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Optimization of CO_2 Laser Cutting Parameters for Sheet Metals

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***Abstract*--** **Laser cutting using CO_2 lasers has become a dominant non-traditional machining process in sheet metal manufacturing due to its high precision, flexibility, and productivity. The quality of laser-cut components is strongly influenced by process parameters such as laser power, cutting speed, assist gas type and pressure, and material thickness. In this study, an experimental investigation is carried out to optimize CO_2 laser cutting parameters for Mild Steel (MS) and Stainless Steel (SS) sheets. The effects of laser power, cutting speed, assist gas pressure, and material thickness on key quality characteristics such as kerf width and heat affected zone (HAZ) are analyzed. Experimental trials were conducted on a high-power CO_2 laser machining center under controlled conditions. The obtained results reveal that appropriate selection and optimization of process parameters significantly improve cut quality while maintaining high cutting efficiency. Comparative analysis between MS and SS sheets indicates distinct trends in kerf width and HAZ due to differences in thermal and optical properties. Based on experimental observations, optimized parameter combinations are recommended for achieving minimum kerf width and reduced HAZ in sheet metal laser cutting applications. The findings of this study provide useful guidelines for industrial practitioners and researchers involved in laser-based manufacturing processes.**

***Keywords*--** **CO_2 laser cutting, Process parameter optimization, Kerf width, Heat affected zone, Sheet metals**

I. INTRODUCTION

Laser cutting is one of the most widely used applications of laser technology in modern manufacturing industries, particularly for sheet metal processing. Among various laser sources, the carbon dioxide (CO_2) laser has been extensively employed due to its high efficiency, stable beam characteristics, and capability to cut a wide range of metallic and non-metallic materials. CO_2 laser cutting offers several advantages over conventional machining processes, including non-contact operation, narrow kerf width, minimal tool wear, high dimensional accuracy, and ease of automation.

In sheet metal industries, materials such as Mild Steel (MS) and Stainless Steel (SS) are commonly used in automotive, aerospace, structural, and general engineering applications. The quality of laser-cut components is primarily evaluated in terms of kerf width, surface roughness, and the extent of the heat affected zone (HAZ).

These quality characteristics are highly sensitive to laser cutting parameters such as laser power, cutting speed, assist gas type, assist gas pressure, focal position, and material thickness.

Improper selection of cutting parameters can result in excessive kerf width, large HAZ, dross formation, and poor edge quality, which may adversely affect subsequent manufacturing operations. Therefore, optimization of CO_2 laser cutting parameters is essential to achieve high-quality cuts with improved productivity and reduced operational costs.

Although several researchers have investigated laser cutting of different materials, systematic experimental optimization of CO_2 laser cutting parameters for MS and SS sheets under industrial conditions remains an important area of study. The present work focuses on experimentally analyzing the influence of key process parameters on cut quality and proposing optimized cutting conditions suitable for sheet metal applications.

II. OBJECTIVES OF THE PRESENT STUDY

The main objectives of this research work are as follows:

1. To experimentally investigate the effect of CO_2 laser cutting parameters on kerf width and heat affected zone (HAZ) for sheet metals.
2. To study the influence of laser power and cutting speed on cutting performance for different material thicknesses.
3. To analyze the role of assist gas pressure in controlling cut quality during laser cutting.
4. To compare the laser cutting behavior of Mild Steel and Stainless Steel sheets.
5. To determine optimized combinations of CO_2 laser cutting parameters for achieving minimum kerf width and reduced HAZ.

III. LITERATURE REVIEW

Laser cutting using CO_2 lasers has been widely investigated due to its extensive industrial applications and sensitivity to process parameters.

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Researchers have focused on understanding the influence of laser power, cutting speed, assist gas pressure, and material properties on cut quality characteristics such as kerf width, surface roughness, and heat affected zone (HAZ).

Scintilla et al. reported a comparative study between CO_2 and disk laser fusion cutting, highlighting that CO_2 laser cutting generally produces better cut quality for medium and thick steel sheets due to higher process temperatures and improved molten material ejection. Their work emphasized the importance of power balance and thermal behavior in determining kerf quality and edge roughness.

Riveiro et al. investigated CO_2 laser cutting of carbon fiber reinforced plastics and demonstrated that careful selection of laser parameters can significantly reduce HAZ while maintaining acceptable cut quality. Their findings underline the importance of parameter optimization even for thermally sensitive materials.

Syn et al. developed a fuzzy logic-based expert system to predict surface roughness and dross formation in CO_2 laser cutting. Their results showed strong correlation between experimental and predicted values, indicating that intelligent optimization techniques can effectively support parameter selection.

Li and Tsai employed grey relational analysis to optimize laser cutting parameters for electronic substrates, concluding that multi-objective optimization methods are effective in minimizing both surface roughness and HAZ simultaneously. Similar conclusions were drawn by Çaydaş and Hasçalık, who optimized laser cutting parameters for structural steel using Taguchi and grey relational approaches.

Stournaras et al. experimentally analyzed CO_2 laser cutting of aluminum alloys and established empirical relationships between laser power, cutting speed, and kerf characteristics. Their work confirmed that laser power is a dominant parameter affecting kerf width and HAZ.

Despite extensive research, limited studies focus on a comparative experimental optimization of CO_2 laser cutting parameters for Mild Steel and Stainless Steel sheets under identical industrial conditions. The present study addresses this gap by systematically analyzing and optimizing key process parameters to achieve improved cut quality for both materials.

IV. Experimental Setup And Methodology

4.1 Laser Cutting System

The experimental investigations were carried out using a CNC-controlled CO_2 laser cutting machine (Trumpf Trumatic L2530) installed at an industrial laser processing facility.

The machine is equipped with a high-power CO_2 laser source capable of delivering stable laser output suitable for sheet metal cutting applications. The laser system operates in continuous wave (CW) mode and is integrated with a closed-loop CNC controller to ensure precise control of cutting parameters and repeatability of experiments.

4.2 Workpiece Materials

Two commonly used engineering sheet metals, namely Mild Steel (MS) and Stainless Steel (SS), were selected for the present study. These materials are widely employed in automotive, structural, and general fabrication industries. Sheet specimens of varying thicknesses were prepared according to standard industrial practices. Prior to laser cutting, the sheets were cleaned to remove surface contaminants such as oil, dust, and oxide layers to ensure consistent cutting conditions.

4.3 Assist Gas and Optical Arrangement

Assist gases play a crucial role in laser cutting by facilitating molten material removal and influencing cut quality. In this study, oxygen was used as the assist gas for Mild Steel cutting, while nitrogen was employed for Stainless Steel cutting. The assist gas pressure was varied within a predefined range to study its effect on kerf width and heat affected zone (HAZ). The laser beam was focused using a suitable focusing lens, and the focal position was maintained near the workpiece surface for all experimental trials.

4.4 Process Parameters and Their Ranges

Based on preliminary trials and machine capability, key laser cutting parameters were selected for investigation. The primary process parameters considered in this study include laser power, cutting speed, assist gas pressure, and material thickness. These parameters were varied systematically while keeping other conditions constant to isolate their individual effects on cut quality characteristics. The selected ranges of parameters were chosen to reflect realistic industrial cutting conditions.

4.5 Experimental Procedure

Straight-line cutting experiments were conducted on MS and SS sheet specimens using the selected combinations of laser cutting parameters. Each experimental run was repeated to ensure consistency and reliability of results. After cutting, the samples were allowed to cool naturally to room temperature. Kerf width measurements were carried out using an optical microscope at multiple locations along the cut length, and average values were recorded. The extent of the heat affected zone (HAZ) was evaluated by visual inspection and microscopic examination of the cut edges.

4.6 Evaluation of Cut Quality

Kerf width and heat affected zone were considered as the primary quality characteristics for evaluating laser cutting performance. These parameters directly influence dimensional accuracy and mechanical integrity of laser-cut components. The measured data were analyzed to identify trends and relationships between process parameters and cut quality. Based on the experimental observations, optimized parameter combinations were identified for achieving minimum kerf width and reduced HAZ for both Mild Steel and Stainless Steel sheets.

V. Results And Discussion

The experimental results obtained from CO_2 laser cutting of Mild Steel (MS) and Stainless Steel (SS) sheets were systematically analyzed to understand the influence of key process parameters on cut quality. The analysis primarily focuses on kerf width and heat affected zone (HAZ), as these characteristics directly affect dimensional accuracy and edge integrity of laser-cut components.

5.1 Effect of Laser Power

Laser power was found to be one of the most influential parameters affecting both kerf width and HAZ. An increase in laser power resulted in higher energy input per unit length, leading to enhanced material melting and wider kerf formation. For both MS and SS sheets, kerf width increased with increasing laser power due to excessive heat input and lateral heat conduction. Similarly, higher laser power caused an expansion of the HAZ as more thermal energy penetrated into the surrounding material.

However, excessively low laser power led to incomplete cutting and poor edge quality, particularly for thicker sheets. Therefore, an optimum laser power range was identified where complete penetration was achieved with acceptable kerf width and minimal HAZ.

5.2 Effect of Cutting Speed

Cutting speed exhibited an inverse relationship with kerf width and HAZ. At lower cutting speeds, prolonged interaction time between the laser beam and workpiece resulted in excessive heat accumulation, producing wider kerfs and larger HAZ. As cutting speed increased, the exposure time decreased, thereby reducing heat input per unit length and improving cut quality.

For both materials, an optimum cutting speed was observed beyond which cut quality deteriorated due to insufficient energy input, leading to striation formation and incomplete cutting.

Stainless Steel required relatively lower cutting speeds compared to Mild Steel due to its lower thermal conductivity and higher reflectivity.

5.3 Effect of Assist Gas Pressure

Assist gas pressure significantly influenced molten material ejection and oxidation behavior during laser cutting. For Mild Steel, oxygen assist gas enhanced the cutting process through an exothermic reaction, improving cutting efficiency. However, excessive oxygen pressure resulted in increased kerf width and oxidation effects. In the case of Stainless Steel, nitrogen assist gas minimized oxidation and produced cleaner cut edges. Higher nitrogen pressure improved molten material removal but marginally increased kerf width due to mechanical erosion.

An optimal assist gas pressure range was identified for both materials, ensuring effective material ejection while maintaining minimal kerf width and controlled HAZ.

5.4 Influence of Material Type and Thickness

Material properties played a critical role in laser cutting behavior. Mild Steel generally exhibited larger kerf widths compared to Stainless Steel under identical cutting conditions due to its higher oxidation tendency in oxygen-assisted cutting. Stainless Steel showed comparatively narrower kerf widths but slightly larger HAZ due to reduced thermal conductivity.

An increase in material thickness necessitated higher laser power or lower cutting speeds to achieve complete penetration. Thicker sheets consistently resulted in increased kerf width and HAZ, highlighting the importance of parameter optimization for different thickness ranges.

5.5 Optimization of Laser Cutting Parameters

Based on experimental observations, an optimized combination of laser cutting parameters was identified for achieving minimum kerf width and reduced HAZ. The optimization strategy focused on selecting moderate laser power, higher cutting speed within stable cutting limits, and controlled assist gas pressure. The optimized parameter combinations differed for MS and SS sheets due to variations in thermal and optical properties.

For Mild Steel, oxygen-assisted cutting with moderate laser power and relatively higher cutting speed yielded superior cut quality. For Stainless Steel, nitrogen-assisted cutting with controlled power input and optimized cutting speed resulted in minimal oxidation, reduced kerf width, and acceptable HAZ. The analytical evaluation confirms that multi-parameter optimization is essential for achieving high-quality laser cutting performance in industrial sheet metal applications.

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VI. Conclusions

Based on the experimental investigation and analytical evaluation of CO_2 laser cutting parameters for Mild Steel and Stainless Steel sheet metals, the following conclusions are drawn:

1. Laser power and cutting speed were identified as the most influential parameters affecting kerf width and heat affected zone (HAZ) in CO_2 laser cutting of sheet metals.
2. An increase in laser power led to wider kerf formation and expansion of HAZ due to higher heat input, whereas excessively low power resulted in incomplete cutting and poor edge quality.
3. Higher cutting speeds reduced kerf width and HAZ by minimizing laser–material interaction time; however, very high speeds caused unstable cutting and striation defects.
4. Assist gas pressure played a significant role in molten material ejection and cut edge quality. Oxygen-assisted cutting of Mild Steel improved cutting efficiency, while nitrogen-assisted cutting of Stainless Steel produced cleaner, oxidation-free edges.
5. Material properties such as thermal conductivity and oxidation behavior caused noticeable differences in cutting performance between Mild Steel and Stainless Steel under identical cutting conditions.
6. Optimized combinations of moderate laser power, controlled assist gas pressure, and higher cutting speed within stable cutting limits resulted in minimum kerf width and reduced HAZ for both materials.
7. The optimized CO_2 laser cutting parameters obtained from this study provide practical guidelines for improving cut quality and productivity in industrial sheet metal fabrication.

VII. Scope For Future Work

The present study can be extended in several directions to further enhance the understanding and optimization of laser cutting processes:

1. Multi-objective optimization techniques such as Taguchi–Grey relational analysis or response surface methodology can be applied to simultaneously optimize kerf width, surface roughness, and HAZ.
2. Artificial intelligence-based modeling approaches, including artificial neural networks (ANN) and machine learning algorithms, may be employed for predictive analysis of laser cutting performance.
3. Comparative studies between CO_2 lasers and modern fiber laser systems can be conducted to evaluate cutting efficiency and quality for different sheet metals.
4. The influence of focal position, nozzle diameter, and beam mode on cut quality can be investigated for further refinement of cutting parameters.
5. Microstructural and metallurgical analysis of cut edges can be performed to assess mechanical property variations due to thermal effects.

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