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Optimization and analysis of process parameters of CO2 laser cutting process in stainless steel-Review

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Abstract:
Metal cutting industries face the challenge of enhancing productivity and sheet metal part quality, especially regarding dimensional accuracy and surface finish. Laser cutting, widely employed across various sectors, offers precision and flexibility but poses challenges like heat generation and oxidation. High pressure and variable cutting velocity result in heat buildup at the torch-sheet interface, causing issues such as burning, roughness, and burr formation, notably in thick stainless-steel sheets. Excessive heat can also induce thermal stress, affecting part flatness. Nitrogen gas use in laser cutting can mitigate these challenges by preventing oxidation, improving surface finish, and enhancing cutting speed, albeit with drawbacks like operational costs and safety risks. Exploring alternatives to minimize nitrogen usage while optimizing input parameters is crucial for achieving maximum dimensional accuracy and minimum burr on cut edges in finished parts.
Keywords - AISI SS304, ANOVA, Burr, Cutting Surface, DOE, Laser cutting, Process Optimization, RSM

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I. Introduction

Laser-beam cutting machining utilizes highly coherent light for precise material removal, making it a prominent unconventional manufacturing process capable of cutting various materials with intricate shapes. This method offers numerous advantages for metal fabrication, including higher processing accuracy, superior cut quality with reduced surface roughness, narrower cut width for material saving, minimal heat-affected zone, and increased productivity. Additionally, it boasts characteristics such as high precision, low noise, no tool wear, and minimal waste generation, eliminating the need for cutting lubricants.

Laser technology finds extensive applications beyond cutting, encompassing wire stripping, cosmetic surgery, circuit skiving, drilling, marking, welding, sintering, and heat treatment across industries ranging from military and aerospace to medical and manufacturing. Its versatility extends to materials such as stainless steel, aluminum alloy, wood, rubber, plastic, brass, and Hardox-400, demonstrating its broad utility across diverse sectors

The utilization of CO2 laser cutting processes for stainless steel materials stands at the forefront of modern manufacturing techniques, offering unparalleled precision and efficiency. In this study, we embark on an exploration into the investigation and optimization of CO2 laser cutting processes specifically tailored for stainless steel. Our focus lies on employing Design of Experiment (DOE) techniques to comprehensively analyze the influence of process parameters on two crucial aspects: dimensional accuracy and burr height. With stainless steel serving as a pivotal material in numerous industries, ensuring precise dimensional accuracy and minimizing burr height are paramount for achieving high-quality finished products. Through systematic experimentation and optimization methodologies, this research aims to provide valuable insights into the intricate interplay between process parameters and the resulting dimensional accuracy and burr height

II. Literature

K. Rajesh, V.V. Murali Krishnam Raju, S. Rajesh, and N. Sudheer Kumar Varma explore laser-beam cutting for precise material removal, emphasizing advantages like minimal heat zones and low noise. Investigating CO2 laser parameters for SS-304 Stainless Steel, they analyze laser power, cutting speed, and gas pressure with Surface Roughness (Ra) and Kerf width (Kw) as output responses. Using ANOVA and regression, optimal inputs are determined, employing AMADA Quattro FANUC AF1000E laser cutter with Nitrogen assist gas. Surface roughness and kerf width guide modeling, with laser power identified as a key factor. The study emphasizes the efficacy of laser beam cutting machining in achieving precise outcomes for SS-304 Stainless Steel.[1]

Authors D. J. Kotadiya and D. H. Pandya presented a study on the optimization of laser cutting parameters, crucial for enhancing productivity and quality in metal processing, using stainless steel-304 as the workpiece material. The study employs Design of Experiment (DOE), Analysis of Variance (ANOVA), and Response Surface Methodology (RSM) to analyze and optimize cutting parameters such as laser power, cutting speed, and gas pressure, considering workpiece surface roughness. Results highlight laser power's significance, with gas pressure and cutting speed also influential. Regression analysis identifies optimal parameter values for minimizing surface roughness, improving cut section quality and efficiency. The study emphasizes expert knowledge in laser technology and offers insights for optimal cutting conditions in manufacturing industries.[2]

Ahmet Cekic, Derzija Begic-Hajdarevic, Malik Kulenovic, and Alma Omerspahic investigate the optimization of laser cutting parameters to enhance productivity, accuracy, and quality in metal processing. The study emphasizes the advantages of laser cutting, such as precise cut surfaces, narrow kerf width, and minimal heat affected zones. Investigating input parameters like laser type, power, cutting speed, and assist gas pressure, along with output parameters like surface roughness and heat affected zone width, the research develops mathematical models through regression analysis. These models optimize cutting parameters for high-alloyed steels, considering factors like cutting speed and assist gas type and pressure. Experimental results validate the models, emphasizing the importance of N2 assist gas for improved cutting surface quality.[3]

Vi Nguyen, Faisal Altarazi, and Thanh Tran explore laser cutting parameter optimization for enhanced productivity and quality in metal processing, emphasizing the need for expertise in laser technology. They review previous research, discussing factors like power and cutting speed's impact on surface quality and optimization methods like DOE. Stainless steel (304) is used as a workpiece material. The study highlights the importance of considering factor interactions, presenting regression models and ANOVA tables. Optimal parameter sets are determined using RSM and Taguchi methods, with RSM outperforming in minimizing dimensional error. Overall, the paper offers insights for selecting methodologies and settings to improve laser cutting processes.[4]

H.K. Hasan's research paper explores the optimization of laser cutting parameters, focusing on gas pressure, cutting speed, and power supply for 4 mm thick stainless steel. Using factorial design and response surface modeling, the study examines the influence of these parameters on surface roughness and kerf width. ANOVA identifies significant factors affecting kerf width, with speed having the most significant effect, followed by power and pressure. The study concludes that the optimal parameters for achieving a small kerf width are a power supply of 1250 W, cutting speed of 500 mm/min, and pressure of 104.154 bars, resulting in a quality improvement of up to 35%. Recommendations for further research include investigating additional parameters such as auxiliary gas flow rate and composition to enhance predictability and optimize cutting outcomes.[5]

Sangwoo Seon, Jae Sung Shin, Seong Yong Oh, Hyunmin Park, Chin-Man Chung, Taek-Soo Kim, Lim Lee, and Jonghwan Lee investigate methods to enhance thick steel plate cutting using a 6-kW fiber laser. They explore preheating techniques and compare constant speed cutting with waiting time and step-like speed increase approaches. Waiting time showed initial improvement but was sensitive to conditions, while step-like speed increase demonstrated simplicity and improved performance. Optimal conditions achieved a cutting speed of 72 mm/min, 2.4 times higher than constant speed cutting, confirmed by temperature measurements. The study highlights significant potential for improving cutting performance in various industrial applications, including nuclear facility dismantling, through laser technology.[6]

Engin Nas and Sabri Uzuner conducted a study to optimize laser cutting parameters for AISI 304 stainless steel, aiming to enhance manufacturing efficiency and part quality. Various factors like gas pressure, cutting speed, and frequency significantly affect cutting outcomes, with higher speeds reducing surface roughness and kerf width. Optimal parameters of 5.1 bar pressure and 3200 mm/min cutting speed are identified using the Taguchi method. ANOVA analysis highlights cutting speed's dominant impact on surface roughness. Regression analysis establishes a predictive model for different parameters. Overall, Nas and Uzuner emphasize the importance of fine-tuning laser cutting parameters to enhance part quality, productivity, and cost-effectiveness in manufacturing [7]

Irene Buj-Corral, Lluís Costa-Herrero, and Alejandro Domínguez-Fernández focused on investigating the laser cutting of AISI 304 stainless steel sheets, aiming to optimize cutting parameters and minimize roughness, dimensional error, and burr thickness. Utilizing an AlphaLaser AC200 Nd-YAG machine, experiments varied frequency, pulse width, and speed, analyzing their impact on cut quality. Results highlighted pulse frequency as most influential on roughness, while pulse width significantly affected dimensional error, and frequency primarily impacted burr thickness. Multi-objective optimization suggested high frequency (80 Hz), pulse width (0.6 mm), and speed (140 mm/min) for minimizing all three-quality metrics simultaneously.[8]

Ahmet Cekic and Derzija Begic-Hajdarevic conducted a comprehensive study aimed at optimizing laser cutting parameters for high-alloy steel. The research underscores the complexity of achieving optimal results in laser technology due to various interconnected factors. Key parameters such as cutting speed, assist gas pressure, and focus position were identified as crucial for enhancing cut quality. Through mathematical modeling using regression analysis, the authors determined optimal parameter values to minimize surface roughness and heat affected zone width, thus advocating for the efficacy of laser cutting technology. The study emphasizes the importance of comprehensive parameter optimization to maximize efficiency, material savings, and product quality.[9]

Sagar Hiwale and Rajiv Basavarajappa, probed experiments to optimize laser cutting parameters for Hastelloy C276, a high-alloy steel. Using a Prima 4000W CW CO2 laser cutting system, they analyzed the effects of laser power, cutting speed, gas pressure, working distance, and focal position on kerf width and taper. Employing response surface methodology (RSM), they developed regression models and used analysis of variance (ANOVA) to assess parameter significance. Desirability analysis identified optimal parameters, validated through confirmatory tests. Evolutionary optimization techniques, including the Blackhole and Krill herd algorithms, further optimized parameters. Results showed the Krill herd algorithm's faster convergence and better performance. The study highlights RSM and evolutionary algorithms' effectiveness in improving laser cutting efficiency and quality for high-alloy steels.[10]

Elyas Haddadi, Mahmoud Moradi, Ayub Karimzad Ghavidel, Ali Karimzad Ghavidel, and Saleh Meiabadi analyzed laser cutting's intricacies, particularly its application to polystyrene sheets. They focused on optimizing parameters like laser power, cutting velocity, and covering gas to achieve high-quality cuts. Their findings provide valuable insights into enhancing efficiency and accuracy in laser cutting processes for polystyrene, addressing a significant research gap. This research contributes to the advancement of manufacturing techniques, particularly in industries reliant on precise cutting of polymer materials.[11]

Miroslav Duspara, Waldemar Matysiak, Ivan Vidaković, and Simon Sedmak explored methods to optimize cutting parameters in fiber laser processes to reduce nitrogen consumption without sacrificing quality. By adjusting parameters such as focus distance, operating nitrogen pressure, and nozzle height, it was possible to achieve satisfactory cuts at lower pressures, leading to significant gas savings without compromising quality. The study highlighted the intricate relationship between cutting parameters and cutting quality, emphasizing the importance of parameter optimization for efficiency and cost-effectiveness in laser cutting processes. Overall, the findings provided valuable insights into optimization strategies for fiber laser cutting, offering a pathway for enhanced efficiency and savings in metal sheet processing.[12]

Sonagara Kaushik A and A. M Varsi discuss the principles and applications of laser technology, focusing on CO2, ND: YAG, and fiber lasers, and their roles in laser cutting processes. They highlight advantages such as high precision, complex shape cutting, and reduced contamination compared to traditional methods. The study outlines experimental setups conducted at JC METAL FAB, Sachin-Surat, using stainless steel 304 with varying plate thicknesses. Results indicate the effectiveness of laser cutting in achieving superior edge quality and dimensional accuracy, with the choice of assist gas (oxygen or inert gas) impacting the process. These findings contribute to understanding the practical applications of laser technology in industrial manufacturing, demonstrating its versatility and efficiency in various cutting applications.[13]

Sonagara Kaushik A and A. M Varsi examined the effects of laser power, cutting speed, and gas pressure on SS 304 sheet cutting using a

Bystronic 4020 fiber laser machine. With 17 experimental runs, they found that laser power significantly influences surface roughness, decreasing it with higher power. Cutting speed showed a slight increase in roughness, while gas pressure decreased roughness. Optimal parameters were determined as 5.25 kW power, 12 bar gas pressure, and 125 mm/min cutting speed, resulting in a minimum roughness of 9.89 µm. These findings highlight the potential to improve cutting quality and efficiency by adjusting process parameters.[14]

Mr. Umeshkumar Hiralal Chavan and Dr. Chetan Choudhary orchestrated a comprehensive investigation into laser cutting processes, particularly focusing on the application of laser technology on AISI 304 stainless steel. Their research delves into the optimization of laser cutting parameters to enhance surface quality and kerf characteristics. By utilizing response surface methodology (RSM) and mathematical modeling, they identified optimal values for laser cutting variables aimed at minimizing kerf taper, surface roughness, and dross formation. Through rigorous ANOVA analysis, the study elucidates the relative impact of each variable on kerf quality, providing valuable insights for the optimization of laser cutting processes to achieve superior efficiency and quality.[15]

III. Conclusion

Optimizing laser cutting parameters across diverse materials and applications, including SS-304 Stainless Steel, high-alloyed steels, and thick steel plates, is a focal point of recent research efforts. Studies underscore the pivotal role of laser power, cutting speed, and assist gas pressure, utilizing advanced methodologies like Design of Experiment (DOE), Analysis of Variance (ANOVA), and Response Surface Methodology (RSM) to refine these parameters. Investigations into various cutting strategies, such as preheating techniques and adjustments in cutting speed methodologies, reveal notable enhancements in cutting efficiency and surface quality. Validation through temperature measurements validates the efficacy of preheating methods, emphasizing the transformative potential of laser technology in bolstering productivity, precision, and quality across a spectrum of industrial sectors, spanning aerospace to nuclear facility dismantling.

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