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An experimental investigation of selective laser process parameters on aluminium alloy (AlSi12)

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Abstract

The chase for sustainable manufacturing that contributes to addressing climate change is of research interest across scientists and industrial sectors. The lightweight and high strength properties of aluminium alloys foster sustainable cost, energy consumption and environmental friendliness. This has made aluminium alloys such AlSi12 to be adopted in the transport industry. However, there are difficulties associated with the material when processing with subtractive manufacturing systems. To hardness the benefits of AlSi12, researchers advocate the use of Additive Manufacturing (AM) technologies. One of the AM technology considered in this paper is the Selecting Laser Melting (SLM). SLM is a technique that presents advantages and disadvantages. One of the advantages of the process is the freedom of design complexity. The disadvantage is related to the process that influence the built part. The rapid cooling and heating motion of the interaction between the laser and the powder impact the structure of the printed part. Considering that the SLM process involves a range of process parameters that affect the printed part, this paper employs the Response Surface Methodology to vary the laser power from 50-300 W and the scanning speed from 500-2500 mm/s during the SLM of AlSi12. The result yielded the significant impact of low scanning speed on a printed specimen. Further studies entail conducting parametric optimisation and evaluation of the mechanical properties.

Keywords: Aluminium alloys; Process parameters; SLM; Sustainable manufacturing

1. Introduction

The global issue of greenhouse gas (GHG) emissions has implied the usage of materials such as aluminium for application in aerospace, automobile, aviation and marine [1]. Aluminium alloys are lightweight materials, with high strength, good thermal conductivity, corrosion resistance and low density; their applications can reduce fuel consumption in the transport industry and consequently decrease the carbon footprint [2].
Aluminium alloys have been extensively processed by traditional manufacturing systems such as extrusion, casting and forging. However, many challenges were reported [3] The microstructure of the cast aluminium alloys was found coarse with defects including shrinkage porosity, stresses and lower mechanical properties due to the low cooling rate in casting [3]. Another challenge arose from the lengthy process chain of preparing the aluminium powders according to the specific engineering or performance requirements [4]. Moreover, complex geometrical components require more time for tooling, assembling and welding to achieve the specified design. Addressing these shortcomings, some research [5-8], have recommended the usage of additive manufacturing (AM) to alleviate the issues of supply chains, reduce the delivery lead-times and increase the usage of aluminium alloys.
AM is a technology that allows for unparalleled levels of design freedom that are unlikely to attain with subtractive production. Lattice structure, integrated complex internal

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channels or shapes, topological optimization, and the hybridization of a different metallic substance are examples of design features [9]. These capabilities enable a part's efficiency and functionality to be improved considerably. Waste reduction is another benefit of AM, as the part is made in a layer-by-layer process [5].

Furthermore, to process aluminium alloys using AM, a widely used technique is powder-bed fusion (PBF), with technology such as selecting laser melting (SLM) [10]. To manufacture a component, SLM uses a laser beam as a heat source to fuse or melt metal powders on a bed powder [11]. The process involves rapid heating and cooling that is a result of the interaction between the laser and the powder. The quality of printed components is driven by the configuration of process parameters that influence the microstructure and mechanical properties of the component. These parameters are associated with subsequent challenges of thermal cracks, stresses and balling issues. According to Kotadia [12], considerable research has been conducted on SLM parameters such as hatch spacing, layer thickness, laser beam, laser power and scan speed.

Few researches have been conducted on the parametric studies of SLM for AlSi12 [13-16]. AlSi12 possesses excellent hypoeutectic properties. It is worth noting that defects are caused by an inadequate combination of parameters [17]. The optimal parameters differ between machines and materials. The focus of this article is on the investigation of varying scan speed and laser power parameters to produce fully structured aluminium specimens. This is aimed at obtaining the feasible range of these two process parameters for the SLM of AlSi12. The establishment of the feasible combination of these parameters has not been sufficiently highlighted by the existing literature. It is envisaged that that the outcome of this study will assist manufacturers that employs AM to achieve sustainability during the SLM of AlSi12.

The first section of the paper provides the motivation for the use of AM in the processing of AlSi12. The second section explains the experimental process and the third section presents the results and discussion. Finally, the conclusive remarks and future areas of research are provided in the conclusion.

2. Methodology

This section explains the materials and methods used in the study. The methodology essentially comprises of the numerical experimentations involving the Design of Experiment carried out with the Response Surface Methodology and the validation of the designed experiment via physical experimentations.

2.1 Design of Experiment (DoE)

The Response Surface Methodology (RSM) involving the Central Composite Design (CCD) technique) was used to design the experiment. The Design Expert version 2018 software was used for obtaining the feasible experimental runs of the process parameter combinations [18]. The RSM was used because it enables the optimisation of experimental responses through the modelling of the relationship between the inputs and outputs as a statistical and mathematical technique [19]. Other advantages of RSM are that it assists in obtaining predictive models, feasible range of the process parameters and enables the interactive study of the effect of process parameters on the response of the designed experiment. On the other hand, approach such as fractional factorials are conducted after the experiments have been screened to determine the combination of process parameters and runs that will affect the responses [20]. While in the full factorial design with two factors and four responses, the number of runs might be greater, resulting in many measurements, which leads to higher experimental cost [20]. For the experiment, two process parameters were considered namely; scan speed, which range between a minimum value of 500 to 2500 mm/sec and laser power, which ranges between a minimum values of 50 to 300 W as shown in Table 1.

Table 1. Process parameters.

Factors	Name	units	Low	High	Low coded	High coded	Mean	Std Dev.
A	Laser power	W	50.00	300.00	-1.000	1.000	180.357	84.610
B	Scanning speed	mm/s	500.00	2500.00	-1.000	1.000	1375.000	646.073

The selection of those two process parameters emerged from their impacts in obtaining better quality of the printed part at a reduced time. According to previous works from Aboulkhair *et al.* [21], Ponnusamy *et al.* [22], Siddique [16], the laser power has a significant influence on the energy delivered to irradiate the powder. Also, low laser power during printing of aluminium (Al) alloys prevents full melting of the material from melting completely. Thus, creating empty spaces on the printed part, which consequently lead to defects such as porosity, inhomogeneity of the structural and microstructural aspect of the part, hardness, density and surface roughness.

The scan speed is related to the rate at which the laser energy is dissipated onto the powder [23]. The choice of the process parameters range values of 50 to 300 W for the laser power and 500-2500mm/s for the scan speed stem from the investigated range studied by Louvis *et al.* [24], Aboulkhair et al. [9], Olakanmi *et al.* [13], and Rashid *et al.* [25] research works.

A number of 14 runs were obtained and replicated in a set of three samples per parameters for tensile testing as shown in

Table 2. Experimental parameters.

	Factors	
Run	A: laser power(W)	B: scan speed (mm/s)
1	175.00	1500.00
2	300.00	500.00
3	300.00	2500.00
4	50.00	500.00
5	50.00	2500.00
6	175.00	2000.00
7	175.00	1000.00
8	175.00	750.00
9	50.00	1500.00
10	150.00	1500.00
11	300.00	1500.00
12	175.00	500.00
13	200.00	1500.00
14	250.00	1500.00

2.2 Physical Experiment

The aim of the experiment was to investigate the effect of varying the laser power and scanning speed on the tensile strength of AlSi12 samples produced through SLM. Table 3 presents the AlSi12 powder composition with related percentage of each material.

Table 3. Powder composition.

Al	Mg	Si	Ca	Fe	K	Na
88.97	<0.01	11.8	0.05	0.17	0.03	0.07

The machine used to print the samples is the SLM Solution 280 Machine, which has a bi-directional powder recoating system and accommodates multi-material.

Fig. 1. SLM Solution 280 Machine (Metal Heart).

These parameters were loaded in the Magic software for slicing. The total printing time was 14 hours with constant hatching distance of 0.5 mm and variations of laser power and scanning speed (Tables 2 and 3). The layer thickness considered was 30 µm for accuracy. Upon completion of the parameters loading and setting on the machine, the printing started. Cylindrical specimens with a length of 80 mm and a diameter of 10 mm were produced as depicted in Figure 2.

Fig. 2. Cylindrical specimens produced.

3. Results and Discussion

The combination of experimental parameters resulted in successful and unsuccessful printed samples. The difference came from the physical structure of the cylindrical samples. Unsuccessful prints did not meet the expected solid structure from the computer-aided design (CAD) and produced a hollow structure as shown in Figure 3.
The first observation on the graph in Figure 4 indicates that a laser power at 50 W resulted in unsuccessful prints, whether the scan speed is low or high. This implies that a laser power from below 50 W is insufficient to melt the AlSi12 powder. On the other hand, the successful prints depict that the lowest considerable laser power value is 150 W. Based on the graph, the variations of the scan speed has less influence on the success of the prints. According to Louvis *et al.* [24], the laser high power combined with low speed produces a big melt pool that is difficult to regulate. This may result in defects and possible damage to the powder distribution system. Louvis *et al.* [24] further concluded that the AlSi12 requires a laser power of greater than 50 W to melt the powder.

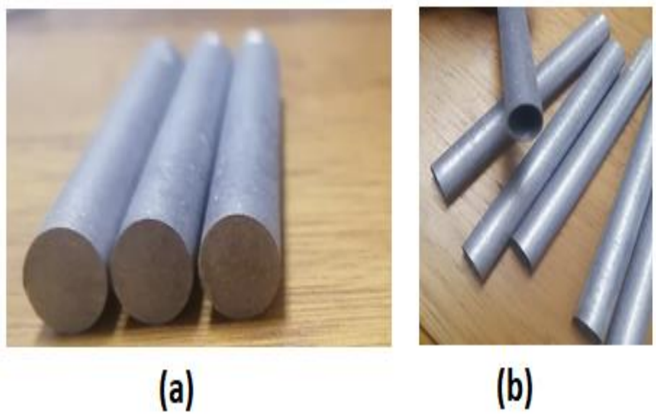

Fig. 3: (a) Successful; (b) unsuccessful.

The high power also increases the density with about 5% due to melting point of the aluminium. An increase in the magnitude of laser power beyond the optimum may result in the development of product with high surface roughness due to the low melting point of aluminium alloys. High surface roughness may affect the product's quality or its ability to meet its service or functional requirements [26]. In addition it may make the process less sustainable. This is because the power consumed during the manufacturing operation of aluminium alloy can enhance the sustainability of the manufacturing process in terms of carbon footprint, energy efficiency and environmental friendliness of the process [27]. The higher the power consumed, the less the sustainability of the manufacturing process and vice-versa.
On the other hand low scan speed produces roughness. Louvis *et al.* [24], study revealed that scan speeds between 100-200 mm/s present the highest relative densities. An increase in the magnitude of the scan speed beyond the optimum may also increase the magnitude of power requirement for the manufacturing process, thereby making the process less sustainable. Hence, this study provides a numerical approach validated via physical experimentations for obtaining optimum energy requirement that promotes sustainable manufacturing of aluminium alloys.

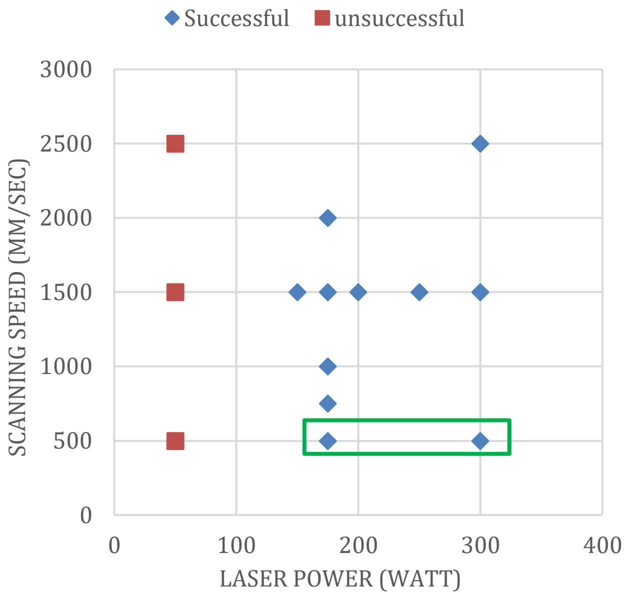

Fig. 4. Printing results.

4. Conclusion

The aim of this article was to study the impact of varying the scanning speed and laser power on the physical structure of AlSi12 specimens. To achieve this aim, the SLM process was used to print triplicate of 14 specimens. The selected range for the scan speeds was from 500-2500 mm/s and laser power from 50 to 300 W with scanning direction kept constant.
The result shown that a low scanning speed of 50W is likely to cause a build to fail, due to the laser power not fully melting the powder. Further concluding remarks can be drawn from this result:
The scanning speed is a major process parameter in determining the success of a print compared to laser power. The variation of laser power between 500- 2500 W yielded optimum range of the scanning speed. The preferable range for scanning speed is in the range of 150-300 mm/s.
This work has established the feasible range of process parameters for the SLM of AlSi12. However, further research needs to be done to optimise the process parameters to obtained exact magnitude of the process parameters. There is also a need to investigate the mechanical properties of the specimens to identify the right set of parameters that produced fully dense AlSi12 specimens.

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