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ORIGINAL ARTICLE

Optimization of Co-Cr Alloys Fabricated by DMLS Using Multi-Objective Grey Relational Analysis

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Abstract

Objectives: To optimize Direct Metal Laser Sintering (DMLS) parameters for Co-Cr alloys to simultaneously enhance microhardness and compressive strength using multi-objective Grey Relational Analysis (GRA). **Method:** Co-Cr alloy specimens were fabricated using DMLS by varying laser power, scan speed, and hatch spacing based on a Taguchi L9 orthogonal array. Microhardness and compressive strength were measured as performance responses. Signal-to-noise ratios were calculated and normalized for GRA to obtain the grey relational grade (GRG). ANOVA was performed to determine the significance of process parameters, and confirmation experiments were conducted to validate the optimal parameter combination. **Findings:** The multi-objective optimization results showed that laser power was the most influential parameter with a contribution of 76.21%, followed by hatch spacing (11.17%) and scan speed (10.37%). The optimal parameter combination was identified as 200 W laser power, 1200 mm/s scan speed, and 0.10 mm hatch spacing. Under these conditions, the Co-Cr alloy exhibited a microhardness of 438 HV and compressive strength of 827 MPa with a GRG of 0.961. The confirmation experiment showed a very low error of 0.3%, confirming the accuracy of the optimization model. Compared to the initial experimental run, the optimized parameters significantly improved both hardness and compressive strength due to improved densification and melt pool stability. The results are consistent with previous studies that reported improved mechanical properties at optimal energy density; however, this study uniquely demonstrates simultaneous optimization using GRA for DMLS-fabricated Co-Cr alloys. **Novelty:** This study presents multi-objective optimization of DMLS-fabricated Co-Cr alloys using Taguchi-GRA with experimental validation for simultaneous improvement of hardness and compressive strength.

Keywords: Direct Metal Laser Sintering; Co-Cr alloy; Multi-objective optimization; Grey Relational Analysis; Mechanical properties

1 Introduction

Cobalt–chromium (Co-Cr) alloys have found wide applications in biomedical implants, dental prostheses, and aerospace engineering owing to their superior mechanical strength, wear resistance, corrosion resistance, and excellent biocompatibility [1], [2]. These alloys are particularly suitable for load-bearing applications where high strength and long-term durability are required. Conventional manufacturing processes for producing Co-Cr components include casting, forging, and powder metallurgy techniques [3]. However, these traditional manufacturing methods have limitations in producing intricate geometries, internal lattice structures, and patient-specific customized components. In addition, conventional processes may result in material wastage, microstructural inhomogeneity, and residual defects that adversely affect the mechanical performance of the fabricated parts [4].

Additive manufacturing (AM) has emerged as a transformative manufacturing technology capable of producing complex geometries with minimal material waste [5], [6]. Among various AM techniques, DMLS has gained significant attention due to its ability to fabricate high-precision metallic components with superior dimensional accuracy and mechanical properties [7]. In the DMLS process, a high-energy laser selectively melts metal powder layer-by-layer to produce near fully dense components. The quality and performance of DMLS-fabricated parts are strongly dependent on processing conditions and manufacturing parameters.

The mechanical properties of DMLS-fabricated components are significantly influenced by process parameters such as laser power (LP), scan speed (SS), hatch spacing (HS), and layer thickness (LT) [8], [9]. Improper selection of these parameters may result in manufacturing defects including porosity, balling effect, lack of fusion, residual stresses, and microstructural inconsistencies, which consequently reduce the mechanical strength and reliability of the fabricated components [10]. Therefore, optimization of DMLS process parameters is essential to achieve improved mechanical performance and component integrity.

Recent studies have reported that optimization of DMLS process parameters plays a crucial role in enhancing the mechanical and corrosion properties of additively manufactured Co-Cr alloys [11], [12]. Several researchers have investigated the effects of laser power, scan speed, hatch spacing, and energy density on density, hardness, tensile strength, surface quality, and corrosion resistance of Co-Cr alloys [13], [14] [15]. Although these studies have provided valuable insights into process–property relationships, most investigations primarily focused on single-response optimization, where only one performance characteristic such as hardness, density, or tensile strength was optimized. Consequently, the obtained process parameters may not provide the best overall mechanical performance required for practical applications.

In biomedical implants and structural engineering applications, multiple mechanical properties must be optimized simultaneously. For instance, high microhardness is required to improve wear resistance and surface durability, whereas high compressive strength is essential to withstand service loads without failure. Optimizing only one response may lead to compromised performance in another response. Therefore, multi-objective optimization techniques are necessary to identify the best combination of process parameters that can simultaneously satisfy multiple performance requirements.

The Taguchi method is a widely accepted statistical approach for experimental design and process optimization because it reduces the number of experiments while effectively evaluating the influence of control variables [16]. However, the conventional Taguchi method is primarily suitable for single-response optimization and cannot directly address multiple conflicting responses. To overcome this limitation, GRA can be integrated with the Taguchi method to perform multi-objective optimization [17]. GRA converts multiple performance characteristics into a single GRG, thereby enabling simultaneous optimization of several responses. The Taguchi-GRA approach has been successfully applied in machining, welding, surface engineering, and additive manufacturing processes for solving complex multi-response optimization problems [18].

Despite the growing interest in DMLS-fabricated Co-Cr alloys, limited studies have been reported on the simultaneous optimization of microhardness and compressive strength using a multi-objective framework. Most previous investigations concentrated on microhardness, density, tensile strength, or corrosion behavior individually, whereas compressive strength-based optimization has received comparatively little attention. Furthermore, studies specifically employing Taguchi-GRA for multi-response optimization of DMLS process parameters in Co-Cr alloys remain scarce. This represents a significant research gap because both hardness and compressive strength are critical performance indicators for biomedical and structural applications.

To address these limitations, the present study proposes a multi-objective optimization framework based on the integration of the Taguchi design methodology and Grey Relational Analysis. The DMLS process parameters, namely laser power, scan speed, and hatch spacing, were optimized to simultaneously improve the microhardness and compressive strength of Co-Cr alloys. An L9 orthogonal array was employed for experimental design, while Analysis of Variance (ANOVA) was used to determine the significance and contribution of process parameters. Confirmation experiments were subsequently performed to validate the optimized parameter combination. The proposed methodology provides a systematic and reliable approach for multi-response optimization and contributes to the development of high-performance Co-Cr components for advanced biomedical, dental, and structural applications.

2 Methodology

2.1 Materials

In the present study, cobalt–chromium (Co-Cr) alloy powder was used as the base material for fabrication of specimens using the DMLS process. Co-Cr alloy powder was chosen owing to its outstanding mechanical properties, corrosion resistance and biocompatibility, therefore it can be used for biomedical and aerospace applications. These powder particles were obtained using gas atomization and had spherical shapes and high flowability. This characteristic makes them suitable for additive manufacturing applications using powder bed fusion technology.

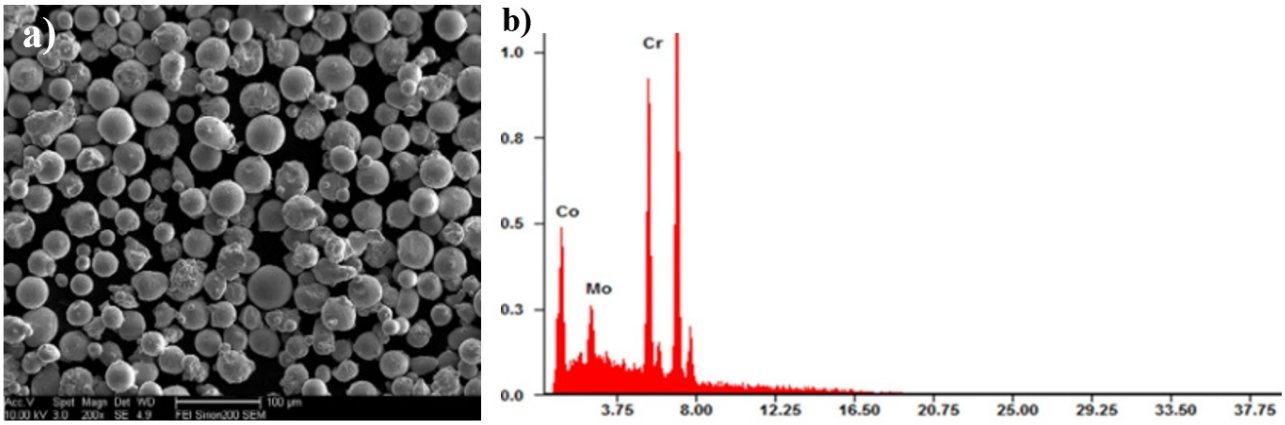


Fig 1. (a) Co-Cr alloy SEM image (b) Co-Cr alloy EDAX

The morphology of the Co-Cr alloy powder was studied by SEM is depicted in Figure 1(a). SEM analysis revealed that the alloy powder particles were predominantly spherical with an equal particle size distribution, which is important for obtaining a uniform melt and strong bonding between layers during the DMLS method. EDAX was performed to identify the chemical composition are shown in Figure 1(b). According to the EDAX results, the major elements in the alloy were identified as cobalt, chromium, and molybdenum, in addition to smaller amounts of other elements.

The Co–Cr alloy powder consisted of 60-65 wt.% Co, 27-30 wt.% Cr, 5-7 wt.% Mo, 1-2 wt.% Si, 0.5-1 wt.% Mn, and 0.5-1 wt.% Fe, while the contents of C, Ni, and W were each less than 0.1 wt.%. The high chromium content enhances corrosion resistance by promoting the formation of a stable passive oxide layer, whereas molybdenum improves mechanical strength and hardness. The minor alloying elements further contribute to the overall mechanical performance and corrosion resistance, making the powder suitable for DMLS-based biomedical and structural applications.

2.2 Experimental details

The samples were fabricated using the DMLS technique, an additive manufacturing process based on the powder bed fusion principle. In this process, metal powder is selectively melted layer by layer using a high-energy laser beam to produce fully dense components. The DMLS system consists of a powder delivery unit, recoater mechanism, build platform, and laser scanning system, as illustrated in Figure 2(a), while the fabrication process is schematically shown in Figure 2(b). During fabrication, an argon atmosphere was maintained within the build chamber to prevent oxidation of the metal powder. The process was carried out using a laser power of 200 W, scan speed of 1200 mm/s, hatch spacing of 0.10 mm, and layer thickness of 30 μm. The build platform was preheated to 200°C to minimize thermal gradients and residual stresses during fabrication. These process parameters were maintained throughout the experiments to ensure consistent fabrication conditions.

In this study, three important DMLS process parameters, namely laser power, scan speed, and hatch spacing, were selected as the control factors for optimization. Each parameter was investigated at three levels using a Taguchi L9 orthogonal array. The laser power was varied at 180, 200, and 220 W, the scan speed at 1000, 1200, and 1400 mm/s, and the hatch spacing at 0.08, 0.10, and 0.12 mm, respectively. These parameter levels were selected based on previous literature and preliminary experimental trials, as they significantly influence the melting behavior, densification, microstructure, and mechanical properties of DMLS-fabricated Co–Cr alloy components.

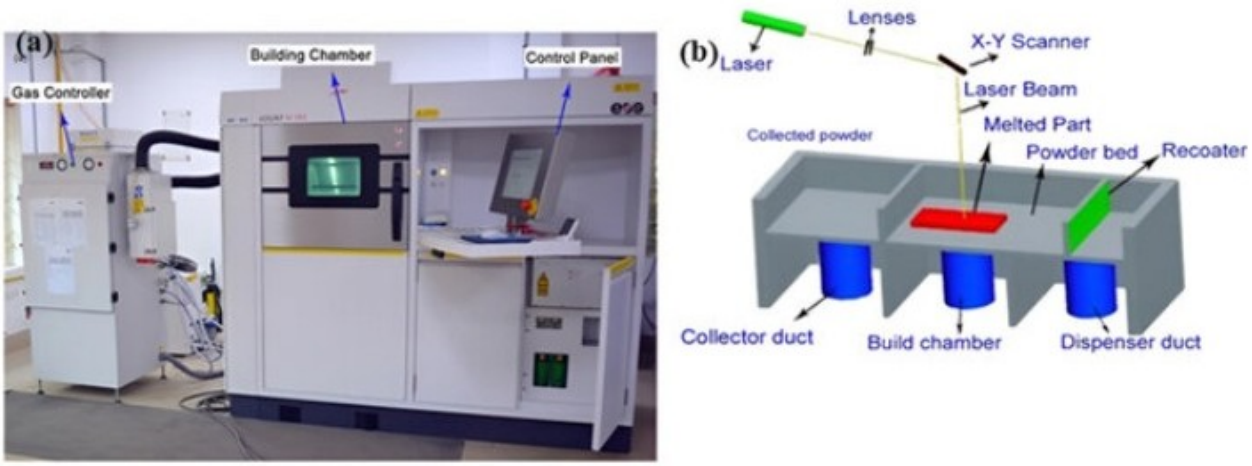


Fig 2. (a) Experimental Configuration of DMLS (b) Schematic Representation of DMLS

The experiments were designed using a Taguchi L9 orthogonal array to reduce the number of experimental runs while maintaining the accuracy of the results. Based on the L9 design, nine specimens were fabricated using different combinations of process parameters [19].

Microhardness testing was carried out using a Vickers microhardness testing machine in accordance with ASTM E384, Standard Test Method for Micro indentation Hardness of Materials. The test was performed under a load of 1000 g with a dwell time of 10 s, and the average of three measurements was recorded for each specimen [20].

Compressive strength testing was performed using a universal testing machine in accordance with ASTM E9, Standard Test Methods of Compression Testing of Metallic Materials at Room Temperature. The cylindrical specimens were tested under compressive loading at room temperature using a constant strain rate, and the average of three measurements was considered for analysis [21].

The experimental results obtained from microhardness and compressive strength tests were analyzed using the Taguchi method and GRA to determine the optimal combination of DMLS process parameters.

3 Results and Discussion

The experimental results obtained from the L9 orthogonal array for microhardness and compressive strength are presented in Table 1. The results show that both microhardness and compressive strength vary significantly with changes in DMLS process parameters such as laser power, scan speed, and hatch spacing.

Table 1. Expanded L9 of process parameters and output responses

Exp. No.	Laser power (W)	Scan speed (mm/s)	Hatch spacing (mm)	Microhardness (HV)	Compressive strength (MPa)
1	180	1000	0.08	372	756
2	180	1200	0.10	406	807
3	180	1400	0.12	385	765
4	200	1000	0.10	434	821
5	200	1200	0.12	423	827
6	200	1400	0.08	427	812
7	220	1000	0.12	383	786
8	220	1200	0.08	418	811
9	220	1400	0.10	414	807

From Table 1, it is observed that the microhardness values range from 372 HV to 434 HV, while the compressive strength values range from 756 MPa to 827 MPa. The highest microhardness value of 434 HV was obtained in Experiment 4 (200 W, 1000 mm/s, 0.10 mm), whereas the highest compressive strength value of 827 MPa was obtained in Experiment 5 (200 W, 1200

mm/s, 0.12 mm). The variation in mechanical properties is mainly attributed to the variation in laser energy density and melt pool characteristics during the DMLS process.

In general, higher laser power combined with moderate scan speed produced better mechanical properties due to improved melting and bonding between powder particles, which resulted in reduced porosity and improved densification.

3.1 Signal-to-Noise Ratio Analysis

The signal-to-noise (S/N) ratio was calculated for both microhardness and compressive strength using the "larger-is-better" criterion, and the results are presented in Table 2. The S/N ratio helps to identify the optimal parameter levels by minimizing variability and improving performance characteristics.

Table 2. Results of S/N conversion for Micro hardness and Compressive strength

Trial No.	Microhardness (HV)	S/N of Microhardness (dB)	Compressive strength (MPa)	S/N of Compressive strength (dB)
1	372	51.41	756	57.57
2	406	52.17	807	58.14
3	385	51.71	765	57.67
4	434	52.75	821	58.29
5	423	52.53	827	58.35
6	427	52.61	812	58.19
7	383	51.66	786	57.91
8	418	52.42	811	58.18
9	414	52.34	807	58.14

From Table 2, the highest S/N ratio for microhardness was observed in Experiment 4 (52.75 dB), while the highest S/N ratio for compressive strength was observed in Experiment 5 (58.35 dB). This indicates that different parameter combinations influence different mechanical properties, which necessitates the use of multi-objective optimization techniques such as GRA.

3.2 ANOVA Variance Analysis

The ANOVA method was employed to evaluate the optimal data using the S/N ratio table. Before utilizing ANOVA, the Anderson–Darling (AD) test was performed to assess normality. A p-value greater than 0.05 signifies a normal distribution. The p-values derived from the AD test, following the transformation of S/N values for micro hardness and compressive strength, exceeded 0.05, as illustrated in Figure 3 (a & b). Following the validation of normal distribution in the responses, ANOVA analysis was conducted accordingly[22].

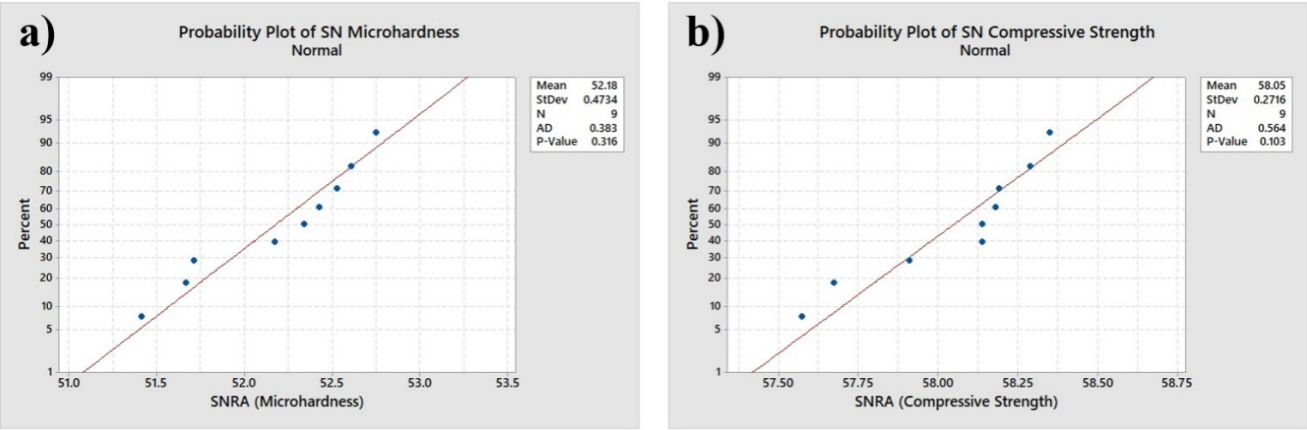


Fig 3. (a) Normality test for S/N of Microhardness and (b) Normality test for S/N of Compressive strength

3.3 Influence of Control Variables on Microhardness

The influence of DMLS process parameters on microhardness was evaluated using the S/N ratio based on the "larger-is-better" criterion. The ANOVA results presented in Table 3 and the main effects plot shown in Figure 4 were used to analyze the significance and trend of each control variable. From Table 3, it is evident that laser power is the most dominant parameter affecting microhardness, contributing 63.95% of the total variation. In comparison, hatch spacing and scan speed contribute 17.40% and 14.97%, respectively, while the error contribution is relatively low (3.69%), indicating good experimental accuracy. The higher F-value associated with laser power further confirms its strong influence on hardness.

Table 3. S/N of Microhardness ANOVA analysis

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Laser power (W)	2	2456.2	63.95%	2456.2	1228.11	17.35	0.054
Scan speed (mm/s)	2	574.9	14.97%	574.9	287.44	4.06	0.198
Hatch spacing (mm)	2	668.2	17.40%	668.2	334.11	4.72	0.175
Error	2	141.6	3.69%	141.6	70.78		
Total	8	3840.9	100.00%				

Although the ANOVA results showed p-values greater than 0.05, laser power exhibited the highest contribution to microhardness (63.95%), followed by hatch spacing (17.40%) and scan speed (14.97%). The relatively high p-values may be attributed to the limited experimental runs in the L9 orthogonal array. Therefore, laser power was identified as the dominant parameter based on its contribution percentage and observed influence on microhardness. The main effects plot in Figure 4 indicates that microhardness increased with laser power from 180 W to 200 W and then slightly decreased at 220 W, suggesting that 200 W is the optimum laser power for achieving maximum hardness. At lower laser power, incomplete melting can lead to poor bonding and increased porosity, whereas excessive laser power may cause overheating and grain coarsening, thereby reducing hardness [23]. Similarly, microhardness increased with scan speed up to 1200 mm/s and then decreased at 1400 mm/s, indicating that a moderate scan speed provides sufficient interaction time for effective melting and consolidation. Hatch spacing also showed a significant influence, with the highest microhardness observed at 0.10 mm due to adequate overlap between adjacent melt tracks. Overall, the results confirm that laser power is the most influential parameter affecting microhardness, followed by hatch spacing and scan speed.

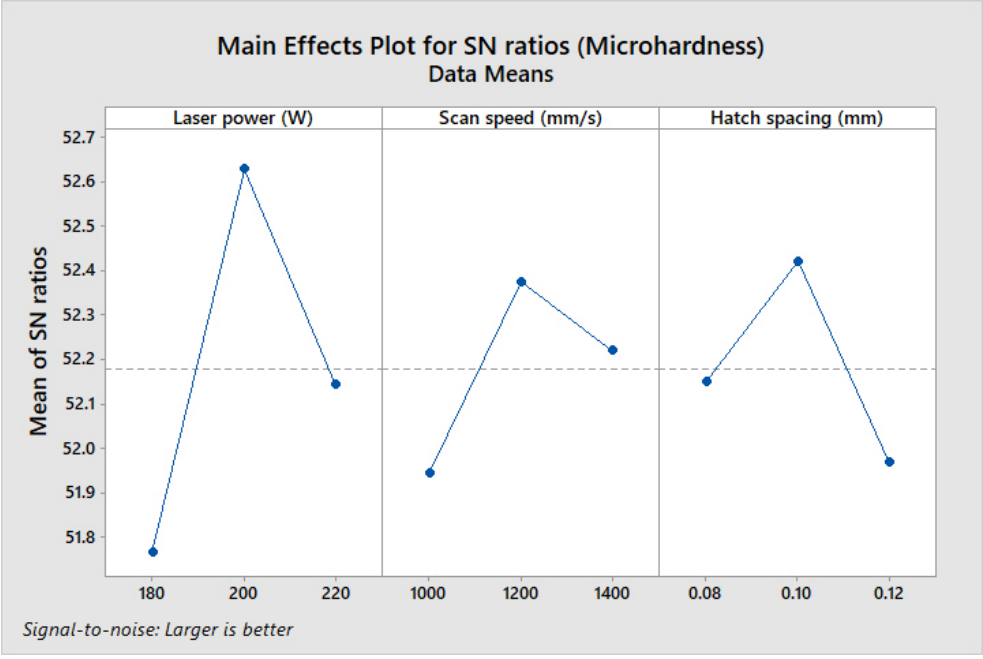


Fig 4. S/N of Microhardness with main effects plot

3.4 Influence of Control Variables on Compressive Strength

Effects of DMLS Process Parameters on Compressive Strength were determined using the S/N ratio method based on the ”larger is better” approach. From the output results obtained from ANOVA as displayed in Table 4 and the graphical representation of the effects of the parameters in Figure 5, it can be seen the influence and trend of each process parameter employed. From Table 4, the most influential process parameter for compressive strength is the laser power (influence 59.93%), followed by the scan speed (influence 24.77%) then the hatch spacing (influence 14.53%). Error influence is negligible (influence 0.77%).

Table 4. S/N of Compressive Strength ANOVA analysis

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Laser power (W)	2	2926.22	59.93%	2926.22	1463.11	77.92	0.013
Scan speed (mm/s)	2	1209.56	24.77%	1209.56	604.78	32.21	0.030
Hatch spacing (mm)	2	709.56	14.53%	709.56	354.78	18.89	0.050
Error	2	37.56	0.77%	37.56	18.78		
Total	8	4882.89	100.00%				

The main effects plot in Figure 5 shows that compressive strength increases as laser power increases from 180 W to 200 W, and then slightly decreases at 220 W. This trend indicates that 200 W is the optimal laser power for achieving maximum compressive strength. At lower laser power, incomplete melting leads to poor interlayer bonding and increased porosity, whereas excessive power may cause thermal instability and microstructural defects, reducing strength [23]. For scan speed, compressive strength increases from 1000 mm/s to 1200 mm/s and decreases at 1400 mm/s. A moderate scan speed of 1200 mm/s provides sufficient interaction time between the laser and powder bed, ensuring proper fusion and improved densification, while higher speeds may result in lack of fusion. Similarly, hatch spacing shows that compressive strength increases up to 0.10 mm and slightly decreases at 0.12 mm. Proper hatch spacing ensures adequate overlap between adjacent melt tracks, reducing defects and enhancing load-bearing capacity. The findings indicate that laser power is the crucial parameter, followed by scan speed and hatch spacing.

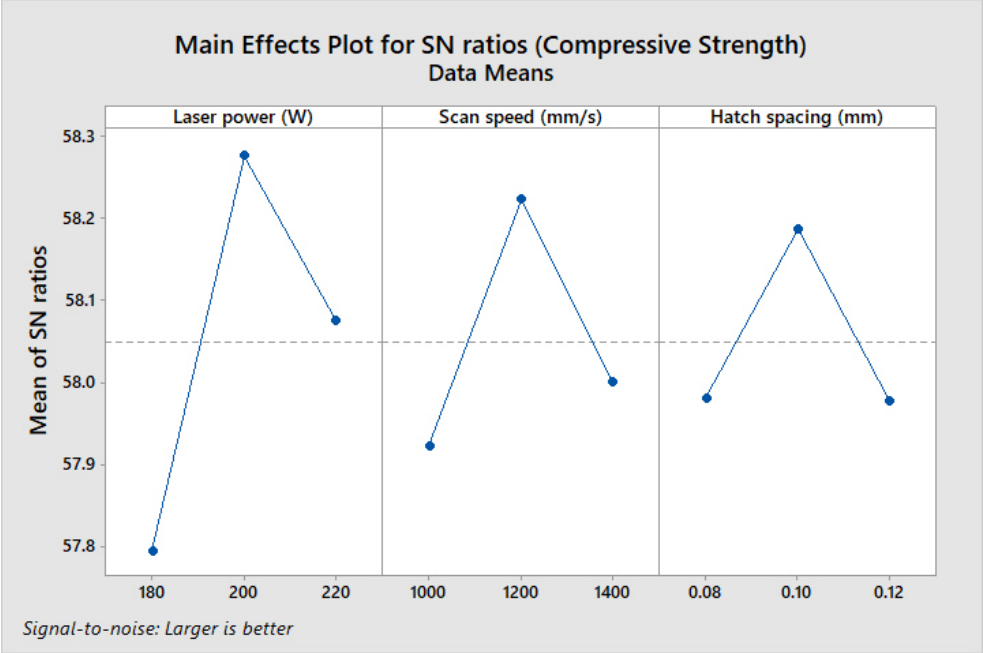


Fig 5. S/N of Compressive Strength with main effects plot

3.5 GRA of Mechanical Responses

In the present study, a multi-objective optimization approach combining the Taguchi design of experiments (DoE) with GRA was employed to simultaneously enhance microhardness and compressive strength of DMLS-fabricated Co-Cr alloys. While the Taguchi method and ANOVA are effective for analyzing the influence of process parameters on individual responses, they are limited when multiple performance characteristics need to be optimized simultaneously. Therefore, GRA was adopted to convert the multi-response problem into a single GRG, enabling the identification of the optimal process parameter combination.

The GRA technique evaluates multiple responses by normalizing them into a comparable scale and determining their relational closeness to the ideal condition. In this study, both microhardness and compressive strength follow the "higher-is-better" criterion, as higher values indicate improved mechanical performance [24]. The procedure followed for GRA is described below:

Step 1: S/N Ratio Normalization and Deviation:

The first step in GRA involves normalizing the S/N ratios of the responses to a range between 0 and 1. This eliminates dimensional differences and enables comparison among multiple responses. Since both responses follow the "higher-is-better" criterion, normalization is performed using the following equation:

$$Y_i(p) = \frac{X_i(p) - \min X_i(p)}{\max X_i(p) - \min X_i(p)}$$

where $X_i(p)$ is the S/N ratio of the ith experiment for the pth response.

After normalization, the deviation sequence is calculated as the absolute difference between the ideal (maximum) value and the normalized value.

Step – 2: Grey Relation Coefficient (GRC):

The GRC represents the relationship between the ideal and actual normalized values. It is calculated using the following equation:

$$GRC_i(p) = \frac{\Delta_{\min}(p) + \delta\Delta_{\max}(p)}{\Delta_i(p) + \delta\Delta_{\max}(p)}$$

where:

$\Delta_i(p)$ is the deviation sequence,

$\Delta_{\min}(p)\ and\ \Delta_{\max}(p)$ are the minimum and maximum deviation values,

δ is the distinguishing coefficient (taken as 0.5 in this study).

Step 3: Grey Relational Grade:

The GRG is obtained by averaging the GRCs of all responses. It represents the overall performance index for each experimental run and is calculated as:

$$GRC_i = \frac{1}{n}\sum_{p=1}^{n} GRC_i(p)$$

where n is the number of responses.

The normalized values, deviation sequences, GRCs, and GRGs for all experimental runs are presented in Table 5. The table clearly summarizes the transformation of multiple response characteristics into a single performance index through the GRA approach. Based on these results, ANOVA was performed to evaluate the significance of each input parameter on the overall GRG.

The ANOVA results shown in Table 6 indicate that laser power is the most influential parameter, contributing 76.21% to the overall performance, followed by hatch spacing (11.17%) and scan speed (10.37%). This confirms that the energy input during the DMLS process plays a dominant role in determining the combined mechanical properties.

Furthermore, the GRG ranking in Table 5 reveals that Experiment 4 achieved the highest GRG, indicating the best overall performance among all trials. This experimental run corresponds to a parameter combination of 200 W laser power, 1000 mm/s scan speed, and 0.10 mm hatch spacing. In addition, Fig.6 illustrates the ranking of GRG values along with the corresponding mechanical responses, providing a clear visualization of the optimization results.

Table 5. Data normalization, deviation, GRC and GRG values

Trial No.	S/N of Micro hardness			S/N of Compressive strength			GRG	Rank
	Normalized	Deviation	GRC	Normalized	Deviation	GRC		
1	0.000	1.000	0.333	0.000	1.000	0.333	0.333	9
2	0.548	0.452	0.525	0.718	0.282	0.640	0.583	6
3	0.210	0.790	0.388	0.127	0.873	0.364	0.376	8
4	1.000	0.000	1.000	0.915	0.085	0.855	0.928	1
5	0.823	0.177	0.738	1.000	0.000	1.000	0.869	2
6	0.887	0.113	0.816	0.789	0.211	0.703	0.759	3
7	0.177	0.823	0.378	0.423	0.577	0.464	0.421	7
8	0.742	0.258	0.660	0.775	0.225	0.689	0.674	5
9	0.677	0.323	0.608	0.718	0.282	0.640	0.624	4

Table 6. S/N of GRG ANOVA analysis

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Laser power (W)	2	0.275790	76.21%	0.275790	0.137895	33.88	0.029
Scan speed (mm/s)	2	0.037527	10.37%	0.037527	0.018764	4.61	0.178
Hatch spacing (mm)	2	0.040435	11.17%	0.040435	0.020218	4.97	0.168
Error	2	0.008141	2.25%	0.008141	0.004070		
Total	8	0.361893	100.00%				

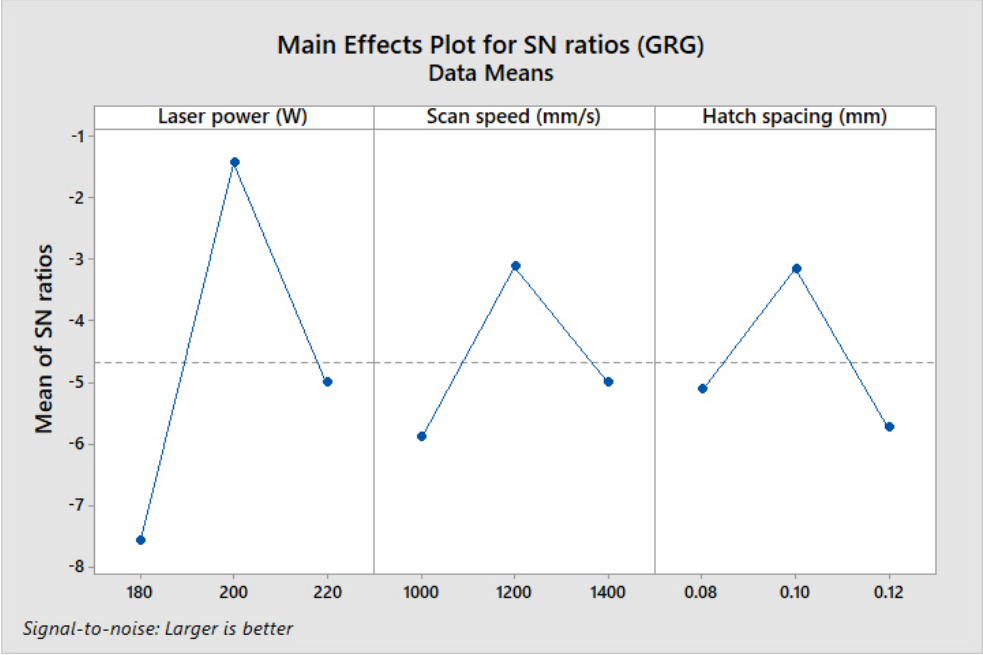


Fig 6. S/N of GRG with main effects plot

3.6 Experimental Validation

The final step consists of experimental validation and performance evaluation of the model. After the input values have been established for optimal performance, the validation of the model is done by using the same setup with these values to evaluate the responses generated. The predicted and actual responses as well as their respective percentage errors are shown in Table 7. The maximum error was 0.3%.

Table 7. Experimental validation and comparison

Input parameters / Output responses	4^{th}run [Taguchi design]	Predicted optimal set	Experimental validation
Laser power (W)	200	200	200
Scan speed (mm/s)	1000	1200	1200
Hatch spacing (mm)	0.10	0.10	0.10
Microhardness (HV)	434	-	438
Compressive strength (MPa)	821	-	827
GRG	0.928	0.964	0.961

The results obtained in the present study demonstrate significant improvements in the mechanical performance of DMLS-fabricated Co-Cr alloys through multi-objective optimization. The optimized parameter combination of 200 W laser power, 1200 mm/s scan speed, and 0.10 mm hatch spacing resulted in a microhardness of 438 HV and a compressive strength of 827 MPa. These values are comparable to or higher than those reported in several recent studies on additively manufactured Co-Cr alloys.

3.7 Comparison with Previous Studies and Novel Contributions

Vinod Kumar Jat et al.[25] reported that the mechanical performance of DMLS Co-Cr–Mo alloys is strongly influenced by processing parameters and scanning strategies, with optimized conditions leading to enhanced strength and fracture resistance. Similarly, Tuna et al.[26] observed that the processing route and laser sintering conditions significantly affect the integrity and performance of Co-Cr components used in biomedical applications. Other studies on laser-based manufacturing of metallic alloys have also demonstrated that careful optimization of process parameters improves densification and mechanical properties. However, most of these investigations focused on individual responses such as hardness, tensile strength, corrosion resistance, or fracture behavior rather than simultaneous optimization of multiple mechanical characteristics[27],[28],[29],[30].

In contrast, the present study employs a Taguchi-GRA framework to simultaneously optimize microhardness and compressive strength, thereby addressing a practical multi-objective optimization problem. Unlike conventional single-response optimization approaches, the proposed methodology converts multiple performance measures into a single grey relational grade, enabling identification of an optimal parameter combination that balances both responses.

Another important contribution of this work is the quantitative evaluation of parameter significance through ANOVA. The results revealed that laser power contributes 76.21% to the overall grey relational grade, confirming that energy input is the dominant factor governing the combined mechanical performance of DMLS-fabricated Co-Cr alloys. Furthermore, the experimental validation yielded a GRG of 0.961 with an error of only 0.3%, demonstrating the reliability and predictive capability of the optimization approach.

Therefore, the novelty of this study lies in the simultaneous optimization of microhardness and compressive strength of DMLS-fabricated Co-Cr alloys using a Taguchi-GRA methodology, supported by statistical validation and confirmation experiments.

4 Conclusion

The present study successfully achieved its objective of optimizing the DMLS process parameters for Co-Cr alloys through a multi-objective optimization framework based on the Taguchi method and GRA. The influence of laser power, scan speed, and hatch spacing on microhardness and compressive strength was systematically investigated using an L9 orthogonal array. The experimental results demonstrated that both mechanical properties are significantly affected by the selected process parameters, with laser power emerging as the most influential factor. ANOVA results revealed that laser power contributed 63.95% to microhardness and 59.93% to compressive strength, highlighting the critical role of energy input in determining the quality of DMLS-fabricated components.

A key novelty of this work lies in the simultaneous optimization of microhardness and compressive strength of DMLS-fabricated Co-Cr alloys using a Taguchi-GRA approach. Unlike previous studies that primarily focused on single-response optimization, the proposed methodology effectively integrated multiple performance characteristics into a single GRG, enabling the identification of an optimal parameter combination. The optimum process settings were determined as 200 W laser power, 1200 mm/s scan speed, and 0.10 mm hatch spacing. Confirmation experiments conducted at these conditions yielded a microhardness of 438 HV and a compressive strength of 827 MPa, with a GRG of 0.961 and a prediction error of only 0.26%, confirming the robustness and reliability of the optimization approach.

From a practical perspective, the optimized process parameters can be utilized to manufacture high-performance Co-Cr components with improved mechanical properties for biomedical implants, dental prostheses, and structural applications. The findings provide valuable guidelines for process parameter selection in DMLS and contribute to the advancement of additive manufacturing technologies for critical engineering applications.

4.1 Future scope of work

To further investigate the wear, corrosion, fatigue, density, and porosity characteristics of DMLS-fabricated Co-Cr alloys by incorporating lattice/nTopology-based designs along with process parameters. Advanced optimization techniques integrating Taguchi-GRA with artificial intelligence and machine learning models can also be explored for enhanced multi-objective performance prediction and process optimization.

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