Optimization of additive manufactured part made by Ti6Al4V alloy to achieve best relative density and surface roughness

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ABSTRACT

One the most popular Additive manufacturing (AM) technique called Laser Powder Bed Fusion (LB-PBF). Several parameters involved in this method and 4 of most important factors are Laser Power (LP), Scanning Speed (SS), Infill Pattern Angle (PA) and Hatch space (HS). Change in this parameter has a direct effect on defects and fabricated parts quality. Post processing treatment such as heat treatment cared out in order to improve part property and applications. Built time and costs reduce significantly by suitable choice of process parameters and post processing treatments. In this article Genetic Algorithm (GA) cared out to highest relative density and lowest surface roughness and best value of each parameter presented. The results shown that the best output could achieve by using of 102-105 Watt of laser power, 623-630 mm.s^{-1} scan speed, 73-76 μm of hatch space and 638-640 °C of heat treatment temperature.

KEYWORDS

Additive Manufacturing, Relative Density, Surface Roughness, Powder Bed Fusion, Genetic Algorithm.

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1. Introduction

Additive manufacturing (AM) also named rapid prototyping (RP) or 3D-Printing, is the method to fabricated part layer by layer, the first commercial AM machine works with ultra-violet ray introduce in 1987 called stereo lithography [1]. LB-PBF machines categorized according to size and application in 3 major category [2]. Ti6Al4V is suitable to fabricate implant and body parts due to the excellent mechanical properties, high strength to weight ratio and adaptability with human body [3]. The parts made by AM technologies are not error less, varus factors are corresponding to amount and types of defects in samples. Some of these defects seen in the surface and some of them are in the middle of part. Relative density (*RD*) is a good factor to determine fracture of defects in sample [4]. According to the Gibson et al. [5, 6] founding the most important factors in manufacturing Ti6Al4V alloy by LB-PBF method effective on relative density and surface roughness are: Laser power, Scanning speed, Hatch spacing and scanning pattern angle. Joango et al. [7] study the effects of heat treatment temperature on LB-PBF manufactured part made by Ti6Al4V alloy and found that mechanical properties improved by increasing heat treatment temperature, reducing defects and β to α phase transition due to heat treatment are correspond to this. In this research, multi-objective optimization Genetic algorithm (MO-GA) is carried out to determine the best process parameters and heat treatment temperature to maximize the relative density and minimize the surface roughness simultaneously.

2. Methodology

Gibson et al. [5, 6] used L25 Taguchi design of experiment (DoE) method to determine the relation between laser power, scan speed, hatch space, pattern angle and heat treatment temperature on surface roughness and relative density. Figure 1-A and b shown the mean value analysis relative density and surface roughness respectively according to their studies. In this research, Nondominated Sorting Genetic Algorithm II (NSGA-II) is carried out to obtain the situation corresponding to the best surface roughness and relative density according to the Gibson et al. results. The level set of parameters that leads to the best results and could be determined by the mean value analysis, but mean value analysis is a single target tool, multi-objective optimization algorithms are more effective tools to achieve two or more goals simultaneously.

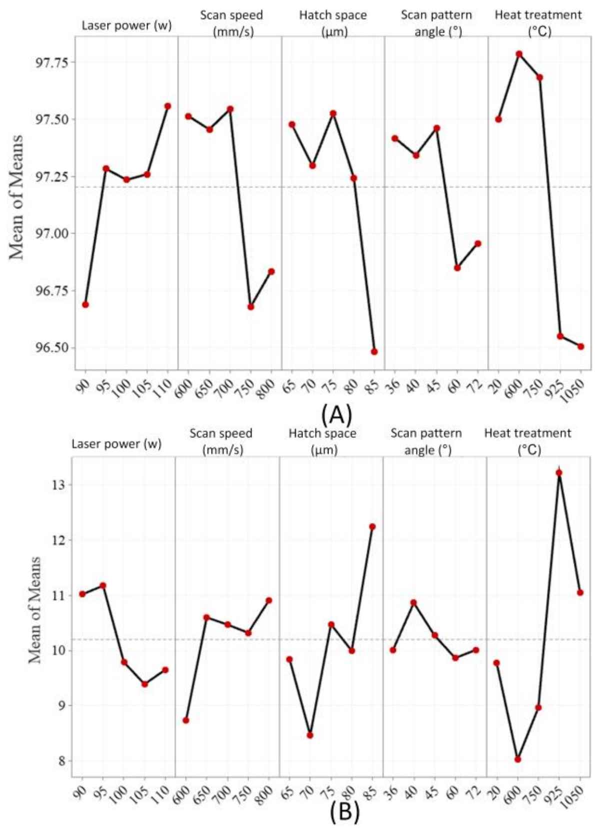

Figure 1. Taguchi Mean Analysis for optimization of (A) Relative density, and (B) Surface roughness, separately [5, 6].

GA procedure for finding best situation presented in Figure 2.

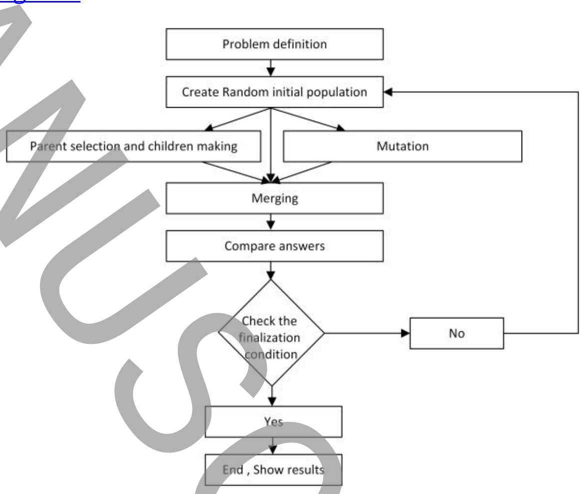

Figure 2. GA flow chart for the Optimization

3. Results and Discussions

Figure 3 Shows the Pareto front diagram as a result of optimization process. All the 50 points in this diagram could be considered as the best answer.

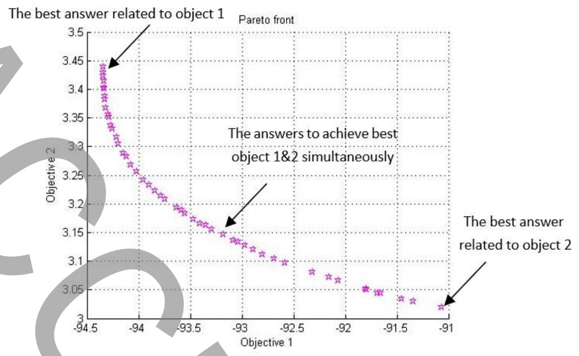

Figure 3. Pareto front formed by 50 best answers

LB-PBF manufacturing process divide to tow main category according to the laser penetration depth: key hole mode and conduction mode. The process parameter and influential parameter on melting pool temperature and size determine the mode of fabrication. Generally, conditions corresponding to low energy density leads to temperature decrease and reduction of melted region size (conduction mode), and increase in input energy density that leads to increase in melt region size (keyhole mode).

Increase energy density also affected on reducing surface tension so wettability and dispersibility of molted region increased, it leads to decrease Ra. Reducing energy density (by reducing laser power or increase scanning speed) leads to balling and residual powder particle defect on part. It leads to increase *Ra* and decrease *RD* [8]. Decrease in scan speed leads to reduction of balling and residual particles defects. Increase in scanning speeds also leads to increase cooling rate, higher cooling rate, leads to finer grain formation and according to Hall-Petch theory mechanical properties increased [9]. Increase in overlap (lower hatch space) leads to manufacturing time increase. It also affects the remelting region. Increase on remelting area leads to decrease in defects between the hatch directions. The maximum allowance value for hath space is equal to beam diameter, but because of Gaussian beam destitution, hatch space sets less than beam diameter. The acceptable range for hatch space is in the range of 60% to 80 % of beam diameter [10]. Heat treatment is performed as a complementary process on the parts. Increasing the temperature of heat treatment causes softening and reduces defects due to low energy density in non-melted particles.

4. Conclusion

In this research, genetic algorithm used in optimize the laser beam powder bed fusion process with respect to two objective functions of minimization surface roughness and maximization relative density.

The results presented by the genetic algorithm are in an acceptable and reasonable range. Based on the results, the best relative density and surface roughness correspond to the ranges of laser power of 102-to-105-Watt, laser speed of 623 to 630 mm/s, distance between two consecutive paths of 73 to 76 µm and the temperature of the heat treatment of 638 to 640°C. Heat treatment temperature is the most effective factor affecting surface roughness and relative density.

5. References

[1] P.J. Bártolo, I. Gibson, History of stereolithographic processes, in: Stereolithography, Springer, 2011, pp. 37-56.
[2] A. Khorasani, I. Gibson, J.K. Veetil, A.H. Ghasemi, A review of technological improvements in laser-based powder bed fusion of metal printers, International Journal of Advanced Manufacturing Technology, (2020).
[3] W. Harun, N. Manam, M. Kamariah, S. Sharif, A. Zulkifly, I. Ahmad, H. Miura, A review of powdered additive manufacturing techniques for Ti-6al-4v biomedical applications, Powder Technology, 331 (2018) 74-97.
[4] E. Hernández-Nava, C. Smith, F. Derguti, S. Tammas-Williams, F. Léonard, P. Withers, I. Todd, R. Goodall, The effect of density and feature size on mechanical properties of isostructural metallic foams produced by additive manufacturing, Acta Materialia, 85 (2015) 387-395.
[5] A.M. Khorasani, I. Gibson, A. Ghasemi, A. Ghaderi, A comprehensive study on variability of relative density in selective laser melting of Ti-6Al-4V, Virtual and Physical Prototyping, 14(4) (2019) 349-359.
[6] A.M. Khorasani, I. Gibson, A. Ghasemi, A. Ghaderi, Modelling of laser powder bed fusion process and analysing the effective parameters on surface characteristics of Ti-6Al-4V, International journal of mechanical sciences, 168 (2020) 105299.
[7] M.T. Jovanović, S. Tadić, S. Zec, Z. Mišković, I. Bobić, The effect of annealing temperatures and cooling rates on microstructure and mechanical properties of investment cast Ti–6Al–4V alloy, Materials & design, 27(3) (2006) 192-199.
[8] C. Qiu, C. Panwisawas, M. Ward, H.C. Basoalto, J.W. Brooks, M.M. Attallah, On the role of melt flow into the surface structure and porosity development during selective laser melting, Acta Materialia, 96 (2015) 72-79.
[9] A. Leicht, C.-H. Yu, V. Luzin, U. Klement, E. Hryha, Effect of scan rotation on the microstructure development and mechanical properties of 316L parts produced by laser powder bed fusion, Materials Characterization, 163 (2020) 110309.
[10] Y.-L. Lo, B.-Y. Liu, H.-C. Tran, Optimized hatch space selection in double-scanning track selective laser melting process, The International Journal of Advanced Manufacturing Technology, 105(7) (2019) 2989-3006.