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AN EFFECT OF PROCESS PARAMETER OF DIRECT METAL LASER SINTERING (DMLS) PROCESS ON DIMENSIONAL ACCURACY

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Abstract

Productivity, lead time and quality of injection moulding product in plastic industries have been relied on cooling system which provided in die. Nowadays, conformal cooling in die through additive manufacturing emerges new era. In conformal cooling system that provides uniform temperature distribution through entire surface of mould. Direct metal laser sintering (DMLS) have been manufacturing metal prototypes and tools directly from computer aided design (CAD) data without use of any human intervening or tooling. Dimensional accuracy of any product or parts play very vital role in success of it, also it is affected the quality of the die or mould in tooling industries, especially when die manufactures with conformal cooling by DMLS. So it is necessary to check dimensional accuracy of die which are made from DMLS. In this research, the relationship between dimensional accuracy and input parameter like orientation and layer thickness in DMLS have been investigated. Layer thickness was most prominent factor to affecting dimensional accuracy. Regression equation for predicting dimensional accuracy of X, Y and Z directions through regression analysis. Optimum determined result was validated and that optimum result have good agreement with performed regression result.

Keywords: DMLS, sintering, Dimensional Accuracy, ANOVA

1 Introduction:

Direct metal laser sintering (DMLS) is emerging technology among various Rapid prototyping methods. However, Direct metal laser sintering process can able to produce metallic parts from various metallic powder which can be used as functional unit or as end user application or as tooling purpose. It is fast growing technology for direct production of metallic parts or tool from CAD sources. [Jae-Ho Lee, 2009]. Nowadays, neck cut competition running between industries and also demands from customer like high quality parts, higher efficiency with having fewer prices which is very challengeable for industries. Many industries are shifting on recyclic of materials and make product with good quality so it can be produce parts or product at less price.

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Industries uses rapid prototyping technology to make prototype and models which use for visualization and functional part. [L.M. Galantucci] complexities of product are increasing day by day, hence several industries are focusing on RP methods which full fill demand of industries. Recently, RP having great demand of improvement of their specification, size and accuracy for fulfill the requirement of industries. [L.M. Galantucci, 2009]

2 Background

Ahmed Hussein et all (2013) worked on advance lattice structure for Additive manufacturing process. They suggested that manufacturing of complex parts, cost and build time has greatly affected by part's design and selection of support structure. Low vol. Fraction and Lattice structure can affect the design and manufacturing. They have carried out experiments through DMLS by using titanium alloy Ti6Al4V powder. It can be seen that the type of structure, volume fraction and cell size are the main factors influencing the manufacturability, amount of support, and built time of lattice support structures. Lattice supports with very low volume fraction up to 8% were built, saving significant amount of materials used in the support while reducing built time of making Additive manufacture parts.

Luigi Ventola (2014) investigated on artificially roughness for heat sink. They found that peak of 73% for the convective heat transfer enhancement (63% on average) compared to smooth surfaces. On rough (single) finned surfaces, the best performance is found to be 40% (35% on average) compared to smooth finned surface. Subrata Kumar Ghosh (2011) carried out experiment to varied size and volume fraction of SiCp to analyze the crack and wear behaviour of the composite. Their study has suggested that crack density increases significantly after 15 volume percentage (vol.%) of SiCp, and also suggested that when size (mesh) of reinforcement increases, wear resistance of the composite drops. T.J. Gill shown that effects of parameter changes are related to the initial powder blend composition and energy density, with lower polyamide content resulting in greater sensitivity to processParameters.Francis. E.H. Tay et all (2002) investigated to improve the surface quality of the rapid tooling produced by DMLS technique to an industrial acceptance level. Electroless nickel (EN) plating and semi-bright nickel electroplating have been chosen for their unique characteristics while they are applied either alone or combined with each other to achieve the best possible results. Shafaqat Siddiqueet all(2015) have obtained tensile strength and yield strength values four times that of sand-cast alloy and twice the corresponding properties of die-cast alloy. The increase in strength is result of fine microstructure achieved by high cooling rate in the process. Yield strength still higher than those of cast alloys was obtained by reducing the energy density to 50%, thus doubling the build rate. Generally, for manufacturing of mold inserts the dimensional accuracy and surface quality are of special concern. Experiments showed that the shrinkage of the developed material during laser sintering is nearly zero. However, the heat-affected zone (HAZ) of the laser beam on the boundary of the part generates some dimensional offset. Therefore, pre-contouring and post-contouring techniques were used to decrease the HAZ and thus improving dimensional accuracy (A. Simchiet all, 2003). It has been revealed that increases in the hatch space reduces the total scan distance and hence reduce the build time. It has been observed that change in layer thickness had no effect on the efficiency (S.H. Choi,2002). H.H. Zhu (2003) investigated on direct laser sintering Cu-based metal powder. It has been seen that Infiltration of epoxy can improve density but is unable to increase the hardness. Surface finishing of the infiltrated parts is better than those without infiltration. For tissue engineering, the control over mechanical properties and degradation behavior of sintered scaffolds is important. These properties are affected by the biodegradable materials used, scaffold design, and optimization of SLS parameters (Duanet all 2011).The overall surface quality of SLS parts is influenced by decreasing slice thickness, and improving material properties. Due to stair-steps and shrinkage, surface finishing on SLS parts is needed. The overall surface quality of SLS parts can be improved using a robotic finishing system. Because the robotic finishing paths are generated from the original CAD model data, the finishing process can eliminate the influences of stair-steps and shrinkage in the finished parts. (Keshavamurthy.Y.Cet all)

Many researchers concentrated on studying the surface quality and wear rate in various RP methods. No attempt appears to be made in author's knowledge for studying effect of process parameters on dimensional accuracy for Direct metal laser sintering process which is a major cause of sustainability of DMLS process. Therefore, the present work aims on finding out the effect of parameters namely orientation and layer thickness on dimensional accuracy for better accuracy.

In this study, TaguchiL8 method has been adopted for experimental work. Dimensional accuracy of specimen build by DMLS was measured by Percentage difference in the dimensions of CAD model and fabricated prototype along X, Y and Z-axes. Signal noise ratio and analysis of variance were implemented to analyze the main effects on accuracy and to obtain the optimum parameter for maximum accuracy. Regressions equation of dimensional accuracy along X, Y and Z-axes were generated to predicted linear dimension for future work by varying layer thickness and orientation.

3 Material and Method

3.1 Material Powder

The base materials procured in present research work was CL50WS (Concept laser, German based company, grade 50 and work steel) is a powder material. CL50WS is a powder material for manufactured by German based concept Laser Company. Generally, CL50WS material widely used in tooling industries which is highly heat treated and great hardness and impact strength. This

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material have been used for manufacturing die, mold and extrusion die for tooling work. Recently, conformal cooling emerges wide scope in tooling industries. This conformal cooling die can be used where need uniform temperature distribution. Furthermore, the CL50WS material have been used by DMLS which generally can manufacture functional unit. Chemical composition of CL 50WS shown in table 1.

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

Material	carbon	sulphur	Phosphorous	Manganese	Nickle	Chromium	Molybedenum	Cobalt
CL 50 WS	0.038	0.001	0.006	0.096	18.00	0.080	5.050	9.250

3.2 Range of process parameter

Design of experiment give systematic approach to carried out research experiments to determine best combination of input parameters for achieving best or desirable solution for research characteristic. Taguchi is also part of design of experiment, it can be very flexible design related to design parameter and its level. In this study, orientation has two level and layer thickness has four level. So Taguchi suggested L8 orthogonal array best for this parameters and levels. Taguchi can reduce number experiment runs so ultimately it reduce research time and development cost by simultaneously studying a large number of parameters. Range of Process parameters and fixed parameters were used in this research shown in table 2 and table 3 respectively.

Table 2: Range of process parameters – Taguchi L8

Process parameter	Level 1	Level2	Level3	Level4
Build orientation [degree °]	0^0	90^0		
Layer thickness [mm]	0.030	0.04	0.05	0.06

Table 3: Fixed parameters

Sr no.	Parameter	Value
1	Powder Material	CL50
2	Scan speed	600 mm/s
3	Laser power	120 W
4	Hatch distance	0.7 * d

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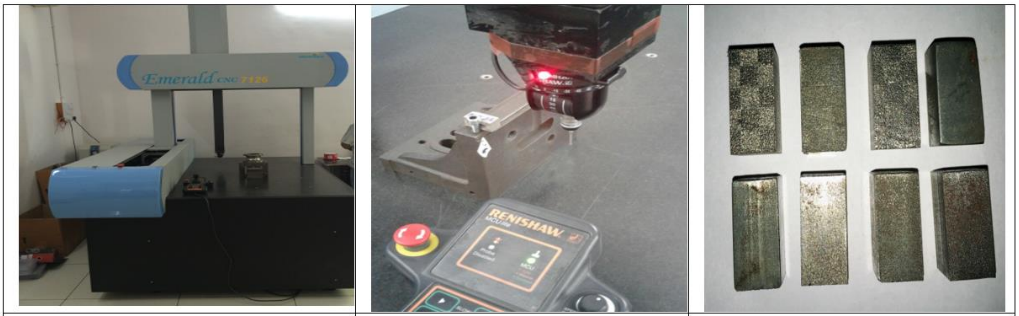
3.3 Responses

Fig 1 (a) and (b) depicts coordinate measuring machine and was measuring dimension of DMLS made specimen. Conformal cooling die or mould have been manufacturing in tooling industries have been using direct metal laser sintering technology. These die or mould can be used as final product or as prototype, it is very required to determined optimum parameter for the dimensional accuracy of DMLS made parts. Also, dimensional accuracy is very important characteristic for engineering application. Also dimensional accuracy of final produce product from injection molding machine or casting very rely on how tool, die and mould manufactured in tooling industries. It will leads to more warpage and failure of product while not provides uniform cooling. In this direction, Research was carried out for behavior of the process parameters responsible for improving the dimensional accuracy of parts built by DMLS process. Fig. 1 (c) specimen which manufactured by DMLS machine.



(a) (b) (c)

Fig. 1 (a) coordinate measuring machine (b) online measurement of DMLS made specimen (c) DMLS made specimen

4 Results

4.1-Dimensional Accuracy

Dimensional accuracy was measured by Coordinate Measurement Machine (CMM). Coordinate measurement machine highly precision machine which use to measure dimension of simple as well as complex geometry of products. There were measured total three readings of each responses along length (L), width (W), height (H) of workpiece and mean was taken as final value of that dimensions. Relative change in dimensions is calculated as per equation 1.

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$$\Delta x = \left| \frac{\text{Measure Value} - \text{Value of CAD Data}}{\text{Value of CAD Data}} \right| \quad (1)$$

ΔX represents relative change in X

The aim of this study to reduce the dimensional error between cad file data and measure value. In this research, relative change in y direction means in length (ΔL), X direction means in width (ΔW) and Z direction means height (ΔH) as small as possible. Therefore "smaller the better" quality characteristic is considered as per the taguchi method. Based on equation 1, experiment reading has been calculated. Experiment value and S/N value of experiment shown in Table 4.

Table 4: Experimental Readings

Sr. no	Layer Thickness [mm]	Orientation [^{0}]	Change in Length	Change in Height	Change in Width	SNRA Change in Length [dB]	SNRA Change in Height[dB]	SNRA Change in Width [dB]
1	0.03	0	0.0057333	0.0075000	0.0075000	44.6817	42.4999	49.5424
2	0.03	90	0.0074000	0.0091667	0.0091667	42.4989	40.7558	61.5836
3	0.04	0	0.0050000	0.0066667	0.0075000	46.0206	43.5219	44.6817
4	0.04	90	0.0070733	0.0091667	0.0083333	42.9953	40.7558	55.5630
5	0.05	0	0.0033433	0.0050000	0.0041667	49.5425	46.0206	43.5218
6	0.05	90	0.0058433	0.0066667	0.0066667	44.6817	43.5219	44.6817
7	0.06	0	0.0033833	0.0033333	0.0033333	49.5425	49.5425	39.3048
8	0.06	90	0.0045933	0.0041667	0.0050000	46.7764	47.6044	41.5836

4.1.1 Main Effects Plot for SNR of Change in Length

The interaction plot for S/N ratio of versus layer thickness and orientation are shown in fig.2. Which has been generated from the value of S/N ratio of as per table 4 in minitab-17 statistical software is useful to find out generate graph so easily can determined optimum parameter value for response variable.

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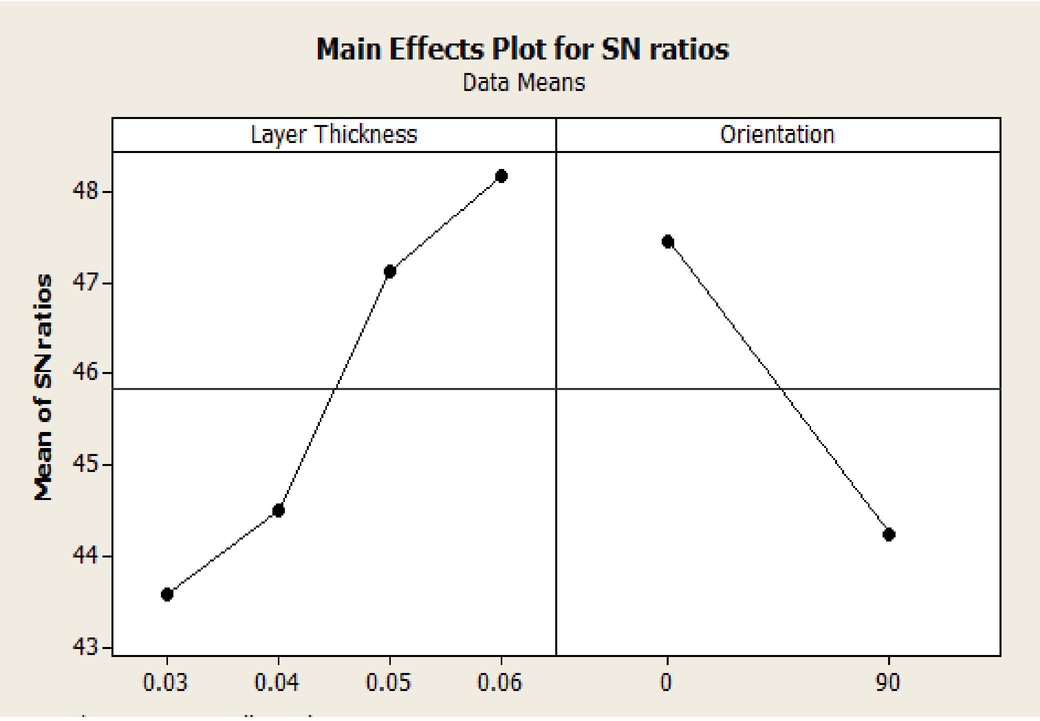

Fig. 2- Effect of control factor on Length

Fig.2 shows that lower change in length will meet at layer thickness 0.03 mm and orientation 90^0. From the fig.2, it has been concluded that the optimum combination of each process parameter for lower length difference is meeting at low layer thickness [A1] and high orientation [B2]. These two levels are significant for change in length.

4.1.2 Main Effects Plot for SNR of Change in Height

From the fig.3, it has been seen that the optimum setting for process parameters for lower Height is meeting at layer thickness [A1] and orientation [B2]. Here it can be said that change in length and change in height both have been rely on similar same level of parameters.

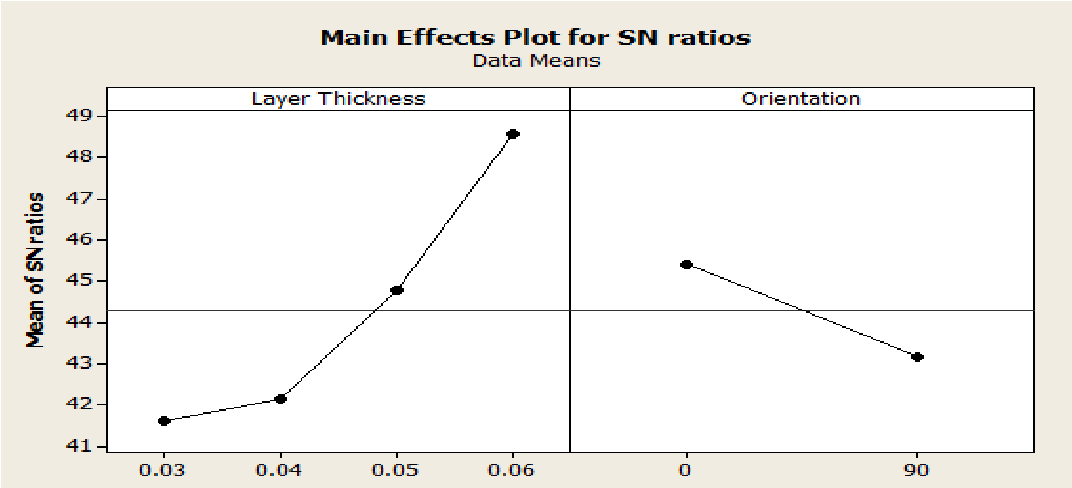

Fig.3- Effect of control factor on Height

4.1.3 Main Effects Plot for SNR of change in Width

From the fig.4, it has been shown that the optimum combination of each process parameter for lower width is meeting at layer thickness [A4] and orientation [B1].

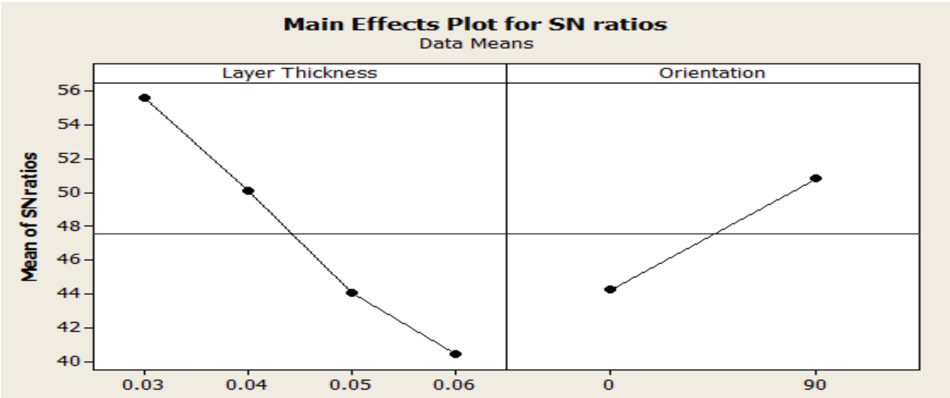

Fig. 4- Effect of control factor on width

Minitab 17 can able to generated table of analysis of variance so it can identified most effective parameters for responses. ANOVA table having probability (p) value of each process parameters which indicated the effectiveness of parameter on responses. If the values of probability are less than 0.05, it indicated that the factors are crucial to the response parameters. Comparing the p-value to a commonly used α- level = 0.05, it is found that if the p- value is less than or equal to α, it can be concluded that the effect is significant, otherwise it is not significant.

Table 5: ANOVA SN ratio table of Length

Source	DF	Adj SS	Adj MS	F	P
Layer thickness	3	27.66	9.21	13.79	0.030
Orientation	1	20.60	20.60	30.80	0.012
Error	3	2.006	0.67		
Total	7	50.27			

From ANOVA table 5, it has been observed that the layer thickness and orientation influencing parameter for change in length, because the value of p for all process parameters are 0.030 and 0.012 respectively which is less than 0.05, so they are effective parameter for change in length.

Table 6: ANOVA SN ratio table of Height

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Layer thickness	3	60.60	60.60	20.20	178.02	0.001
Orientation	1	10.006	10.006	10.006	88.20	0.003
Error	3	0.340	0.340	0.113		
Total	7	70.71	70.71			

From ANOVA table 6, it has been observed that the layer thickness and orientation are influencing parameter for change in height, while the value of p for layer thickness and orientation are 0.001 and 0.003 respectively which are less than 0.05 p values. So, both process parameters responsible parameter for change in height.

Table 7: ANOVA SN ratio table of width

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Layer thickness	3	266.42	266.42	88.81	5.54	0.097
Orientation	1	86.87	86.87	86.86	5.42	0.102
Error	3	48.10	48.10	16.03		
Total	7	401.40	401.40			

From ANOVA table 7, it has been observed that the layer thickness and orientation influencing parameter for change in width, because the value of p for all process parameters are greater than 0.05 so both parameters has been not effective for change in width.

5. Discussion

Shrinkage and Curling are common issue in sintering process because of uneven temperature distribution during part build. Also, residual stress is generating during layer of powder attain close to melting temperature at where have fuse on top of previous layer which is attain room temperature by solidified through lowering piston. Thus, in the next layer, a phenomenal temperature change is observed resulting in irregular contraction. So, melt pool of particle may affect to shrinkage rate which finally affected dimensional accuracy. In DMLS non-uniform thermal shrinkage which occur in entire part. Laser energy also effects melt pool so depth of melt pool increases more uneven temperature which influencing the more dimensional accuracy. It has been seen that this uneven temperature distribution relies on the dimensions of the part and the configuration in which the part has been manufactured. In future, this work can be more explore in this era.

From graph indicated that when uses lower layer thickness which leads higher dimensional accuracy which shown that laser power is enough to sintered thin layer of powder. As layer thickness increase, laser power of process cannot sustain to sintered whole layer of powder. It can be said that layer thickness should be keep lower when process works on lower laser power or constant laser power. Orientation is play important role in DMLS made parts. It has been seen that quality of parts was good at vertical orientation except the holes but vertical orientation leads more number of layers which leads more built time so finally its affected to production time. An angle orientation can reduce build time but also to insufficient dimensional accuracy due to warping (R.

Ummi Nazahah et al., 2014). Vertical orientation in length and height would give better result for dimensional accuracy, but horizontal orientation more effective for width of parts.

6 Empirical Model Derivation

For each combination of parameter settings in L8 Taguchi matrix, percentage shrink values in length, height and width which are mentioned in table 2. Empirical models are derived by linear regression using standard statistical software (MINITAB17). The developed models predict the length, height and width for any set of parameters to scale up the STL file for better accuracy. These developed models are as given below as per equation 2, 3 and 4 for length, height and width respectively.

1. X = 0.008495 - 0.0918 Layer thickness + 0.000021 orientation (2)
2. Y = 0.012375 - 0.1500 Layer thickness + 0.000019 orientation (3)
3. Z = 0.01275 - 0.1583 Layer thickness + 0.000019 orientation (4)

7 Confirmation test

Confirmation experiment is carried out to validate the developed empirical models. Levels of process parameters selected for the confirmation test are optimum parameters as given in Table 4. The estimated shrinkage (%) using the optimal level of the design parameters is expected to fall in the range given below [11].

Expected shrinkage = S_{opt} + C.I. (5)

$S_{opt} = S_m + \sum_{i=1}^{np} (Si - Sm)$ (6)

and confidence interval

$$\text{C.I.} = \left[\frac{F_{(1,\text{DOF}_e)} \times V_e}{N_e}\right]^{0.5}. \quad (7)$$

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In the above three Eqs. (5)–(7), S_m is the overall mean shrinkage, Si is the mean shrinkage (%) at the optimal level, np is the number of main design parameters that affect the quality characteristic, $F_{(1,DOEe)}$ is Fisher value at DOF_e which is degrees of freedom of error term and V_e is the variance of the error term. Effective replications (Ne) is given by [11]

$$N_e = \frac{n}{\mathrm{DOF_m} + \sum_{i=1}^{n_p} \mathrm{DOF}_i}, \quad (8)$$

Table 8: Comparison of shrinkage (%) predicted by ANOVA and confirmation experiment

Sr. no.	Shrinkage direction	Mean of experiment value	Mean Predicted value	From confirmation test
1	Length	0.005296	0.005309	0.005610
2	Height	0.006458	0.00648	0.006214
3	width	0.006458	0.006482	0.006321

In Eqs. 8, DOFm is the degrees of freedom of mean which is always 1 and DOFi is the degrees of freedom of the significant parameters. Table 8 depicts that experiment value, Predicted value and confirmation test value are too much close to each other thus model accuracy of research are better.

8. CONCLUSION

Experimental investigation on direct metal laser sintering of CL50 material was done using various combination of process parameter to build specimen. The following conclusions are made.

1. From the S/N ratio plot the optimum parameter settings for length and height at, ie. Orientation 90^0 and layer thickness 0.03 mm. however, width result is totally reverse it get optimum at Orientation 0^0 and layer thickness 0.06 mm.
2. Also, it can be said that layer thickness kept lower give accurate result because of thin powder layer give less amount of powder melt. It can provide fine structure which reduce surface roughness and laser get sufficient time to melt powder in case of thin powder layer , therefore, temperature difference between laser sintered and unsintered is low. Thus, lower cooling rate produce less shrinkage.
3. It can also observe that layer thickness is the most prominent factor affecting the dimensional accuracy. Its contribution very high compare to orientation.
4. Through use of regression equation, engineer can manipulate range of orientation and layer thickness for this particular work- material. Also it has been find out and predicted

linear dimension of the specimen (Length, width, Height) at any combination of process parameter.

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