to manually spread 1-4.5 mm thick powder beds. AlSi12Mg have the surface oxide layer present on the surface of pure aluminium powder. By adding magnesium produces magnesium rich intermetallic phases and mixed oxides that create discontinuities in the surface aluminium oxide layer and lowers the surface tension of the melt and therefore, the spreading of the molten phases and thereby facilitate the sintering process. The morphology of the acquired single layers is depending on the laser power as shown in the Figure 1.1 [6].
Another study was conducted by A. Simchi to investigate the effect of the laser parameter in the laser sintering process. In A. Simchi study [3, 7], the prepared powders were sintered by using the direct SLS layer by layer to create a rectangular test specimens with dimensions of 10mm×10mm×7mm. The investigated laser sintering parameter condition where the laser power P = 100–215W, scan rate v = 50–600mms^{-1}, layer thickness w = 0.05–0.2mm and scan line spacing h = 0.1–0.4 mm. An alternative scanning pattern from layer to layer with equal line spacing in the X and Y directions was used. The diameter (d) of the laser beam was 0.4 mm.



a) AlMg12 SiC F500HD 10.5A (200x)   b) AlMg12 SiC F500HD 10.5A



c) AlMg12 SiC F500HD 18.0A (200x)   d) AlMg12 SiC F500HD 18.0A

Figure 1.1: SEM and optical micrographs of the external surface (a, c) and the corresponding microstructure (b, d) [6].

Figure 1.2 shows the fractional density of investigated laser power and scan rate as a function of *P/v*, it shows that the density was linear proportion to the ratio of laser power to scan rate in semi-log scale [3, 7].

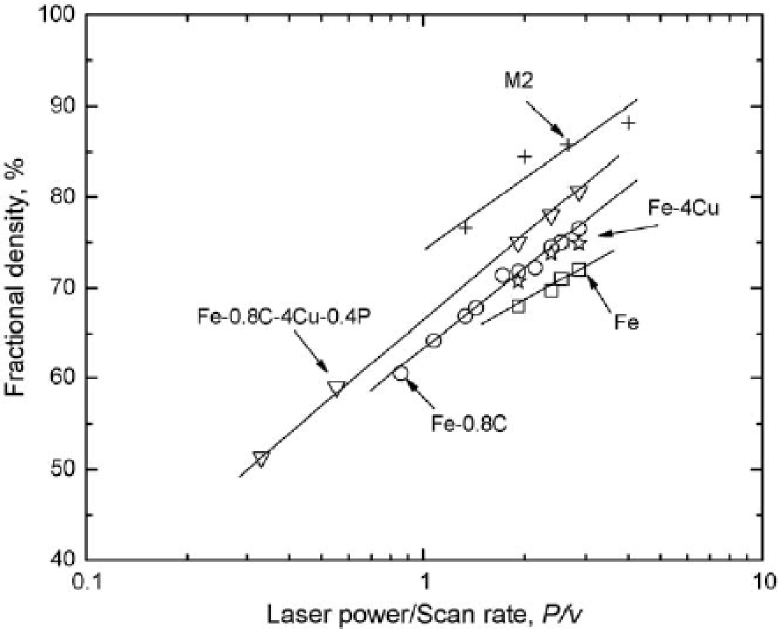


Figure 1.2: Fractional density of laser sintered powders versus the ratio of laser power to scan rate. The layer thickness is 0.1mm and the scan line spacing is 0.3mm in the experiments [3]

The objective of the experiment is to discover a range of laser parameter for the AlSi10Mg powder material and fabricate a single layer of AlSi10Mg material specimen with different combination of laser parameter.

Methodology

Laser sintering experiment process

A 300W of Nd: YAG laser machine was used for the laser sintering experiment as shown in figure 2.1. The laser sintering experiment was done on the Aluminium AlSi10Mg powder material by using the Nd: YAG laser and the powder bed had been prepared to fill up the AlSi10Mg powder material. The laser source used is laser machine Nd: YAG JK300HPS laser, which specification is shown in the Table 2.1.The experiment is to discover a range of laser parameter for the AlSi10Mg powder material and fabricate a single layer of AlSi10Mg material specimen with different combination of laser parameter. Thus, there had few tests in laser sintering experiments on AlSi10Mg to get the range of the laser parameter, which the laser sintering was started from single track test and continued with the multiple track test which creating a single layer of the specimen. The laser parameters that considered in this experiment listed in Table 2.2 as below:

Table 2.2: Nd: YAG JK300HPS laser parameters

Constant parameter	Variable parameter:
Height: 10% Scan speed: 300mm/min	Pulse rate (Hz): 100, 150, 200 Power (W): 30, 35, 40, 45, 50, 55, 60, 65, 70, 75

Specimen characteristics analysis

All the specimen characteristics were analysed in the aspect relative density, surface morphology and dimensional accuracy. Different type of apparatus had been used for each analysis in order to obtain and measure the data.

Surface morphology analysis

Surface morphology analysis was done by using the tool maker measuring microscope. The model of tool maker measuring microscope use for this research is model MM-60/L3T. The measuring microscope had equipped with a live camera and the picture of the surface of the specimen can be snapped. Each part of the specimen had been snapped 15 photos with different focus depth length and then all the photos of that particular part to be combined to get a clear surface photo of the specimen. These data will be collected and analysis to compare the specimen that being fabricated by using different combinations of laser parameter.

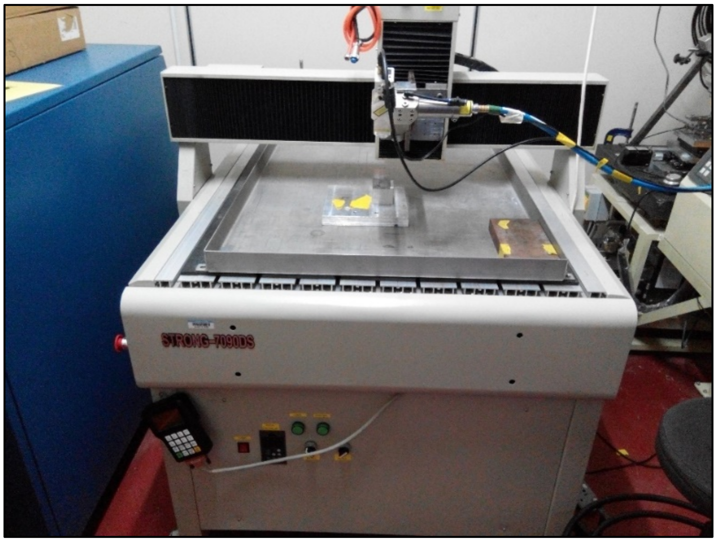


Figure 2.1: Nd: YAG JK300HPS laser machine using JK Luminator™ Process Tools: 40mm Right Angle Welder with 100 recoll.

Table 2.1: Specification of Nd: YAG JK300HPS laser

NO	Performance	Data
1	Max. Average power of laser (W)	300
2	Max. Peak power (kW)	9
3	Max. frequency (Hz)	1000
4	Pulse width range (ms)	0.2-2.0
5	Beam quality	16
6	Max. pulse energy (J)	56
7	Shutter opening time (ms)	<50
8	Standard fiber length	5, 10, 15, 30
9	Standard fiber diameter (m)	300
10	Beam delivery options	Up to 4T or 3E or 2Tx2E combination
11	Max. recollimating lens focal length with 60mm square output housing (mm)	200

Relative Density

The relative density was calculated by using the relative density formula. The weight and the size (volume) of the specimen had been measured first, where the weight was measured by using the weighing and the volume was determined by using the profile projector to measure side lengths of the specimen and calculated by using formula 2.1

$$V=L*W*T \tag{2.1}$$

Where, V is the volume, W is the width, L is the length and T is the thickness.

Once the weight and size had been measured, the density of the specimen is calculated by using the formula 2.2.

$$\rho = \frac{m}{V}, \tag{2.2}$$

Where, ρ is the density, m is mass, and V is the volume.

Dimensional accuracy analysis

Profile projector was used to analysis the dimensional accuracy of the specimen. The model of the profile projector was vertical profile projector PJ-H3000f. Profile projector was a device that applies the principles of optics to the inspection of manufactured parts. In profile projector, the magnified silhouette of the specimen is projected on the build in projection screen. On the screen the profile of the specimen and is magnified for better ease of calculating linear measurement.

Result and Discussion

This chapter, observe and discuss the process of the laser sintering for the single track specimen and single layer specimen. At each stage different parameter was considered during the laser sintering process in order to observe the effect of different parameter to the AlSi10Mg powder material in fabricating the single track and single layer specimen. A few parameter had directly contributed in the object manufactured by the selective laser sintering process. During this observation, a parameter that was considered in the process where laser power, scan speed, pulse rate, and scan spacing which these parameters had brought some effect to the surface morphology, density, and dimensional accuracy of the specimen. Thus, this chapter will demonstrate the effect of different parameter in construction of single layer specimen by using the selective laser sintering process on AlSi10Mg powder material.

Effect of laser parameter on single track laser sintering of AlSi10Mg

Figure 3.1 shows the comparison of good and poor quality of the specimen obtained from the single track test. There were three different areas had been distinguished according to the growth type of the single track specimen. Growth Type I was the specimen that melts with breakage, Growth Type II was the specimen melting with good surface smoothness, but poor integrity, while the Growth Type III was the specimen construct in continuous melting which mean the specimen consist of good integrity. Most of the Growth Type I specimen were fabricated at the power above 65W. The Growth Type II specimen was constructed at laser power ranging between 45W and 60W. The range of the laser which had fabricated Growth Type III specimen were between 30W until 40W. Mostly the integrity and surface smoothness of the specimen when the laser power under 45W. Thus, the outcome of the single track test had shown that the material had its own adequate laser power range to apply in the laser sintering process which can get a good integrity and surface smoothness. The adequate laser power range for the AlSi10Mg material is 30W until 45W.

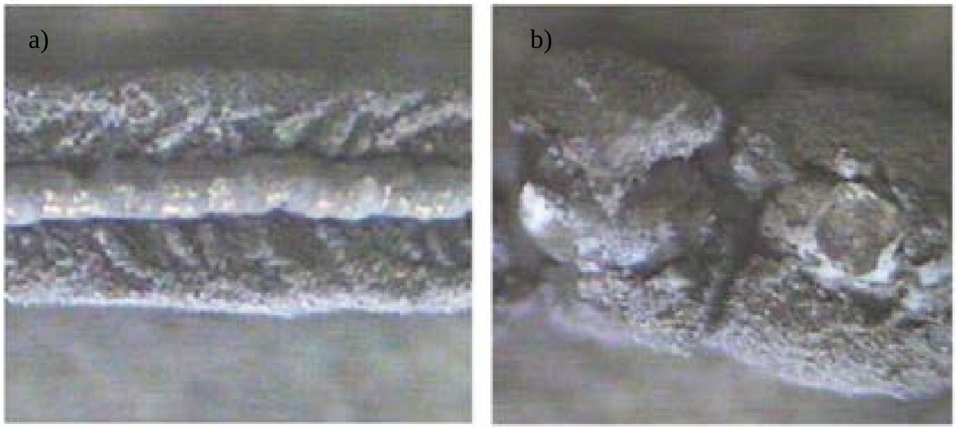


Figure 3.1: Comparison of good quality (a) and poor quality (b) of specimen of single track test.

On the other hand, the effect of the pulse rate was not so noticeable in this single track test, due to the range of power to get a good integrity and surface smoothness at the different pulse rate were almost same, all located in the range of 30W until 45W. Table 2.3 displayed the parameters and result of the growth type on the single track specimen.

Table 2.2: Parameters and result of the growth type on the single track specimen of the single track specimen.

Pulse rate (Hz)	Power (W)	Pulse width (ms)	Height (%)	Scan speed (mm/min)	Energy (J)	Width (mm)	Length (mm)	Growth Type
100	30	1.9	10	300	0.3	1.03	20.6	III
	35	2.1	10	300	0.35	1.06	19.15	III
	40	2.3	10	300	0.4	1.01	21.01	III
	45	2.8	10	300	0.45	2.35	19	II
	50	3	10	300	0.5	2.25	18.01	II
	55	3.3	10	300	0.55	2.15	19.4	I
	60	3.6	10	300	0.6	2.15	19.15	II
	65	3.8	10	300	0.65	1.65	20.15	I
	70	4	10	300	0.7	1.75	20.15	I
	75	4.5	10	300	0.75	1.72	19.55	I
150	30	1.3	10	300	0.2	1.01	19.4	II
	35	1.5	10	300	0.24	1.54	19.6	II
	40	1.7	10	300	0.27	1.06	19.55	III
	45	1.9	10	300	0.3	1.85	21.01	II
	50	2.1	10	300	0.34	1.35	19	II
	55	2.3	10	300	0.37	1.4	18.6	II
	60	2.5	10	300	0.4	2.02	18.7	II
	65	2.7	10	300	0.44	1.7	19.25	I
	70	3	10	300	0.47	2	19.8	I
	75	3.2	10	300	0.5	2.05	18.4	I
200	30	1.1	10	300	0.15	0.75	19.6	III
	35	1.3	10	300	0.18	0.95	19	III
	40	1.5	10	300	0.2	1.1	19.8	III
	45	1.7	10	300	0.23	1	20.3	I
	50	1.8	10	300	0.25	1.3	19.25	I
	55	1.9	10	300	0.28	1.7	19.1	II
	60	2	10	300	0.3	1.45	19.5	I
	65	2.2	10	300	0.33	1.55	19	I
	70	2.3	10	300	0.35	1.54	20.1	I
	75	2.4	10	300	0.38	1.51	19.03	II

Qualitative observation

In the single layer specimen, there were two types of qualitative classification of the sintered part had been distinguished which were listed as follows:

Full melts with poor layer surface quality (Figure 3.2 (b)): a focused, moving back and forward Gaussian beam pounding on the surface of the powder layer cause a full melting over delimited powder surface. The outcome was a sintered layer with a surface which is characterized by poor bonding system between the tracks. A high porosity was observed within a layer in this category.

Full melts with good layer surface quality (Figure 3.2 (a)): a focused, moving back and forward Gaussian beam pounding on the surface of the powder layer cause a full melting over delimited powder surface. The outcome was a sintered layer with a surface which is characterized by good melting and bonding system between tracks. A low porosity was observed within a layer in this category.

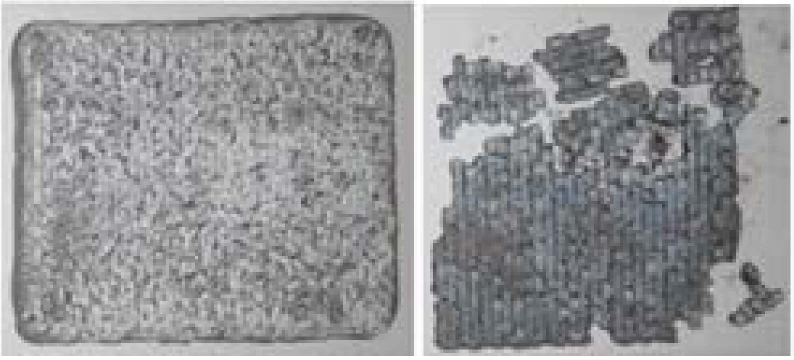

a) Good quality b) Poor qualtiy

Figure 3.2: Single layer specimen fabricated at 60W (a) and 40W (b).

Surface morphology of the single layer specimen

Most of the good surface morphology specimen was fabricated at low scan speed which was 60mm/min. At low scan speed, the surface of the specimen had less porosity compare with the specimen fabricated at high scan speed. At the aspect of scan spacing, the specimen that constructs at low scan spacing consists of better surface smoothness. While for the specimen construct at high scan spacing the shaped of each track were clearly seen at the surface of the single layer specimen. Further increase the laser power also had enhanced the surface smoothness of the single layer specimen. At high laser power, the trace of the track line on the surface of the specimen was not obvious as the specimen at low laser power. Therefore, the best surface smoothness single layer specimen was fabricated at 60W of laser power, 60mm/min of scan speed, and 0.6mm of scan spacing.

Relative density of the single layer specimen

Based on the Figure 3.3, it had shown that the relative density of the single layer specimen was not in a linear line and not consistent when the ratio of laser power to scan speed was increased. This is because at each different single layer specimen, there was some powder stick at the specimen and it had influenced the weight of the specimen which the weight is one of the factors that will influence the relative density of the specimen. However, the average relative density of the specimen that fabricated at the scan spacing 0.6mm were higher than the specimen that fabricated at the scan spacing 0.7mm and 0.8mm, which the scan spacing was inversely proportional to the density.

Figure 3.3: Relative density of the single layer specimen at 0.6mm, 0.7mm, and 0.8mm scan spacing versus the ratio of laser power to scan speed

Dimensional accuracy analysis

There were two main laser parameter that will affect the dimensional accuracy of the specimen which were the laser power and scan speed. The Figure 3.4 had shown the relationship between the scan speed and laser power with the area percentage error of the specimen. From the figure, it showed that when the scan speed increased the percentage error will be decreased, which the scan speed is inversely proportional to the area percentage error. Besides, when the laser power increased the area percentage error will also increase, which the laser power is directly proportional to the area percentage error of the specimen.

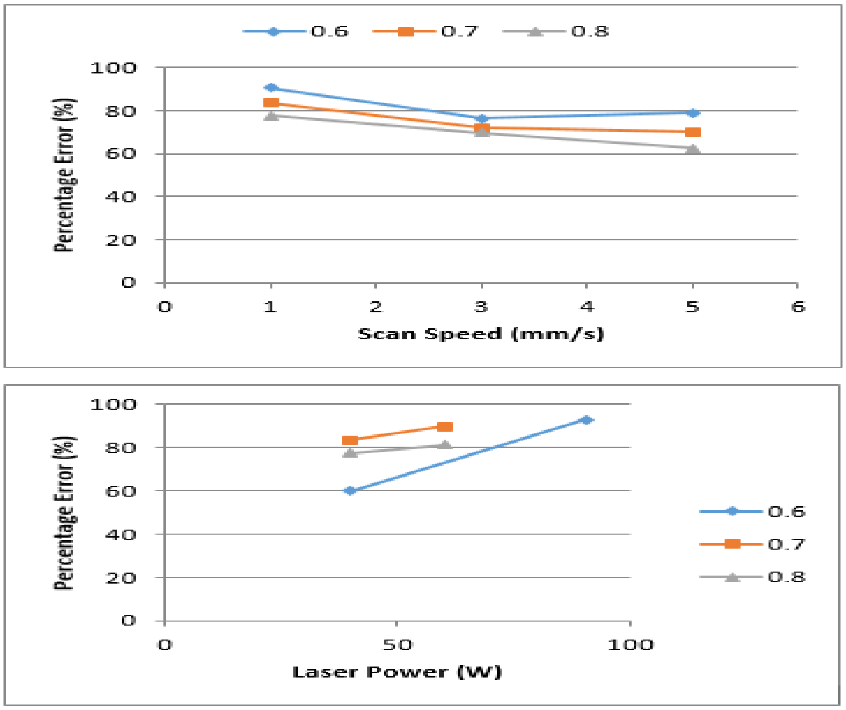


Figure 3.4: Percentage error of the single layer specimen at 0.6mm, 0.7mm, 0.8mm scan spacing versus scan speed, laser power.

Conclusion

The research on the effect of the laser power, scan speed, scan spacing and pulse rate laser parameter to the specimen characteristics on AlSi10Mg material specimen can be concluded as follows:

1) The optimum laser parameter to fabricate a single layer Aluminium AlSi10Mg specimen by using laser sintering technique was 60W laser power, 0.6 scan spacing, and 60mm/min scan speed.
2) The characteristics of the specimen largely impact by laser parameter of laser power and scan speed that associated with the energy density that integrate the powder material.
3) When the scan spacing increases, the specimen show poor integrity and surface smoothness. For the fabrication of good surface smoothness of specimen, the best range of scan spacing were 0.6mm, 0.7mm, and 0.8mm.
4) It was hard to control the dimensional accuracy due to the diffusion of the heat of the laser beam causing the bigger melt pool area being formed, which subsequently made the dimension of specimen larger than the ideal dimension.

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