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An Effect of DMLS Process Parameter on Surface Roughness And Dimensional Accuracy Of CL50WS Material

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Abstract **Direct metal laser sintering (DMLS) process used to make three-dimensional product or joining two elements without any tooling or human intervention from computer aided data (CAD) file. CL50WS material is hot work tool steel which widely used to make die and mould in tooling industries. DMLS widely accepted to manufactured die, mould and tooling insert in tooling industries. It can be made customized tooling insert, die and mould with cooling channel which is also known as conformal cooling. Die, mould or tooling insert are widely used in injection moulding industries which manufacture mass production of discrete parts for assembly or as final product. Thus, worse dimensional accuracy and surface roughness of die and mould affect number of parts or products that make huge losses to industries. Thus, dimensional accuracy and surface roughness of die or mould is very significant parameter for injection moulding industries. Hence, this study carried out for the same. In this study, the relationship between input parameters of DMLS (laser power, layer thickness, scan speed and hatch distance) and performance characteristic (Dimensional accuracy and Surface roughness) have been discussed. From study, it can be seen that Layer thickness and laser power are most affective parameter for mentioned characteristic. Empirical model for both characteristics have been developed for future prediction of DA and SR at outside range of process parameter. Optimum result has been determined by Response Surface methodology (RSM). The obtained result was validated and that optimum result have good agreement with performed regression result.**

Keywords— DMLS, sintering, Surface roughness, Dimensional Accuracy, ANOVA

I. INTRODUCTION

ASTM has defined additive manufacturing (AM) as ‘‘a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies. Synonyms: additive fabrication, additive processes, additive techniques, additive layer manufacturing, layer manufacturing, and Freeform fabrication [1]. The main aim of this review paper is to provide research gap between existing research and lacking of research in additive manufacturing techniques. Also, this paper provides ample knowledge related materials which utilize on specific AM process and review about recent trends and challenges which has been facing by conventional tooling industries. Additive manufacturing (AM) which is also recognized as Rapid Prototyping (RP) is manufactured 3 dimensional products or parts directly from CAD sources without using any tooling or human interference. RP has the ability to fabricate complex and intricate geometric shape of parts or product. Accuracy of the geometric complex shape of parts compares to conventional process are superior. Also, conventional process required number of operation and resources which increase lead time of production, cost and machining time of product [2]. These hurdles have been overcome by the RP method which can produce product directly from CAD file, and can use as pattern, final end user parts or as a functional unit. As per benefits of AM technology, aerospace industries promoting these techniques to produce aerospace parts from titanium alloy and nickel based alloys which widely used in aerospace components like blades or airfoils of various vanes and cases. Unlike conventional manufacturing, AM has not been wasting material to give the shape of parts, utilizing 100% material through non consumed powder material recycle [3].

M. Benedetti et al. [4] have measured surface roughness and they revealed that surface roughness has drasticllay reduced by carried out post treatment. Avi Leon et al. [5] have seen that corrosion resistance and corrosion fatigue life span of the SLM build specimen after polishing Similarly, research has been explored by Bandar AlMangour et al. [6]. They have showed

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the effect of shot peening on surface roughness and concluded that low-cost shot-peening treatment is a very effective to reduce the surface roughness of an untreated, as-built SLM sample. Surface roughness unpolished samples due to presence of cavities and pores. Cavities and pore have induced localized corrosion attack in the form of pitting caused creates a large number of crack initiation in parts. This, crack initiation and crack propagation induced corrosion fatigue failure of AlSi10Mg alloy [5]. P. Mengucci et al. [7] have measured the average value of the surface roughness Ra was 6.69 µm for Ti-6Al-4V material. As a result, they have suggested that surface roughness independent of orientation. G. Casalino et al. [8] have shown that the energy density increase from 1.29 J/mm2 to 2.78 J/mm2, the SR decreases from 22 µm to 15µm. They have suggested that good surface finish achieved at a high laser power and a low scanning speed because of it produced a high-energy density, which resulted in an effective melting of the particles. Yuwei Zhai et al. [9] have compared Laser Engineered Net Shaping (LENS) and Electron Beam Melting (EBM) to fabricated Ti-6Al-4V material for surface roughness. They have showed that LENS give high surface roughness due to high laser power. Evren yasa et al., [10] have suggested that the large inclination angle during printing of parts which carries to reduce waviness of DMLS parts. The average value of the roughness (Ra) was 2.2 µm for Co-Cr-Mo-W alloy after heat treatment [7]. Yasa E. et al. [11] varied layer thickness to measured surface roughness for CL50WS material.

Dimensional accuracy of SLS/SLM build parts depends on the ability to control warpage and shrinkage. Nelson et al. used a numerical model to solve the thermal equilibrium of SLS and investigated the effects of the process parameters on the temperature distribution in the part. Sharanjit Singh et al. [12] used central composition design of response surface methodology to investigate the effect of process parameter on shrinkage polyamide material. They concluded that the scan spacing is the most significant parameter for shrinkage. Ali Ahmadi et al., [13] had presented an optimization algorithm to find the best processing parameters for minimizing warpage. Similarly, Y. Ning et al. [14] have performed experiment to effect of hatch length and building direction on dimensional accuracy. They had showed that shorter length part results in a greater shrinkage. Shrinkage becomes steady with increased length (i.e 0.8 per cent). These studies provide only effect of parameters on shrinkage of polymer material. However, it does not include any discussion or cause of shrinkage. Moreover, it does not include effect of more parameter on metal material or tooling material. Yujia Wang et al. [15] have investigated sintering parameters on the dimensional accuracy of the binder jetting process for SS316 material. They have varied sintering temperature (1010 ^{0}C,1100 ^{0}C and 1190^{0}C), heating rate (4^{0}C/min, 12^{0}C/min and 20^{0}C/min) and sintering time (60 min, 90min and 120 min) using Taguchi L9 methods for shrinkage rate. It has been seen that sintering temperature are playing important role in shrinkage rate of all axes of parts. They have been suggested optimal parameters (1100 degree, heating rate of 12 degrees/min and sintering time for 60 minutes) for lowest shrinkage rate of SS316L material. Casalino et al. [8] have shown that porosities of part's increase with increasing scan speed (400 or 600 mm/s) which exert a worse effect on mechanical properties of maraging steel [14].

Form literature review, it has been seen that several researches have been done on surface roughness and dimensional accuracy for titanium and stainless-steel material. Also, stainless steel has possessed higher carbon percentage which promote more corrosion and cracking behaviour during printing of material in 3D printing. CL50WS is best alternative of stainless steel and other tooling material like P20 and H13 steel. CL50WS material possess higher strength with less carbon percentage which make more suitable for die and tool industries. Nowadays, conformal cooling in die and mould is very new application of AM in tooling industries. Due to conformal cooling temperature distribution in die or mould is uniform and make part with less warpage and accurate. However, CL50WS- hot tool steel has not been addressed properly in previous literature. Also, it has been seen that DMLS process parameters has not been optimized properly for hot tool steel material. Hence, it is very essential to carried out study for dimensional accuracy and surface roughness of DMLS made specimen. In this direction, research have explored to full fill the requirement of tooling industries.

II. EXPERIMENTAL DETAILS

CL50WS material offers an attractive alternative of high carbon tool steel, as it is not suffering from corrosion or cracking problem as it possesses high nickel content and less carbon content, which provides good corrosion resistance and wear resistance (Yasa E. et al.,2010). The chemical composition of CL50WS material is shown in Table1.

The base material in the present research work is CL50WS in the form of powder material manufactured by German based concept Laser Company (Concept laser). The set-up consists of an ytterbium (Yb) fiber laser system (peak power 200 W) and an inert gas chamber. Specimens were manufactured on Concept laser M1 cusing machine. The laser beam was focused directly on the substrate surface to a spot size of 300 µm. The working chamber provided a closed environment that was filled with nitrogen as a protective gas to maintain an oxygen concentration of 1.8 %.

Table 1 Chemical composition (wt.%) of base materials

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Material	carbon	sulphur	Phosphorous	Manganese	Nickle	Chromium	Molybedenum	Copper
CL 50 WS	0.03	0.010	0.010	0.15	17 - 19	0.25	4.50 – 5.20	8.50 – 10.0

2.1 Plan of experiment

Design of experiment gives a systematic approach to carry out research experiments to determine the best combination of input parameters for achieving desirable solution for research characteristic. Box-Behnken design is popular experimental design technique used to optimize the process parameters [SemraKirboga et al., 2013]. In this study, 27 specimens of CL50WS material were fabricated with various combinations of process parameters for optimization. Three levels of four parameters namely laser power, layer thickness, hatches distance and scan speed were chosen. Three-level design of Box and Behnken (1960) method was used. The levels of parameters and plan of experiment used in this research is shown in table 2 and table 3 respectively.

Table 2 Levels of process parameters

Sr no	Process parameter	unit	Level 1	Level 2	Level 3
1	Laser power	Watt	110	120	130
2	Scanning speed	mm/s	550	600	650
3	Layer thickness	mm	0.03	0.04	0.05
4	Hatch distance	mm	0.01	0.015	0.02

Table 3 Plan of experiment

Sr no.	Laser power (W)	Scan speed (mm/s)	Layer thickness (mm)	Hatch distance (mm)	Lateral SR	Relative Depth
1	110	550	0.04	0.015	6.7870	0.0900
2	130	550	0.04	0.015	7.0129	0.1230
3	110	650	0.04	0.015	12.4900	-0.0500
4	130	650	0.04	0.015	7.1240	0.0625
5	120	600	0.03	0.010	6.2526	0.0065
6	120	600	0.05	0.010	10.3350	-0.0075
7	120	600	0.03	0.020	7.0906	0.0515
8	120	600	0.05	0.020	13.6540	0.1275
9	110	600	0.04	0.010	6.0890	0.0100
10	130	600	0.04	0.010	6.6540	0.0510
11	110	600	0.04	0.020	8.3630	0.1425
12	130	600	0.04	0.020	8.4887	0.1010
13	120	550	0.03	0.015	7.1110	0.0250
14	120	650	0.03	0.015	8.4310	0.0100
15	120	550	0.05	0.015	11.2320	0.1230
16	120	650	0.05	0.015	12.8290	0.1375
17	110	600	0.03	0.015	9.6980	0.0250
18	130	600	0.03	0.015	8.2320	0.0230
19	110	600	0.05	0.015	13.5160	0.0160
20	130	600	0.05	0.015	8.7830	0.1055
21	120	550	0.04	0.010	7.0860	0.0625
22	120	650	0.04	0.010	7.9630	0.0065
23	120	550	0.04	0.020	9.8370	0.1275
24	120	650	0.04	0.020	10.6450	0.0875
25	120	600	0.04	0.015	8.9850	0.0900
26	120	600	0.04	0.015	8.4850	0.0610
27	120	600	0.04	0.015	9.1290	0.0600

2.2 Response Surface Methodology (RSM)

RSM consists of a set of mathematical and statistical techniques to develop a functional relationship between a response of interest, y, and a number of associated control (or input, or explanatory) variables, x1, x2,. . ., xk.. RSM suggested second order degree polynomials to approximate the relationships, although there are other functional forms to apply RSM.

$Y = \beta 0 + \sum_{i=1}^{k} \sum_{i=1}^{k} \beta i x i + \sum_{i=1}^{k} \beta i i x i 2 + \sum i \sum_{j} \beta i j x i x j$ + e for i < j

where βi are calculated using the method of least squares from experimental data of average surface roughness as response. **(**Eusebio J. **et al.,2017).**

2.3 Response measurement

The surface roughness tests were carried out using surface Mitutoyo roughness tester Model: SJ201. For each specimen surface roughness was measured at the three different points on lateral surface and the average value of each of them was treated as a surface roughness value of the specimen. Similar, three experiment value has taken per sample for depth and angle of specimen.

III. RESULT AND DISCUSSION

3.1.1Effect of Process parameter on Surface Roughness

Fig. 2, is showing the main effect plots of surface roughness for lateral surface, it can be seen that parameters at level A3, B1, C1 and D1 give minimum surface roughness. Based on the experiments, correlation plot between process parameter and responses were established. According to fig. 2, it can be seen that increase in laser power decreases the surface roughness. But, at the same time increase of scan speed, hatch distance and layer thickness induce more surface roughness. Also, it is seen that effect of layer thickness on surface roughness is high compared to other parameters. Hatch distance and laser power have similar effect on surface roughness. Thus, layer thickness, hatch distance and scan speed should be kept lower and laser power must be kept high. The second order regression empirical model has established, in order to predict the surface roughness for high range of process parameters.

The use of a high laser power induces a high-energy density, which provide a proper melting of powder particle rapidly and exert low surface roughness. Thus, higher laser power attributes to lower surface roughness (G. casalino et al.,2015) Keeping lower layer thickness spreads less amount of powder which require less effort to melt it, otherwise considerable amount of time would be required to melt layer of high layer thickness which subsequently increase the residual stress and warpage of parts. It is also observed that distortion of a part is attributed to high layer thickness. So, it can be said that lower

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layer thickness is very beneficial for surface roughness and for reduction of part distortion or warpage. Also, high laser power and low surface roughness produce martensitic microstructure which gives dense structure.

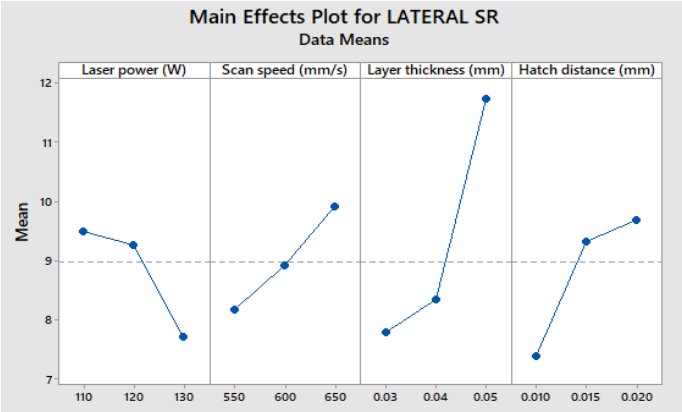

Fig. 2 main effect plot of Lateral Surface roughness

Table 4 analysis variance for Lateral surface roughness

Source	DF	Adj SS	Adj MS	F-value	P-value
Laser Power (W)	2	15.219	7.6095	26.48	0.000
Scan speed (mm/s)	2	11.571	5.7855	20.14	0.000
Layer thickness (mm)	2	27.473	13.7365	47.81	0.000
Hatch distance (mm)	2	15.918	7.959	27.70	0.000
Laser power (W)*Scan speed (mm/s)	4	14.274	7.137	12.42	0.001
Laser power (W)*Layer thickness (mm)	4	15.823	7.9115	13.77	0.000
Error	10	2.873	1.4365		
Lack of fit	8	2.645	1.3225	2.89	0.282
Pure error	2	0.228	0.114		
Total	26	127.289			
S	R-sq	R-sq(adj)			
0.536014	97. 74%	94.13%			

Hatch distance provides space to relieve air bubble from improper melting and fusion which exists during previous track. Hence, annealing effect is provided by hatch distance. High overlapping induces adverse effect on microstructure by developing more martensitic phase, because particles may get burnt and change the texture effect of the part and may induce brittle effect in part (YuweiZhai et al., 2016). The martensitic phase develops rougher surface because of uneven cooling rate. Overheating and re melting causes high surface roughness. Higher scan speed cannot provide enough time to melt and fuse the particle so the surface roughness of part diminishes. Laser should be given enough time to melt and fuse particle necessary for slow cooling rate to track, hence low scan speed provides better surface roughness.

3.1.2 Effect of Process parameter on shrinkage rate

Fig.3, is showing the main effect plots, it can be seen that parameters at level A1, B3, C1 and D1 give minimum Shrinkage rate in depth. According to fig. 3, it can be seen that increase in laser power, hatch distance and layer thickness increase in the shrinkage rate. But, at the same time increase of scan speed reduce shrinkage rate. Also, it is seen that effect of hatch distance is high compared to other parameters. Layer thickness and laser power have similar effect on shrinkage rate. Thus, laser power, hatch distance and layer thickness should be kept lower and scan speed must be kept high. The second order regression empirical model has established, in order to predict the shrinkage rate for depth for out of range of process parameters.

Analysis of variance table was established through set confidence level 95%. Hence, significance level is achieved for p-values below 0.05. In both ANOVA tables, R-Squared values are more than 90%, which indicate that model accuracy is high. From ANOVA table 5, it is observed that hatch distance has the highest effect on shrinkage.

Table 5 analysis variance for Relative change in depth

Source	DF	Adj SS	Adj MS	F value	P-value
Laser Power (W)	2	0.00867	0.004338	4.68	0.037
Scan speed (mm/s)	2	0.012035	0.006018	6.49	0.016
Layer thickness (mm)	2	0.008070	0.004035	4.35	0.044
Hatch distance (mm)	2	0.022308	0.011154	12.02	0.002
Laser power (W)*Scan speed (mm/s)	4	0.10521	0.002630	2.83	0.053
Laser power (W)*Layer thickness (mm)	4	0.005225	0.001306	1.41	0.300
Error	10	0.009278	0.000928		
Lack of fit	8	0.008698	0.001087	3.74	0.228
Pure error	2	0.000581	0.000290		
Total	26	0.069388			
S	R-sq	R-sq(adj)			
0.536014	86.63%	65.23%			

Hatch distance has significant effect on shrinkage rate because of hatching distance provide remelting of powder layer. During high remelting, it produces high thermal gradient which having high cooling rate, thus it produces more shrinkage. Hence, lower hatch distance in terms of lower remelting of powder layer gives small thermal gradient owing to reduce thermal stress and warpage in parts. In this study, remelting range of layer from 0.010 mm to 0.020 mm, gives drastic difference in

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shrinkage rate. Similarly, layer thickness keep lower because high layer thickness gives thick layer of powder that can be difficulted to melted and sintering whole. Laser power has also limitation to melt and fuse particle within very short time. Hence, thin layer can be easily melt and fuse and have uniform temperature gradient which give lower shrinkage rate.

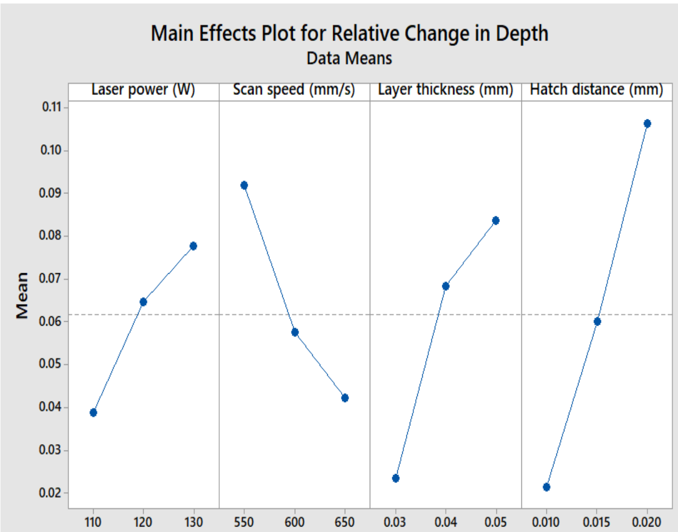

Fig. 3 main effect plot of Relative change in depth

Scan speed has diverse effect on shrinkage rate because of high scan speed exerts small thermal gradient cause cooling rate are slower compared to lower scan speed. Thus, it has been provided less shrinkage rate in higher scanning speed.

3.3 Regression analysis

Based on the experimental data for surface roughness, the second order linear regression equation was developed using Minitab17. Regression analysis using least square method was used to empirical model a relation between the input parameters and the response. The significance of terms in each equation, as well as the significance of the model and of the lack of fit, was evaluated using analysis of variance.
The empirical equation came out to be:

*LATERAL SR = -236 + 1.948 A + 0.348 B + 907 C + 37 D - 0.00280 A*B - 8.17 A*C - 2.2 A*D + 0.14 B*C - 0.07 B*D + 12405 C*D*

Relative Change in Depth = 3.86 - 0.0249 A -0.00610 B - 40.0 C + 30.4 D + 0.000040 A*B + 0.229 A*C - 0.412 A*D + 0.0147 B*C + 0.0160 B*D + 450 C*D

Where; A= laser power; B=scanning speed; C=Layer thickness and D= Hatch distance

3.4. Response surface methodology

Response surface methodology (RSM) is efficient tool to find out desirable response value at range between choose parameters ranges. Basically, it is not possibe to find response value at every point of parameters.

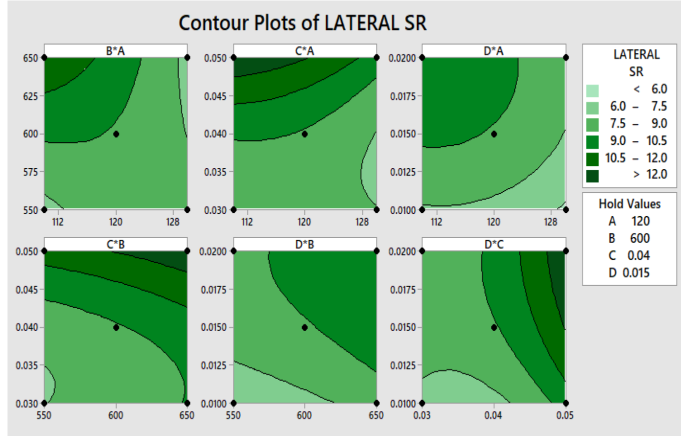

Fig. 5 Interaction contour plot lateral surface roughness Vs. Process parameters

The interaction effect of the process parameters using contour plot by keeping two parameter constants while the other two process parameter are varying within the range of value. For the given contour plots was generated so as to obtain the optimum operating design space in the given range of parameters. The hold values of the remaining two parameter in each case were chosen on the basis of optimality analysis. Fig. 5 (a), shows the contour plotted for Surface roughness as response with laser power and scan speed as variable. It can be said that surface roughness gets while laser power keep lower than 112watt and scan speed kept lower than 540 mm/sec. From the fig. 5 (c), it can be seen that surface roughness gets very lower while laser power increase more than 128 Watt and 0.010 mm hatch distance is recommended. From the fig. (e), it can said that surface roughness decreases with decreasing layer thickness and hatch distance.

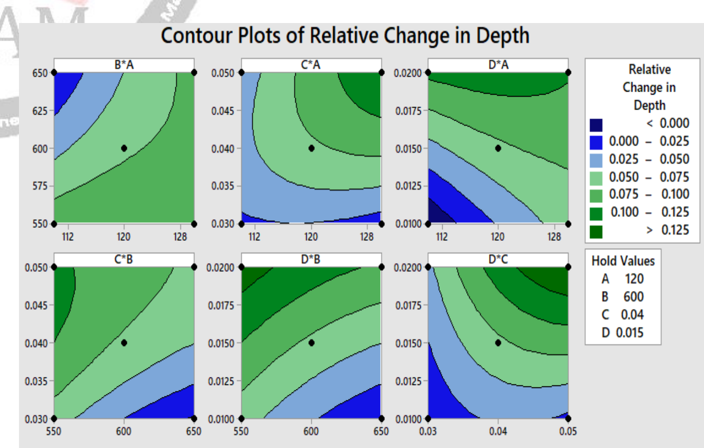

Fig. 6 Interaction contour plot of shrinkage rate Vs. process parameter

Fig. 6 displays contour plot for relative change in depth vs DMLS process parameters. Fig.6 (b), it can be seen that shrinkage rate increases rapidly if layer thickness increase and laser power kept between 115 to 121 Watt. The plot tells that layer thickness keep 0.030 mm to 0.032 mm in range and laser power keep high at 130 Watt which give lower shrinkage rate. Fig. 6(c) depicts that hatch distance should keep minimum and

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laser power keeps less than 110 Watt. Both these results are occurring interrelated conflict. Hence response surface optimizer give one global solution for desirable value.

Large number of conflicting factors and complex process parameter in DMLS process making it difficult to predict the response characteristics based on simple analysis of factor variations. Hence, to determine the optimal setting of process parameters that will minimize the **surface roughness and shrinkage rate** with the use of response optimizer in response surface methodology shown in table 6.

Table 6 Response optimization surface roughness Parameters

Response	Goal	Optimal condition	RSM predicated
Surface roughness	Minimize	Laser Power: 119.272 Watt Scan speed: 650 mm/s Layer thickness:0.03 mm Hatch distance: 0.01 mm	7.4066 µm
Relative change in depth (Shrinkage rate)	Minimize		-0.02699

The response optimization table obtained is shown in table 6. It tell that optimal condition of parameter value setting with laser power 119.272 Watt, scan speed 650 mm/s, layer thickness 0.03 mm and hatch distance 0.01mm. For validation of the obtained above results, a validation experiment was performed, with the optimal input parameter levels as obtained from the analysis. The actual value of surface roughness and shrinkage rate from the experiment came out to be 6. 987 µm and 0.0325 respectively. So, the RSM model used for the analysis of the process predicted the optimum outcome with an error of about 5.66% and 16.2 % respectively of the experimental value which is acceptable for prediction.

IV. CONCLUSION

The end user can directly use the optimal process parameters to make parts on DMLS process. The main effect plot and ANOVA table shows that the surface quality and shrinkage rate is mainly dependent on layer thickness. RSM suggest that the surface roughness and relative change in depth are minimum at intermediate laser power and high scan speed. Moreover, high laser energy density produces homogeneous structure which exert high mechanical property. However, too much high laser energy density creates more residual stress gives warpage and cracking in part, and reduce ductility. Also, too much less laser energy density leads formations of defects like porosity, micro crack and less in strength. Thus, it is very essential to use optimum process parameters for the better result.

From the RSM optimal condition of parameter value setting with laser power 119.272 Watt, scan speed 650 mm/s, layer thickness 0.03 mm and hatch distance 0.01mm gives optimum surface roughness and shrinkage rate.

REFERENCES

[1] William E. Frazier "*Metal Additive Manufacturing: A Review*" JMEPEG (2014) 23:1917–1928

[2] Yujia Wang and Yaoyao Fiona Zhao "*Investigation of Sintering Shrinkage in Binder Jetting Additive Manufacturing Process*" in journal of Procedia Manufacturing 10 (2017) 779 – 790.

[3] L. C. Ardila, F. Garciandia, J. B. González-Díaz, P. Álvarez, A. Echeverria,M.M. Petite, R. Deffley, and J. Ochoa "*Effect of IN718 recycled powder reuse on properties of parts manufactured by means of Selective Laser Melting*" in journal of Physics Procedia 56 (2014) 99 – 107.

[4] M. Benedettia,, E. Torresani, M. Leoni, V. Fontanari, M. Bandini, C. Pederzolli, C. Potrich "*The effect of post-sintering treatments on the fatigue and biological behavior of Ti-6Al-4V ELI parts made by selective laser melting*" Journal of the mechanical behavior of biomedical materials 71 (2017) 295–306

[5] Avi Leon and Eli Aghion "*Effect of surface roughness on corrosion fatigue performance of AlSi10Mg alloy produced by Selective Laser Melting (SLM)*" in journal of Materials Characterization (2017).

[6] Bandar AlMangour and Jenn-Ming Yang "*Improving the surface quality and mechanical properties by shot-peening of 17-4 stainless steel fabricated by additive manufacturing*" In journal of material and design in 2016.

[7] P. Mengucci, A. Gatto, E. Bassoli, L. Denti, F. Fiori, E. Girardin, P. Bastianoni, B. Rutkowski, A. Czyrska-Filemonowicz and G. Barucca "*Effects of build orientation and element partitioning on microstructure and mechanical properties of biomedical Ti-6Al-4V alloy produced by laser sintering*" Journal of the mechanical behavior of biomedical materials 71 (2017) 1–9.

[8] G. Casalino, S.L. Campanelli, N. Contuzzi, A.D. Ludovico "*Experimental investigation and statistical optimisation of the selective laser melting process of a maraging steel*" Optics & Laser Technology 65 (2015) 151–158.

[9] Yuwei Zhai, Haize Galarraga and Diana A. Lados "*Microstructure, static properties, and fatigue crack growth mechanisms in Ti-6Al-4V fabricated by additive manufacturing: LENS and EBM*" journal of Engineering Failure Analysis 2923.

 DOI : 10.18231/2454-9150.2017.0054

ISSN : 2454-9150 Vol-03, Issue-09, Dec 2017

[10] Evren yasa, Ozgur Poyraz, Ezgi Ugur, Guray Akbulur and soner oren "*A study on the stair stepping effect in direct metal laser sintering of a nickel based superalloy*" Procedia CIRP 45(2016) 175 – 178 (3rd CIRP conference on Surface Intefrity).

[11] Yasa E., Kempen K and Kruth J.P. "*Microstructure and mechanical properties of maraging steel 300 after selective laser melting*"

[12] Sharanjit Singh, Vishal S. Sharma and Anish Sachdeva *Optimization and analysis of shrinkage in selective laser sintered polyamide parts*," Materials and manufacturing Processes, vol. 27, no. 6, pp. 707-714, 2012.

[13] Ali Ahmadi, Mohammad R. Movahhedy and Javad Akbari "*Optimization of process parameters for reducing warpage in selected laser sintering of polymer parts*" in journal of Additive manufacturing in year ,2017.

[14] Y Ning, Y S Wong, and J Y H Fuh "*Effect and control of hatch length on material properties in the direct metal laser sintering process*" Department of Mechanical Engineering, National University of Singapore, Singapore.

[15] Yujia Wang and Yaoyao Fiona Zhao "*Investigation of Sintering Shrinkage in Binder Jetting Additive Manufacturing Process*" in journal of Procedia Manufacturing 10 (2017) 779 – 790.

[16] J.A.M. Ferreira, L.M.S. Santos, J. Da Silva, J.M. Costa and C. Capela "*Assessment of the fatigue life on functional hybrid laser sintering steel components*" Procedia Structural Integrity 1 (2016) 126–133.

[17] Semra Kirboga, Mualla Öner "*Application of experimental design for the precipitation of calcium carbonate in the presence of biopolymer*" Powder Technology 249 (2013) 95–104.

[18] Eusebio J. Martinez-Conesa , Jose A. Egea, Valentin Miguel, Carlos Toledo and Jose L. Meseguer-Valdenebro "*Optimization of geometric parameters in a welded joint through response surface methodology*" in journal of Construction and Building Materials 154 (2017) 105–114.

[19] Yuwei Zhai, Haize Galarraga and Diana A. Lados "*Microstructure, static properties, and fatigue crack growth mechanisms in Ti-6Al-4V fabricated by additive manufacturing: LENS and EBM*" journal of Engineering Failure Analysis 2923.

 DOI : 10.18231/2454-9150.2017.0054