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Multitasking characteristics of quality products in Additive Manufacturing Technique

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Abstract-Additive manufacturing is a fast-growing manufacturing process that allows mechanical objects to be produced at a lower cost and in less time.
The goal of this study is to offer a strategy for improving additive manufacturing techniques with multitasking capabilities for high-quality products based on the Taguchi method and Grey relational analysis.
Grey relational grade for quality products calculated from grey relational analysis with multitasking characteristics. Taguchi technique uses grey relational grade as a performance metric to estimate the ideal process parameters such as laser power, layer thickness, and temperature at three levels for each factor.
This approach optimizes mechanical goods with quality factors such as roundness, concentricity, runout, and surface finish with maximizing and minimization.
The experimental results have been enhancing through this approach and total of 9 experiments with repeatability three times that comes to total of 27 experiments were conducted and upshot laser power has the highest influence on quality products, and experiment no. 8 is the optimal value.

Key words: Additive Manufacturing; Taguchi method; Grey relational analysis; optimization.

I INTRODUCTION

The selective laser sintering process is the most preferred industrial procedure for producing high-quality prototypes in a short amount of time and at a low cost. Conceptually, concepts are simple to implement. One of the additive manufacturing techniques is selective laser sintering. Any sophisticated 3D model design that is not possible using a traditional approach can be created. PA 2200 is the material used in the SLS process. The powder form's premise is that a layer of PA2200 powder is rolled on the machine's bed and sintered using a Co2 laser. The second layer is then deposited on top of the previous sintered layer and sintered again, and so on, until the 3D model is completed.

The primary role of process parameters in the output of multitasking response variables is their selection. Laser power, temperature, layer thickness, scan space, particle size, and other process parameters are used in the selective laser sintering process. The most relevant process parameters were chosen based on a literature review. Wang et al. investigated the best strategy for determining process parameters that minimize shrinkage [1]. Nitesh et al. used the Taguchi approach and an orthogonal array of tests to investigate and optimize how process parameters affect part quality [2]. Andreas et al. also focused on improving the bad quality of products by utilizing response surface methods to find correlations between process factors and part quality [3]. Cajal et colleagues developed a volumetric error correction technique based on pattern artefacts to improve the precision and dimensional accuracy of 3D-printed parts [4].

II LITERATURE REVIEW

Many publications in technical research on selective laser sintering process optimization employing Taguchi technique and grey relational analysis to manufacture excellent goods are available. Wang and Li investigated how to limit model shrinkage by improving process parameters utilizing theory and methods of neural networks models. The ideal parameters for improving the accuracy of the model with a neural network model are layer thickness, hatch spacing, laser power, scanning speed, and temperature. The link between process parameters and shrinkage ratio yields minimal when tested experimentally. This model is used to analyze multitudinous nonlinear systems.[5]. Sharanjith et al. also focused on reducing shrinkage using the SLS method to improve the product's quality and usefulness. They proposed a model based on process characteristics such as laser power, scanning spacing, bed temperature, scan length, and scan count to predict shrinkage [6]. Anish et al. used response surface methodology (RSM) to compute the mechanical properties of sintered polyamide parts by optimizing the process parameters laser power, scanning space, bed temperature, and scan count [7]. Many researchers worked on the SLS method to create high-quality goods, such as H.S. Byun and Lee, who used a genetic algorithm to find the best part orientation in layer manufacturing. [8]. M.Pandey et al optimized the SLS process parameters laser power, beam speed, hatch spacing, layer thickness, and hatch pattern to improve part strength [9]. S.Dingal and colleagues By using the Taguchi method to predict density, porosity, and hardness using seven input parameters such as laser peak power density, laser pulse on-time, laser scan speed, stepping distance, interval-spot ratio, grain size, and layer thickness, it was discovered that laser peak power has the greatest influence on the predicted variables [10].

The following are the key goals of this paper:

- To examine the impact of selective laser sintering process factors such as laser power, layer thickness, and temperature on multitasking properties of high-quality products.
- Taguchi method with grey relational analysis for multitasking characteristics optimization of process parameters.
- To produce a quality product, analyze the maximal influence of the process parameter in SLS.

III EXPERIMENT

As shown in the figure, a 3d model is created in Catia V5 and saved with the file extension. IGES (Initial Graphics Exchange Standard) before being transferred to the Rapid Prototyping Machine. For error repairs, the 3D model is imported into Magic's programmed on the machine. The file is saved with the file extension. STL (Standard triangulation language) after removing errors from the 3D model such as curing errors, Voxel overlapping errors, and control errors, and then sliced into layers according to the cross section and layer thickness parameter.

SLS produces functional prototypes in small batches for the automotive, aerospace, and medical industries. Laser power, layer thickness, hatch spacing, scanning speed, orientation, bed temperature, and hatch cure depth are all process parameters in SLS. Laser power, layer thickness, and temperature were chosen for experimentation based on knowledge, a critical literature review, and the machine operator's experience. On the CMM, 9(nine) tests with threefold repeatability were done and tested, totaling 27 experiments (coordinate measuring machine) According to the table and the L9 orthogonal array approach using Taguchi design and analysis from mini tab and grey relational analysis, the process parameters at three levels each for each factor were optimized as shown in the figure.

Table: 1 Levels of Process Parameters

Process parameters	Designation	Units	Level 1	Level 2	Level 3
Laser Power	LP	Watt	67	68	70
Layer thickness	LT	Microns	100	110	120
Temperature	T	Degree Centigrade	174.7	175	176

Fig: 1 Rapid Prototyping machine at Department of Mechanical Engineering Osmania University Hyderabad and sintered PA2200 prototypes

Taguchi grey relational Analysis

The process parameters at three levels for each factor were optimized utilizing the table and the L9 orthogonal array approach employing Taguchi design and analysis using mini tab and grey relational analysis, as seen in the illustration Taguchi grey relational analysis was used. To manufacture quality prototypes on a Rapid prototyping machine, roundness, concentricity, runout, and surface polish are important features.

The trials were carried out, the results were standardized, and the Grey relationship coefficients and grades were determined, as indicated in the table.

Data Preprocessing

The process of converting an original sequence to a comparable sequence is known as data preparation. As a result, the experimental results are standardized in the zero to one range. The following is a step-by-step procedure.

- Roundness, concentricity, runout, and surface polish are the main features, and process parameters are evaluated.
- The three levels of three factors each are chosen
- Orthogonal array L_9 is selected
- Total 9 experiments with repeatability thrice are conducted as per OA
- The experimental results like, roundness, concentricity, runout and surface finish are normalized.
- Grey relational coefficient is calculated
- Grey relational grade is given based on the average of grey relational coefficients.
- Analysis done using Grey relational Grades.
- Optimal levels are selected
- Verification of the optimal process parameters is carried out.

Roundness, concentricity, runout, and surface roughness are employed for the optimal performance of quality prototypes, with the smaller-the-better quality characteristics being used for the roundness, concentricity, runout, and surface roughness.

If the original sequence has the property of "smaller-is-better," the original sequence is normalized as follows.

$$X_i^*(k) = \frac{MaxX_i(k) - X_i(k)}{MaxX_i(k) - MinX_i(k)}$$

Where $X_i^*(k)$ and $X_i(k)$ are the sequence after the data preprocessing and comparability sequence respectively, k=1,2,3 and 4 for roundness, concentricity runout and surface roughness and i=1, 2, 3, 4, …..9 for the experiment numbers 1 to 9 and shown in Table.

Δ_{0i} (k) is the deviation sequence of the reference sequence x_0^* (k) and the comparability sequence x_i^* (k).

The deviation is calculated as follows and shown in Table

$\Delta_{0i}(k) = | x_0^*(k) - x_i^*(k)|$

$\Delta_{0i}(1) = | x_0^*(1) - x_i^*(1)| = |1.00 – 0.00| = 1.0000$

Similarly for other sequences of k = 2, 3 and 4. as shown in the Normalisation Table. $\Delta_{max} = 1.0000$ and $\Delta_{min} = 0.0000$

Grey Relational Coefficient and Grey relational Grade

The grey relational coefficient is determined using the pre-processing sequence after the data has been pre-processed. It shows how the ideal and actual normalised experimental outcomes compare.

$$\xi_i(k) = \frac{\Delta_{min} + \Gamma(\Delta_{max})}{\Delta_{0i}(k) + \Gamma(\Delta_{max})}$$

Where $\Delta_{0i}(k)$ is the deviation sequence of the reference sequence $X_0^*(k)$ and the comparability sequence is $X_i^*(k)$. τ, identification coefficient.

All the parameters are given equal preference, τ is taken as 0.5. The grey relational coefficient for each experiment of L_9 OA can be calculated using equation and shown in Table.

$$\in_i = \frac{1}{4}\left\{\xi_i(1) + \xi_i(2) + \xi_i(3) + \xi_i(4)\right\}$$

1. Results and Discussions of Grey Relational Analysis

The table 2 shows experimental values for roundness, concentricity, runout, and surface finish for multitasking features. Using a L9 orthogonal array and grey relational analysis, the multitasking features are analysed for the best machining process parameter.

Table: 2 experimental layout of L_9 orthogonal array and performance results.

Exp. No.	Laser Power Watt	Layer Thickness Microns	Temp centigrade	Roundness mm	Concentricity mm	Runout mm	Surface finish Microns
1	67	100	174.7	0.0954	0.054	0.081	9.8
2	67	110	175	0.0388	0.0388	0.072	10.4

3	67	120	176	0.0458	0.0388	0.072	8.8
4	68	100	175	0.0673	0.0467	0.082	10.2
5	68	110	176	0.0784	0.0634	0.083	9.2
6	68	120	174.7	0.0548	0.0564	0.078	10.4
7	70	100	176	0.0383	0.0442	0.075	9
8	70	110	174.7	0.0292	0.0287	0.062	10.2
9	70	120	175	0.0572	0.0524	0.072	9

Table: 3 Sequence of each performance characteristics after data processing

Exp.No.	Roundness	Concentrici ty	Runout	Surface Roughne ss
Ref.Sequence	1.0000	1.0000	1.0000	1.0000
1	0.0000	0.0000	0.0952	0.375
2	08549	0.8485	0.5238	0.0000
3	0.7492	0.8485	0.5238	1.0000
4	0.4244	0.7301	0.0476	0.125
5	0.2567	0.4797	0.0000	0.75
6	0.6132	0.5847	0.2380	0.0000
7	0.8625	0.7676	0.3809	0.875
8	1.0000	1.0000	1.0000	0.125
9	0.6495	0.6446	0.5238	0.875

Table: 4 Normalization

	Δ_{0i} (1)	Δ_{0i} (2)	Δ_{0i} (3)	Δ_{0i} (4)
Exp no.1	1.0000	1.0000	0.9048	0.625
Exp no.2	0.1451	0.1515	0.4762	1.0000
Exp no.3	0.2508	0.1515	0.4762	0.0000
Exp no.4	0.5756	0.2699	0.9524	0.875
Exp no.5	0.7433	0.5203	1.0000	0.25
Exp no.6	0.3868	0.4153	0.762	1.0000
Exp no.7	0.1375	0.2324	0.6191	0.125
Exp no.8	0.0000	0.0000	0.0000	0.875
Exp no.9	0.3505	0.3554	0.4762	0.125

Table: 5 The calculated Grey Relational Grade and its order in the optimization of process

Exp .No.	Grey Relational Coefficient				Grey Relational Grade $€_i = ¼ (\xi_i(1) + \xi_i(2) + \xi_i(3) + \xi_i(4))$	Rank
	Roundness $\xi_i(1)$	Concentricity $\xi_i(2)$	Runout $\xi_i(3)$	Surface Roughness $\xi_i(4)$		
1	0.3333	0.3333	0.3559	0.4444	0.3667	9
2	0.7750	0.7674	0.5121	0.3333	0.5969	5
3	0.6659	0.7674	0.5121	1.0000	0.7363	2
4	0.4648	0.6494	0.3442	0.3636	0.4555	8
5	0.4021	0.4900	0.3333	0.6666	0.473	6
6	0.5638	0.5462	0.3961	0.3333	0.4598	7
7	0.7843	0.6826	0.4467	0.8	0.6784	3
8	1.0000	1.0000	1.0000	0.3636	0.8409	1
9	0.5878	0.5845	0.5121	0.8	0.6211	4

The grey relational grade outcomes for each experiment utilising the L9 orthogonal array are listed in the table. The higher the grey relational grad, the closer the value is to the ideal normalised value. The average Grey Relation Grade across all nine studies with three levels of repeatability is €mean = 0.5809.

Experiment number 8(eight) has the best multitasking qualities among the 9(nine) experiments with thrice repeatability because it has the highest grey related grade and laser power at level 3(70 watt), layer thickness at level 2 (119 microns), and temperature at level 1 (174.7°C).

Analysis of mean for grey relational grade

Response of each Machining parameters of Grey relational grade can be done using ANOM (Analysis of mean as shown in the table.

Table: 6 Response for the grey relational grade ANOM

LEVELS	Laser Power LP (watt)	Layer Thickness LT(microns)	Temperature T(Centigrade)
LEVEL 1	1.67	1.5	1.667
LEVEL 2	1.388	1.91	1.673
LEVEL 3	2.14	1.8172	1.887
RANGE	0.752	0.41	0.22
RANK	1	2	3

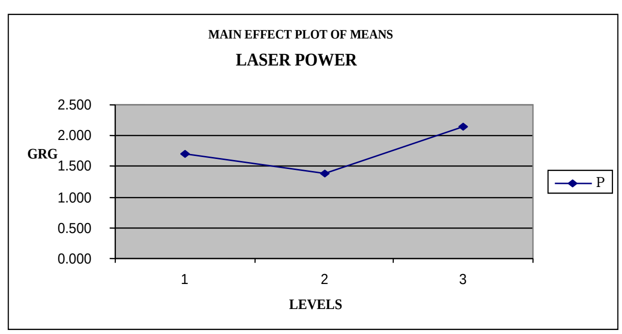

Fig: 2 Main effect plot of Laser Power

As shown in Fig.2 the grey relational grade decreases as the laser power increases from 67 to 68 watts, while the grey relational grade increases as the laser power increases from 68 to 70 watts. This is because as the laser power increases, more energy is depicted on the powder particles, resulting in a denser product. Another reason is that proper laser sintering causes very close fusion of powder particles, resulting in a compact model.

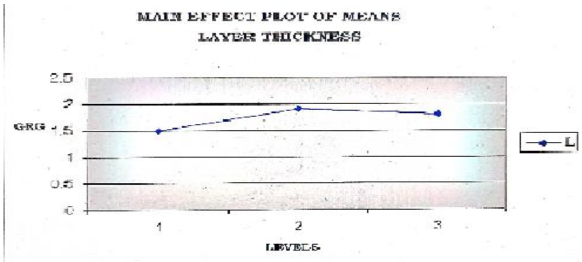

Fig:3 Main effect Plot of Layer Thickness

When the layer thickness is optimum at 110 microns the grey relation grade is highest. As layer thickness varies the change in the penetration depth of the laser sintering process causes a further increase to 120 microns drop in grey relational grade. This pattern is depicted in Fig 3.

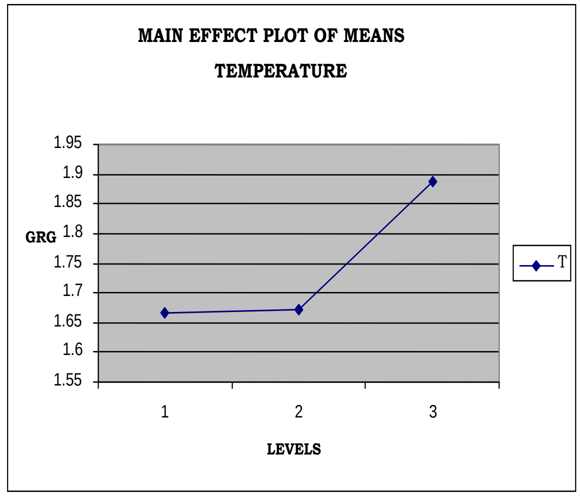

Fig:4 Main effect Plot of Temperature

It can be shown in Fig.4 As the temperature rises from a lower to a higher level, the grey relational grade rises, indicating good sintering and thus better density and strength. Low grey relational grade is caused by poor sintering at lower temperatures.

Analysis of S/N Ratio for Grey Relational Grade

Table: 7 Response TABLE for the grey relational grade S/N RATIO

Factors	Levels	Experimental run	GRG	S/N ratio	Avg S/N Ratio
LP	1	1	0.3667	8.713	5.284
		2	0.5969	4.481	
		3	0.7363	2.658	
	2	4	0.4555	6.83	6.693
		5	0.473	6.502	
		6	0.4598	6.748	
	3	7	0.6784	3.37	3.003
		8	0.8409	1.505	
		9	0.6211	4.136	
LT	1	1	0.3667	8.713	6.304
		4	0.4555	6.83	
		7	0.6784	3.37	
	2	2	0.5969	4.481	4.162
		5	0.473	6.502	
		8	0.8409	1.505	
	3	3	0.7363	2.658	4.514
		6	0.4598	6.748	
		9	0.6211	4.136	
T	1	1	0.3667	8.713	5.655
		6	0.4598	6.748	
		8	0.8409	1.505	
	2	2	0.5969	4.481	5.149
		4	0.4555	6.83	
		9	0.6211	4.136	
	3	3	0.7363	2.658	4.176
		5	0.473	6.502	
		7	0.6784	3.37	
		SUM	15.6858		44.94
		Avg.	0.580956		4.993333

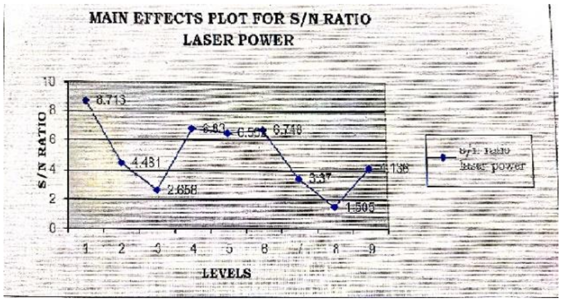

Fig: 5 Main effect Plot of S/N ratio laser Power

The laser power at level 3 70 watts maximises the S/N ratio for better quality prototypes that are closer to the goal, as shown in Fig.5

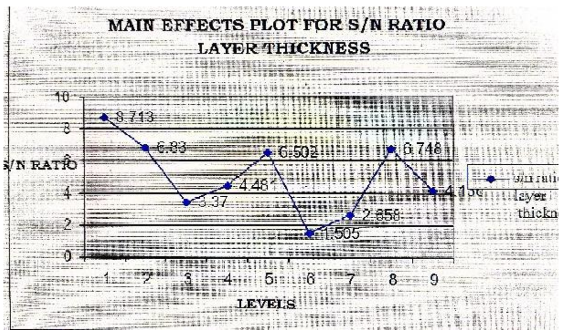

Fig: 6 Main effect Plot of S/N ratio Layer Thickness

The layer thickness at level 2 110 microns maximizes the S/N ratio for better quality prototypes, as shown in Fig.6

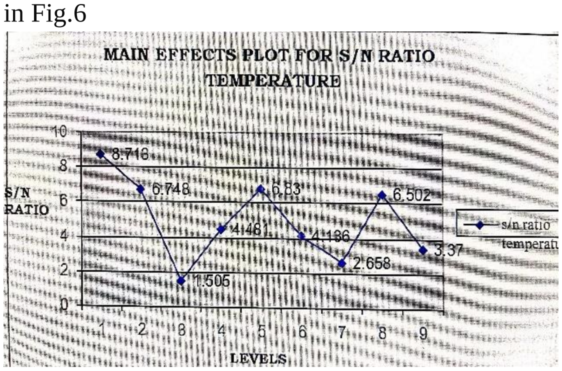

Fig: 7 Main effect Plot of S/N ratio Temperature

The temperature at level 1 174.7 ºC maximises the S/N ratio for excellent prototypes, as shown in Fig.7

In response Tables 5.5 and 5.6, the Mean and S/N ratio Grey Relational Grade for each process parameter are shown. The closer the product quality is to the ideal value, the higher the Grey Relational Grade. The grey relationship grade should be greater for optimal performance. Laser Power (LP) at Level 3 (70 watts), Layer Thickness (LT) at Level 2 (110 microns), and Temperature (T) at Level 3 (176 ºC) are the best specifications for a high-quality prototype. The process parameter's optimal level is the highest grey relational grade, as indicated in Table5.4.

The experiment number 8 gives best results with laser power level 3 70 watts and layer thickness level 2 110 microns and temperature at level 1 174.7 ºC.

GREY PREDICTIVE MODEL

It's a predictive model for enhancing the quality of PA2200 prototypes with several performance attributes. Using the optimal level of the process parameter, the Grey Relational Grade is determined using the formula below.

ϵ_{mean} = 0.5809 Total mean of the Grey Relational Grade.

$\epsilon = \epsilon_{mean} + \sum^{q} (\epsilon_i - \epsilon_{mean})$ i=1

ϵ_i = mean of the grey relational grade at optimal level..

The optimal level parameters for quality prototype are Laser Power (LP) at Level 3 (70 watts), Layer thickness (LT) level 2 (110 microns), and Temperature (T) at level 3 (176 degrees centigrade).

q = Number of process parameters which effects the multi performance characteristics.

$\epsilon = 0.5809 + (0.7133 - 0.5809) + (0.6366 - 0.5809) + (0.629 - 0.5809) = 0.817.$

The response parameters in their absolute form are computed for the best Grey relational grade. The following numbers were obtained for the example computation.

Table 8 Response table for GRA of the sample

Roundness mm	Concentricity mm	Runout mm	Surface Roughness microns	Grey relational Grade
0.0319	0.0296	0.0633	8.9	0.817

CONCLUSION

Taguchi grey relational analysis was used to investigate the impact of process parameters on the quality of prototypes for multitasking features.

1. Optimal process parameters such as laser power (70 watts), layer thickness (120 microns), and temperature (176 ºC) are used in the selective laser sintering process to achieve excellent optimum surface roughness 9.7 microns.
2. Temperature has the greatest impact on surface roughness (20.5 percent), followed by layer thickness (3.25 percent) and laser power (0.16 percent).

3. Laser power (70 watts) has the greatest influence on runout (62 microns) and roundness (29 microns) among the selected process parameters, followed by layer thickness (110 microns), temperature for runout (174.7 ºC) and temperature for roundness (175 ºC) on runout (62 microns) and roundness (29 microns) due to the fact that the sintering process improves with higher laser power, resulting in dimensional accuracy.
4. The thickness of the layer has the greatest impact on concentricity, followed by the laser power and temperature. The laser penetration and heat conduction diminish as the layer thickness increases by 10 microns. Laser penetration and heat conduction are improved at optimal layer thickness, resulting in fewer concentricity mistakes (25-30 microns).
5. Grey relational analysis is used to optimise the process parameters to build quality prototypes for the multi-performance experiment number 8 with laser power at level 3 (70 watts), layer thickness at level 2 (110 microns), and temperature at level 1 (174.7 ºC), which produces the best results with the highest Grey relational grade of 0.8409.
6. The findings of the experiments suggest that the laser power (70 watts) is the most important process parameter that influences multitasking features.

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