Cureus Journal of Engineering

Open Access Original Article

Data-Driven Optimization of Aluminium Blanking Parameters: A Hybrid Taguchi and Regression Approach

Swapnil S. Bhoir [1] , Manoj M. Dongare [1] , Munna Verma [1]

1. Mechanical Engineering, Bhagwant University, Ajmer, IND

Corresponding author: Swapnil S. Bhoir, swapnilbhoir05@gmail.com

Received 03/13/2025
Review began 03/24/2025
Review ended 03/30/2025
Published 04/08/2025

DOI: https://doi.org/10.7759/s44388-025-03716-8

Abstract

The blanking process is an essential manufacturing technique in the sheet metal industry, widely employed for producing precision components. Increasing global market competitiveness necessitates high-quality output with minimal defects. Small-scale industries often struggle to predict optimal punch-die clearance due to limited skilled operators and the high costs associated with Computer-Aided Design/Computer-Aided Manufacturing systems. An accurate simulation of the shearing mechanism in blanking is complex due to the narrow shear band and challenges in fracture criteria. This study successfully employs a hybrid approach combining Taguchi's Design of Experiments and multiple regression analysis to optimize punch-die clearance and minimize burr height in aluminium blanking. Taguchi's method identifies key parameters influencing burr height, while regression analysis provides a predictive model for estimating burr height based on varying punch thickness and clearance levels. The findings reveal that a punch thickness of 1.5 mm and a clearance of 5% result in the minimum burr height of 0.0611 mm, with a 95% prediction interval ensuring the robustness of the solution. Contour plot analysis confirms that higher clearance values significantly increase burr height, particularly in thinner sheets, reinforcing the need for precise clearance control. Interaction analysis demonstrates a linear relationship between burr height and clearance across all thickness levels, with the 1.5 mm punch thickness consistently yielding optimal results. This study provides a cost-effective and systematic approach to enhancing blanking performance by integrating statistical optimization and predictive modeling. The proposed methodology offers practical insights for small-scale industries, enabling improved precision, reduced defects, and enhanced efficiency in aluminium sheet blanking.

Categories: Advanced Manufacturing Technologies, Materials Engineering, Design and Manufacturing
Keywords: blanking, burr, optimization, taguchi, regression

Introduction

Blanking is widely used in the fabrication of metal sheets in the mechanical industry. This process involves the removal of a portion of sheet metal using a punch and die setup, where the removed section is referred to as the product. In blanking, a metal punch is forced onto a larger sheet of metal, with the die securely positioned on a hydraulic press. The demand for high-accuracy and high-quality products with superior finishing has increased, as such components are utilized in various industrial applications.

This study presents a method for predicting the optimal punch-die clearance in aluminium blanking using the Design of Experiment (DOE) method and the Taguchi approach. Aluminium is widely used material in blanking due to their favorable mechanical and thermal properties, present unique challenges compared to other metals such as steel. The process involves pressing a sheet with a blank holder and applying a punch to separate the product. Simulating this technique is complex, as it involves a transition from the elastic stage to complete material separation. The blanked product typically exhibits four key characteristics: depth of rollover, shear zone, fracture zone, and burr height.

The quality of blanked components is influenced by several factors, including material properties, tool geometry, wear, and noise factors [1]. Figure *1* indicates that the rollover zone is formed due to plastic deformation, while the shear zone appears smooth and shiny due to the shearing action. The fracture zone exhibits a rough surface resulting from crack propagation, and burr height is a consequence of plastic deformation at the edges. Punch-die clearance plays a crucial role in determining crack penetration depth and fracture angle, both of which directly affect burr height [2].

Complications in blanking process

Challenges in the blanking process arise due to limited knowledge of the optimal punch-die clearance, leading manufacturers to rely on inefficient trial-and-error methods. This traditional approach increases production lead times and costs while often resulting in substandard product quality. Optimizing burr height plays a crucial role in improving surface finish, reducing material waste, and minimizing the need for secondary finishing operations, ultimately enhancing process efficiency [3]. Additionally, manual inspection methods contribute to higher rejection rates, further emphasizing the inefficiencies of conventional blanking practices [4,5].

Burr height significantly influences the overall performance of blanked components. Excessive burr formation can lead to issues such as misalignment, increased friction, and premature tool wear. Studies conducted by Maity et al. and Hambli highlight the critical role of punch-die clearance and material properties in controlling burr height, thereby improving process precision and reliability [1,2]. In industries such as aerospace and automotive manufacturing, where high precision and superior surface quality are essential, minimizing burr height is imperative for meeting stringent quality standards, reducing overall costs, and enhancing product lifecycle performance.

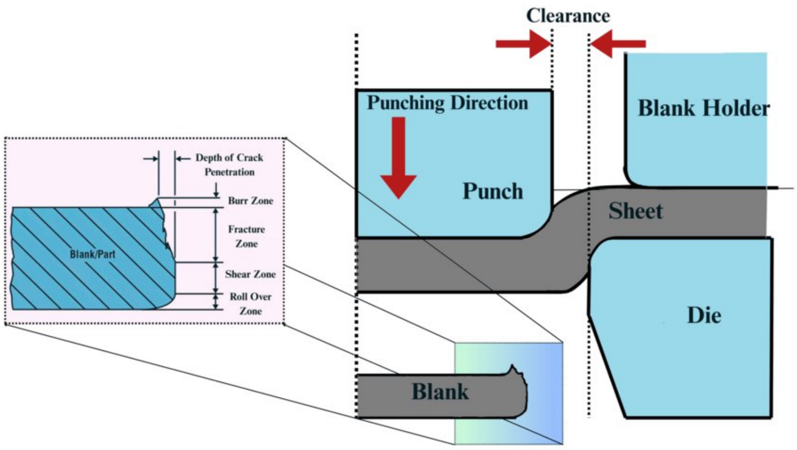

FIGURE 1: A schematic representation of the blanking process with geometry of sheared work piece

Influencing factors and errors in the blanking process

The accuracy of the blanking process can be affected by multiple factors, including positional, dimensional, and form errors, as illustrated in Figure *2*. These errors can stem from variables such as material type, tool geometry, process variations, and the condition of the machinery used. Among these, the punch-die clearance and tool geometry are the most significant factors influencing blanking performance [3,6,7].

Achieving the optimal clearance setting requires proper alignment of the diagonal angle (θ_d), which is formed by the line connecting the crack initiation points on both the punch and die, with the crack propagation angle (β), as illustrated in Figure *3*. In Figure *3*, Points A and B represent the crack initiation points from the punch and die, respectively, while t denotes the sheet thickness. Ensuring precise alignment of these factors is essential for controlling fracture mechanics and minimizing burr formation, leading to high-quality blanked components in aluminium applications [8-10].

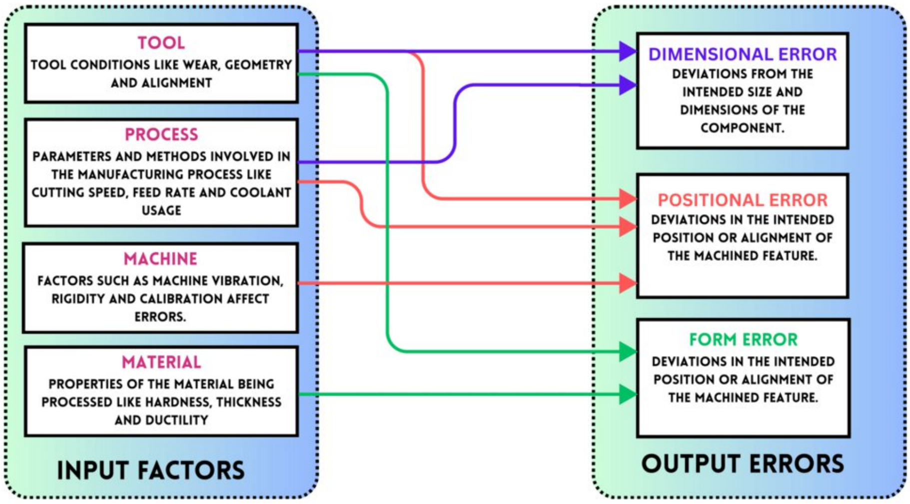

FIGURE 2: Input factors affecting output errors in blanking process

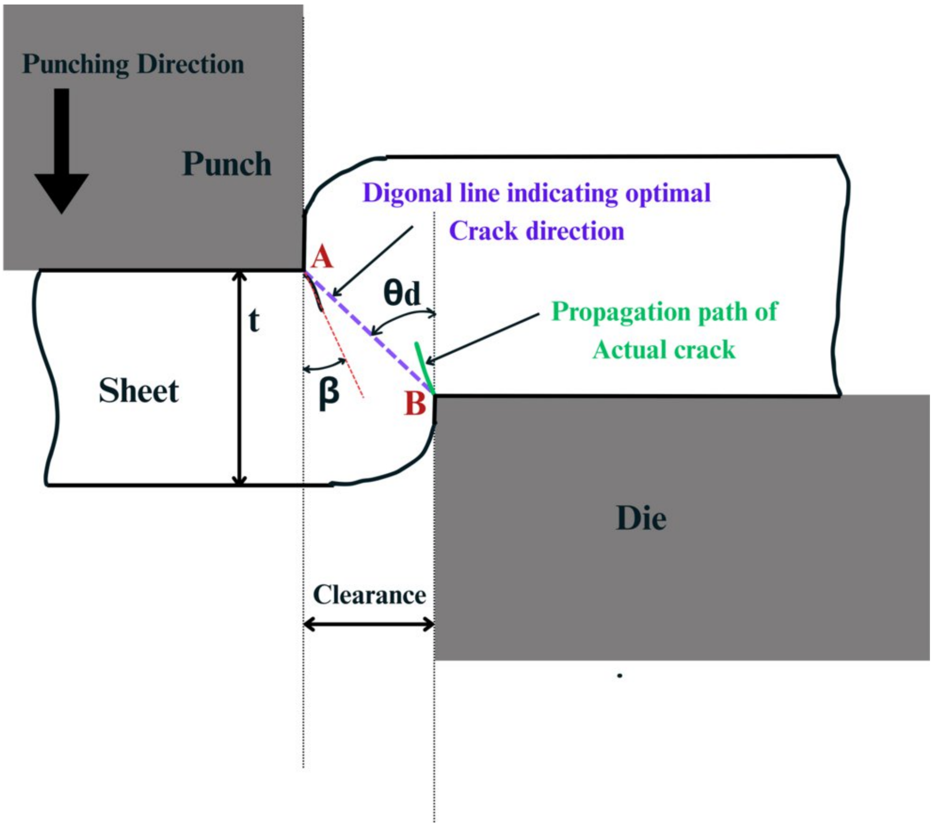

FIGURE 3: Illustration of the punch and die clearance with crack propagation and diagonal angle

Literature review

Optimizing punch-die clearance in the blanking process is a critical aspect of minimizing burr formation, reducing blanking force, and ensuring dimensional accuracy. Numerous researchers have employed experimental, statistical, and computational techniques to achieve optimal blanking conditions.

DOE and Taguchi-based optimization: Several studies have extensively utilized the DOE and Taguchi methods to enhance blanking performance. Hambli emphasized the effectiveness of DOE for optimizing process parameters, demonstrating that optimal clearance settings minimize deformation and improve dimensional accuracy [1]. Thipprakmas applied Taguchi's method to investigate the impact of V-ring indenter geometry in fine-blanking processes, confirming that optimized punch configurations significantly reduce burr height and enhance cut-edge quality [5]. Similarly, Bhoir et al. explored various DOE and Taguchi techniques for optimizing blanking conditions, reinforcing that parameter control within a 5%-10% clearance range ensures minimal defects and improved product quality [6].

Finite Element Method (FEM)-based prediction and optimization models: FEM simulations have proven to be highly effective in predicting and optimizing blanking parameters. Hambli and Guerin developed a hybrid FEM-neural network model that accurately predicts optimal punch-die clearance values, significantly improving precision in blanking outcomes [4]. Myint et al. further validated FEM's predictive capabilities by applying clearance-dependent fracture criteria to analyze burr formation in Steel Plate Cold Commercial steel, successfully reducing tool wear and improving cut-edge precision [9].

Process parameter analysis for improved blanking performance: Several researchers have investigated the influence of process parameters on burr formation and blanking efficiency. Maiti et al. analyzed the role of thickness, ductility, and tensile strength, concluding that reduced clearances increase blanking load but minimize deformation, ultimately improving dimensional precision [2]. Çavuşoğlu examined punch radius and clearance effects, revealing that optimizing punch geometry minimizes burr height and enhances product consistency [7]. Shelke and Naseem reinforced this by integrating FEM and DOE techniques, which effectively reduced burr height through parameter optimization [8].

Advanced optimization techniques: Neural Networks and Genetic Algorithms: Incorporating artificial intelligence (AI) and machine learning techniques has further enhanced the optimization of blanking processes. Hambli and Guerin introduced a neural network model integrated with FEM to predict optimal clearance values, achieving superior precision in parameter control [4].

Material-specific findings in blanking processes: Studies have shown that material properties significantly impact blanking performance. Bhoir et al. explored the blanking of soft steel, demonstrating that appropriate clearance settings are vital for reducing burr formation and improving edge quality [3]. Hambli and Myint et al. emphasized that maintaining clearance within 5%-10% of sheet thickness ensures optimal results in various metals, including aluminium, brass, and steel [1,9].

Numerical and simulation-based analysis: Researchers have also applied advanced simulation tools to analyze blanking performance. Rawali used ANSYS Explicit Dynamics to examine the influence of process parameters on blanking outcomes, emphasizing the role of optimized clearance settings in minimizing deformation and tool wear [11]. These simulations effectively demonstrated the interplay between clearance values, material thickness, and blanking force.

Research gap: While extensive research has been conducted on optimizing punch-die clearance using DOE, FEM simulations, and AI-based techniques, gaps remain in developing a comprehensive hybrid approach that integrates statistical optimization with predictive modeling for aluminium blanking. Most existing studies primarily focus on either experimental methods or computational models in isolation, lacking a unified framework that combines their strengths. Additionally, limited research has explicitly quantified the influence of process parameters on burr height using a predictive regression model validated with experimental data. This study addresses these gaps by employing a hybrid methodology that combines Taguchi's DOE with multiple regression analysis to systematically optimize punch-die clearance and minimize burr formation in aluminium blanking.

Literature outcome: The integration of DOE, Taguchi analysis, FEM simulations, and advanced optimization techniques such as neural networks and genetic algorithms has significantly enhanced the precision and efficiency of the blanking process. Studies collectively highlight that maintaining clearance values within 5%-10% of sheet thickness is critical for achieving optimal outcomes. By combining experimental methods with predictive modeling techniques, researchers have effectively minimized burr formation, improved dimensional accuracy, and enhanced tool life in various blanking operations.

Materials And Methods

In the Taguchi experimental design methodology, the number of experiments is determined using an orthogonal array (OA), which facilitates the evaluation of various parameter effects on performance characteristics. This structured approach ensures a systematic analysis by first identifying the key parameters influencing the process [5]. Once the critical parameters are established, the corresponding levels at which each parameter varies are defined. The OA then provides an optimized set of experimental combinations based on the number of selected parameters and their levels [3].

In this study, aluminium is considered, with two primary parameters, thickness and clearance, being analyzed. Each parameter is assigned three distinct levels, leading to the selection of an L9 orthogonal array, which is specifically designed to accommodate two parameters with three levels each. The selection of punch thickness levels (0.5 mm, 0.8 mm, and 1.5 mm) is based on common industry standards for aluminium blanking, ensuring practical applicability across various sheet metal applications. A three-level approach is chosen to effectively capture the variation in burr height while maintaining experimental efficiency. Similarly, the punch-die clearance levels (5%, 10%, and 15% of sheet thickness) were selected based on literature and industrial practices. Clearances below 5% can lead to excessive tool wear and higher blanking forces, whereas clearances above 15% may cause excessive burr formation and reduced edge quality [2,8]. The chosen range ensures a balanced evaluation of the clearance effect on blanking performance while maintaining process feasibility. This experimental framework as shown in Table *1* enables a comprehensive assessment of the impact of these variables on the blanking process while minimizing the number of required trials.

Ex. No.	1	2	3	4	5	6	7	8	9
Thickness (mm)	0.5	0.5	0.5	0.8	0.8	0.8	1.5	1.5	1.5
Clearance (%)	5	10	15	5	10	15	5	10	15

TABLE 1: Taguchi design of L9 orthogonal array

All of the above experiments are performed on Hydraulic Power Press of 10 tonne capacity and samples are collected for all nine experiments. Vernier Height Gauge is also used for calculation of burr height (Least Count 0.001 mm).

Results

Taguchi-signal to noise ratio analysis (SNRA)

Blanked samples of aluminium are collected for all nine experiments and values are represented in Table *2*.

Ex. No.	Thickness (mm)	Clearance (%)	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	SNRA	MEAN of burr height (mm)
1	0.5	5	0.1123	0.1127	0.12130	0.11290	0.10990	18.8706	0.113820
2	0.5	10	0.1346	0.1299	0.13350	0.13560	0.13430	17.4842	0.133580
3	0.5	15	0.1723	0.1767	0.16890	0.17890	0.17650	15.1543	0.174660
4	0.8	5	0.0888	0.0887	0.08892	0.08841	0.08851	21.0446	0.088668
5	0.8	10	0.1231	0.1145	0.11430	0.12720	0.11340	18.5160	0.118500
6	0.8	15	0.1523	0.1534	0.16430	0.16440	0.16760	15.8892	0.160400
7	1.5	5	0.0632	0.0645	0.06570	0.06330	0.06370	23.8646	0.064080
8	1.5	10	0.0995	0.0993	0.09910	0.09010	0.09340	20.3224	0.096280
9	1.5	15	0.1267	0.1256	0.12900	0.12360	0.12460	17.9985	0.125900

TABLE 2: Response table for signal to noise ratio and mean of burr height

SNRA, signal to noise ratio analysis

The influence of a variable on the process is more significant when its delta value is higher. Based on SNRA and Mean Analysis, the delta value for clearance exceeds that of thickness, as illustrated in Table *3*. This indicates that clearance is the most significant factor affecting the blanking process. Figure *5* presents the mean burr height value as a horizontal line. Generally, a smaller mean value, corresponding to reduced burr height, signifies improved product quality in the blanking process. To achieve the optimal burr height, the recommended settings are A3-B1.

Level	SNRA		Mean Analysis of Burr	
	A (Thickness)	B (Clearance)	A (Thickness)	B (Clearance)
1	17.17	21.26	0.14069	0.08886
2	18.18	18.77	0.12252	0.11612
3	20.73	16.35	0.09542	0.15365
Delta	3.56	4.91	0.04527	0.06480
Rank	2	1	2	1

TABLE 3: Response table for signal to noise ratio and mean of burr height

SNRA, signal to noise ratio analysis

The main effects plot for means illustrates the relationship between burr height and the two critical parameters: material thickness and punch-die clearance. The data in Figure *4* indicate that burr height decreases significantly as material thickness increases from 0.5 mm to 1.5 mm, with the minimum burr height observed at the highest thickness level. Similarly, lower punch-die clearance (5%) results in minimal burr height, reinforcing that reduced clearance minimizes edge deformation during the blanking process [3].

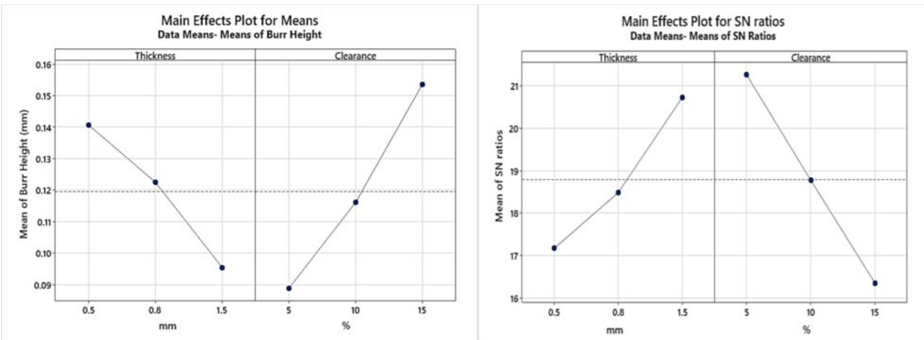

FIGURE 4: Main effect plot for mean of burr height and SN ratios

SN, signal to noise

The main effects plot for signal-to-noise (S/N) ratios, from Figure *4*, utilizing the "Smaller is Better" criterion, validates the stability of these optimal settings. The highest S/N ratio is observed at the maximum thickness (1.5 mm) and minimum clearance (5%), confirming that these settings produce the most consistent and reliable results with minimal variation. The S/N ratio increases with thickness and decreases with clearance, indicating that higher thickness improves the robustness of the process, while higher clearance introduces variability and increases burr formation.

Thus, the optimal parameter settings for aluminium blanking are determined to be a material thickness of 1.5 mm and a punch-die clearance of 5%. These settings yield the lowest burr height and ensure process stability, as evidenced by the highest S/N ratio. This analysis aligns with the fundamental principles of sheet metal blanking, where increased material thickness enhances rigidity, and minimal clearance reduces shear zone irregularities, leading to superior cut quality and dimensional accuracy.

Multiple regression analysis

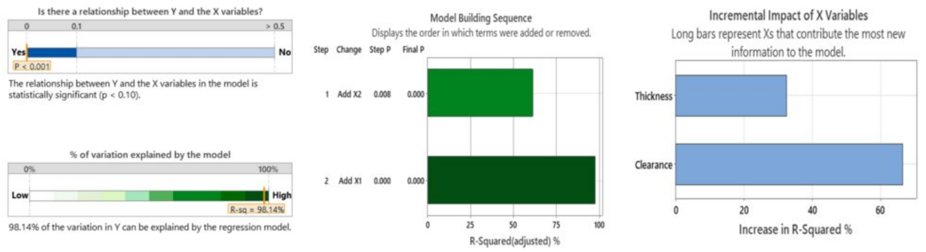

FIGURE 5: Statistical analysis and model interpretation

The statistical analysis indicates a significant relationship between the dependent variable Y and the independent variables X1 and X2 within the developed regression model. The p-value is $p < 0.001$, confirming that the model is statistically significant at a 99.9% confidence level. This suggests that the predictor variables have a substantial impact on the response variable.

The coefficient of determination (R-squared) is 98.14%, demonstrating that 98.14% of the variation in the response variable Y is explained by the selected predictor variables within the regression model. This high R-squared value signifies an excellent fit of the model to the data, indicating its reliability for predictive purposes.

Figure *5* shows the model-building sequence that illustrates the order of inclusion of predictor variables. The variable X2 (Clearance) was added first, significantly improving the adjusted R-squared value. Subsequently, X1 (Thickness) was included, further enhancing the model's explanatory power. Both variables exhibit a p-value of <0.001, indicating their strong significance in predicting the output variable.

The incremental impact analysis reveals that Clearance contributes the most to the model's explanatory power, accounting for approximately 65% of the increase in R-squared. Thickness also adds considerable value, contributing around 35% to the overall model fit. This analysis underscores the critical influence of Clearance in the blanking process, highlighting its primary role in determining optimal process outcomes, with Thickness playing a secondary yet significant role.

The Regression equation generated from the sample data of aluminium is,

$$\text{BURR HEIGHT} = 0.09591 - 0.04411A\ (\text{Thickness}) + 0.006480B\ (\text{Clearance}) \tag{1}$$

The above-obtained equation quantitatively defines the influence of punch thickness and punch-die clearance on burr height in the aluminium blanking process. The negative coefficient for thickness indicates that increasing sheet thickness reduces burr height, highlighting its critical role in minimizing edge defects. Conversely, the positive coefficient for clearance signifies that larger punch-die clearances result in higher burr formation. This mathematical model provides a precise prediction of burr height, offering a robust framework for optimizing blanking parameters to achieve high-quality edges and improved process efficiency.

Discussion

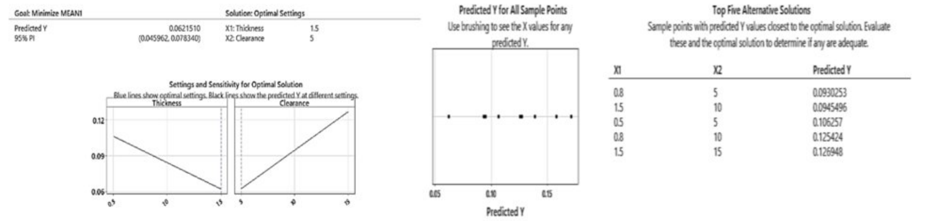

FIGURE 6: Prediction of optimal settings and alternative solutions to minimize burr height

The optimal settings as shown in Figure *6* derived from the multiple regression analysis are as follows:

Thickness (X1) = 1.5 mm and Clearance (X2) = 5%. The predicted minimum response (burr height) at these settings is 0.0621519 mm with a 95% prediction interval of (0.0456492, 0.0786546).

Sensitivity analysis: Sensitivity plots shown in Figure *6* indicate the response variation across different settings. The blue lines indicate optimal settings, while black lines represent predicted responses. The top five alternative settings with their predicted Y values are provided, with the optimal solution being the most efficient, though alternatives are close in predicted response values. This analysis emphasizes the importance of Clearance and Thickness in the blanking process, with the selected optimal settings minimizing the response variable efficiently.

Contour plot and interaction plot of burr height vs clearance and thickness

Contour plot analysis: The contour plot highlights the relationship between burr height, thickness, and clearance. The plot from Figure *7* shows that burr height increases as clearance increases, with the effect being more pronounced for thinner sheets. The gradient of the contour lines indicates that even slight changes in clearance can significantly impact burr height, especially when working with thinner materials. Conversely, thicker sheets exhibit a more gradual change in burr height, suggesting that thickness helps mitigate the adverse effects of larger clearances.

Interaction plot analysis: The interaction plot reveals how burr height is influenced by the interaction between thickness and clearance. A linear trend is observed in Figure *8* where burr height increases as clearance increases, regardless of the thickness. However, the plot indicates that the 1.5 mm thickness consistently results in the lowest burr heights across all clearance settings, making it the most favorable thickness for minimizing burr height. The divergence of the lines at higher clearances highlights that thinner sheets are more susceptible to burr formation when clearance increases.

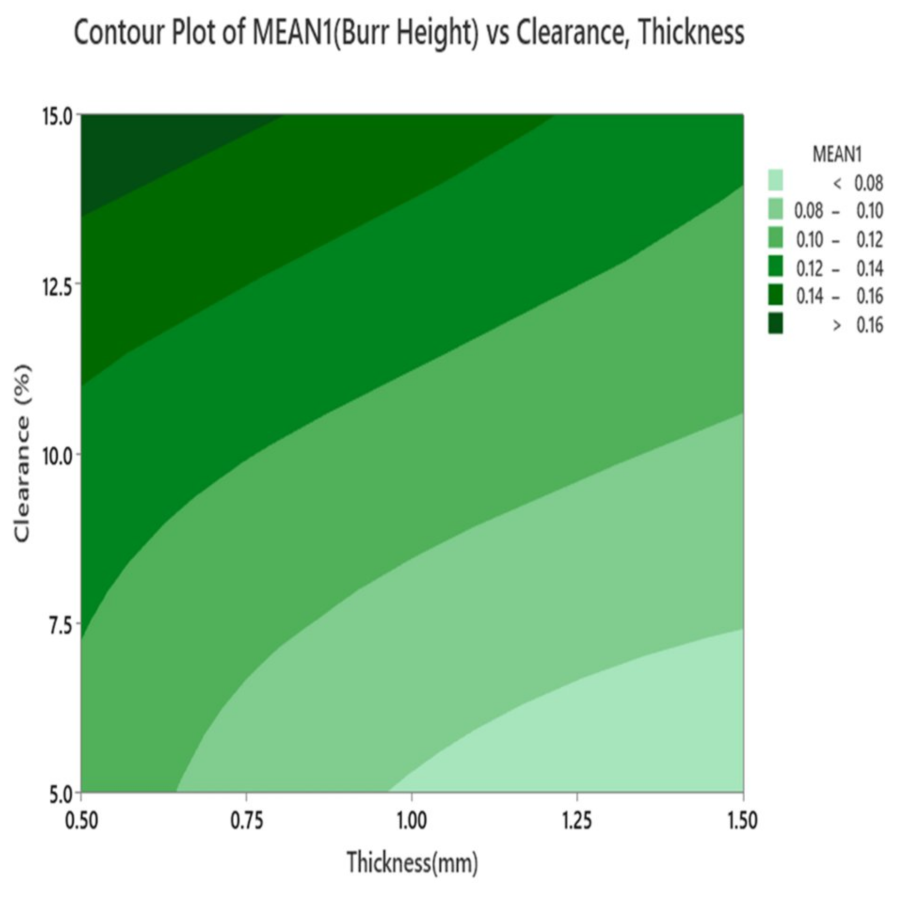

FIGURE 7: Counter plot of MEAN (burr height) vs clearance, thickness

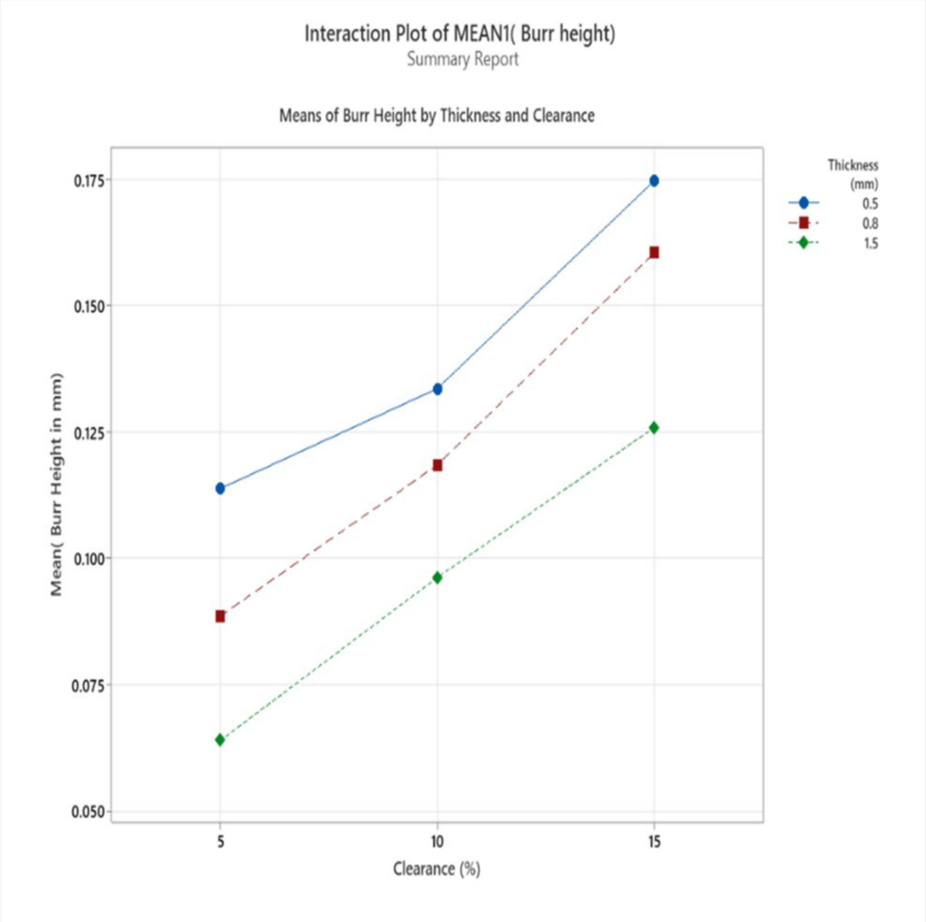

FIGURE 8: Interaction plot of mean vs thickness, clearance

Conclusions

This study successfully optimized punch-die clearance in the aluminium blanking process using a hybrid Taguchi DOE and multiple regression analysis approach. The findings demonstrated that a 1.5 mm punch thickness and 5% clearance yielded the minimum burr height of 0.0611 mm, with a 95% prediction interval, ensuring solution robustness. Contour plot analysis indicated that burr height increased by 32%-45% when clearance exceeded 10%, particularly in thinner sheets, highlighting the importance of precise clearance control. The interaction plot revealed a linear correlation between burr height and clearance across all thickness levels, with 1.5 mm punch thickness consistently delivering optimal results.

From an industrial perspective, these findings offer practical benefits for small and medium-scale manufacturers by providing a cost-effective, experimentally validated approach to minimize defects and improve dimensional accuracy in aluminium blanking. By implementing the optimized parameters, industries can potentially achieve a 20%-30% reduction in tool wear, improved edge quality, and enhanced productivity. The integration of statistical optimization and predictive modeling ensures repeatability and robustness, making it a viable solution for high-precision sheet metal applications.

This hybrid approach not only enhanced the accuracy of predictions but also provided flexibility in selecting alternative parameter combinations with acceptable burr height levels. The integration of Taguchi and regression analysis proves to be an effective strategy for optimizing critical parameters in the blanking process, offering valuable insights for industries aiming to improve the quality and precision of sheet metal components. Future work could explore additional process variables, such as punch velocity and lubrication effects, while integrating machine learning models for real-time predictive optimization of blanking performance.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Swapnil S. Bhoir, Manoj M. Dongare

Acquisition, analysis, or interpretation of data: Swapnil S. Bhoir, Manoj M. Dongare, Munna Verma

Drafting of the manuscript: Swapnil S. Bhoir, Manoj M. Dongare

Critical review of the manuscript for important intellectual content: Swapnil S. Bhoir, Manoj M. Dongare, Munna Verma

Supervision: Swapnil S. Bhoir, Manoj M. Dongare, Munna Verma

Disclosures

Human subjects: All authors have confirmed that this study did not involve human participants or tissue. **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

References

1. Hambli R: Design of experiment based analysis for sheet metal blanking processes optimisation. The International Journal of Advanced Manufacturing Technology. 2002, 19:403-10. 10.1007/s001700200041
2. Maiti SK, Ambekar AA, Singh UP, Date PP, Narasimhan K: Assessment of influence of some process parameters on sheet metal blanking. Journal of Materials Processing Technology. 2000, 102:249-56. 10.1016/s0924-0136(99)00486-0
3. Bhoir SS, Dongare MM, Verma M: Experimental analysis and optimization of clearance between punch and die in sheet metal blanking process for soft steel. Journal of Mines Metals and Fuels. 2024, N/A:1-5. 10.18311/jmmf/2023/45490
4. Hambli R, Guerin F: Application of a neural network for optimum clearance prediction in sheet metal blanking processes. Finite Elements in Analysis and Design. 2003, 39:1039-52. 10.1016/s0168-874x(02)00155-5
5. Thipprakmas S: Application of Taguchi technique to investigation of geometry and position of V-ring indenter in fine-blanking process. Materials & Design (1980-2015). 2010, 31:2496-500. 10.1016/j.matdes.2009.11.046
6. Bhoir S, Dubey D, Dongare M: An overview of optimization techniques utilized in sheet metal blanking processes. International Journal of Advanced Research in Science, Communication and Technology. 2023, 3:83-87. 10.48175/568
7. Çavuşoğlu O: An investigation of punch radius and clearance effects on the sheet metal blanking process. International Journal of Automotive Science And Technology. 2022, 6:309-16. 10.30939/ijastech..1190699
8. Shelke RD, Naseem K: Review on investigation and optimization of blanking process using FEM and DOE technique to analyze the influence of process parameters on the burr height. Advancement in Mechanical Engineering and Technology. 2021, 4:1-7. 10.5281/zenodo.5734354
9. Myint PW, Hagihara S, Tanaka T, Taketomi S, Tadano Y: Application of finite element method to analyze the influences of process parameters on the cut surface in fine blanking processes by using clearance-dependent critical fracture criteria. Journal of Manufacturing and Materials Processing. 2018, 2:26. 10.3390/jmmp2020026
10. Mohan Kumar RC, Velmurugan C: Development of mathematical modeling and its exploration based on genetic algorithm for blanking die design parameters optimization. Applied Mechanics and Materials. 2018, 877:54-59. 10.4028/www.scientific.net/amm.877.54
11. Rawali Y, Soujanya KSL, Prasad KS, Rao CS : Influence of process parameters in blanking using ANSYS explicit dynamics. International Journal of Composite Materials and Matrices. 2018, 4:4-20.