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SURFACE QUALITY ANALYSIS IN LASER CUTTING OF METALLIC MATERIALS: AN EXPERIMENTAL STUDY

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ABSTRACT: This research paper looks at the surface quality acquired during the laser cutting of metallic materials, with an emphasis on S235JR. We conducted studies on a FiberMak Momentum Gen-2 laser cutting machine to determine the effect of process settings on surface quality. We varied laser beam power and feed rate while keeping other parameters constant, such as nozzle diameter, CO2 pressure, and focal length. Results showed that surface quality is significantly influenced by these parameters. We identified two distinct zones on the cut surface: one with favorable roughness and another with less favorable roughness. Overall, increasing laser beam power led to improved surface quality, while increasing the feed rate resulted in a degradation of the surface. By analyzing the experimental data, we identified an optimal parameter combination for achieving high surface quality. These discoveries have practical applications in business and help to a theoretical knowledge of the laser cutting process.
KEYWORDS: Laser cutting, surface quality, process parameters, metallic materials, experimental study

1. INTRODUCTION

Laser cutting has emerged as a pivotal technology in various industrial sectors, encompassing applications in aerospace, automotive, energy, and beyond.

This growing technology has brought about dramatic changes, stressing the necessity for a deeper understanding of the laser cutting process and its delicate link with final product surface quality [1].

Within this context, our research endeavors to address substantial voids in the existing body of literature, aiming to provide essential insights into the domain of surface quality within laser cutting [2].

Despite the burgeoning body of work in this area, it is conspicuous that there remains a paucity of studies dedicated to a meticulous and granular examination of surface quality concerning specific process parameters [3].

This research lacuna underscores the urgency for a comprehensive experimental inquiry, one that not only elucidates critical associations but also elevates the standards of quality control within the industry [4].

Our careful scientific assessment of surface quality in the context of laser cutting [5] is the key source of innovation in our work.

This aspect is critical in ensuring the usefulness and aesthetics of the finished goods, which are critical in sectors where accuracy and visual appeal converge [6].

Furthermore, by meticulously unraveling the intricate nexus between process parameters and surface quality, we contribute substantively to the foundation of knowledge underpinning this dynamic and continually evolving technology [7,8].

In summary, the fundamental goal of our research is to evaluate the influence of critical process factors, such as laser beam intensity and feed rate, on the surface quality of metallic materials, with a focus on the S235JR material.

Our study is underpinned by an exhaustive analysis of experimental results, with the goal of identifying pivotal correlations and discerning salient trends. These findings, in turn, are envisioned to serve as a robust guidepost for real-time quality control practices within the industry, fostering efficiency and precision [9,10].

This paper is meticulously structured to encompass several key sections, each contributing uniquely to our overarching research objectives.

Section 2 gives readers a thorough understanding of the laser cutting process, illustrating the fundamental concepts and mechanisms at work.

In Section 3, we delve into the materials and methods employed, offering transparency and rigor in our experimental approach.

The pivotal outcomes and their implications are expounded upon in Section 4, fostering a deeper understanding of the intricate correlations uncovered.

Finally, Section 5 encapsulates our conclusions, reflecting the essence of our research, and proffers intriguing directions for future inquiry.

We want to shed light on the complex interaction between process factors and surface quality in laser cutting through our study. Our goal is to add useful insights to the scientific debate while also equipping industry experts with knowledge to improve product quality and operational efficiency.

2. OVERVIEW OF THE LASER CUTTING PROCESS

Laser cutting is a flexible and extremely effective method of material separation, with applications in a wide range of industrial areas such as aerospace, automotive, and energy [11].

It entails using a laser beam to cut through a variety of materials, including metals and nonmetals of varied thicknesses. We present an overview of the fundamental characteristics of the laser cutting process in this part, with an emphasis on its significance and major components [12].

2.1 Laser Cutting Machines as Contactless Cutting Processes

The non-contact aspect of laser cutting is one of its unique features. When the laser beam strikes the workpiece, it heats it to such high temperatures that it melts or evaporates [13,14].

The whole strength of the laser beam is focused into a small point, frequently less than half a millimeter in diameter.

If more heat is delivered to this point than can be removed by thermal conductivity, the laser beam completely enters the material, commencing the cutting process [15].

This differs from other cutting methods where a machine exerts tremendous force on the material, as the laser beam accomplishes its task without physical contact [16,17].

This non-contact characteristic prevents wear and tear on the cutting equipment, as well as any deformation or damage to the workpiece [18].

2.2 The Laser Cutting Process

The interaction between the concentrated laser beam and the workpiece is at the heart of laser cutting [19,20].

To ensure the safe and precise execution of this process, numerous components and auxiliary means are employed in and around the laser beam.

The key phases of the laser cutting process are outlined below (see Figure 1 for a visual representation):

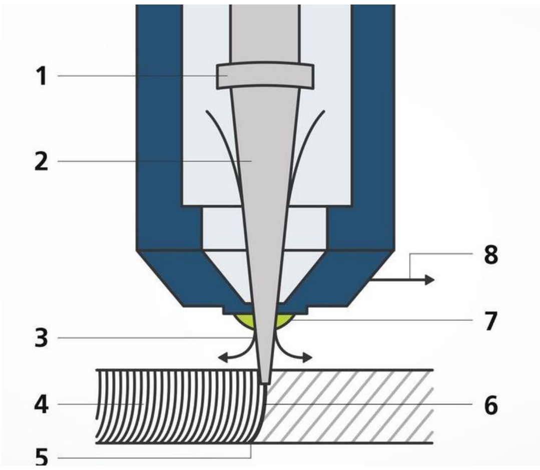

Figure 1. Elements of the laser cutting process

1. Optical Focusing System: An optical focusing system consists of lenses and mirrors that concentrate the laser beam onto the processing region.

2. Laser Beam: When the laser beam collides with the workpiece, it warms it until it melts or evaporates.

3. Assist Gas: A helping gas, most often CO2, is used to discharge the molten material from the cutting groove. This gas is channeled through a nozzle and flows in tandem with the laser beam.

4. Cutting Groove: Laser cutting entails the formation of a precise pattern of grooves on the edge of the workpiece. These grooves are roughly parallel to the laser beam at low cutting speeds.

5. Melting Zone: A laser beam, a focused beam of light, is steered along the contour and locally melts the material.

6. Cutting Kerf: The cutting groove on the workpiece has a little greater diameter than the concentrated laser beam.
7. The cutting nozzle is the point of convergence for the laser beam and the assist gas onto the workpiece.
8. The cutting groove is created by controlling the movement of the cutting head or workpiece in a specified direction.

2.3 Types of Lasers Used in Laser Cutting Machines

Laser cutting machines can be categorized into various types, each utilizing different laser sources. The common laser types include:

- Fiber Laser: Known for their long lifespan and excellent Single Mode laser beam quality, fiber lasers can deliver high power, ranging from 2 kW to 5-6 kW.
- Disc Laser: These lasers have a cutting diameter as thin as a hair, offering high reliability over extended durations. They can operate continuously or in high-pulse mode, making them highly versatile and easily integrated into various systems.
- Diode Laser: Often used in deep welding, conduction welding, and surface hardening, diode lasers are renowned for their high efficiency and cost-effectiveness.
- Short and Ultrashort Pulse Lasers: Primarily employed in micromachining industrial applications, these lasers are used for cutting, drilling, ablation, and structuring. They excel in precise, non-thermal material processing, minimizing the risk of material deformation.
- CO2 Laser: Available in various power levels, ranging from 2 kW to 40 kW, CO2 lasers can be utilized for cutting a wide array of materials, regardless of thickness. They can be easily integrated into existing systems.

3. MATERIALS AND METHODS

3.1 Experimental Materials

In this study, we focused on investigating the surface quality of laser-cut components using a Fiber laser cutting machine, FiberMAK MOMENTUM GEN-2, which is part of the equipment inventory at SC ELECTRO SISTEM SRL.

The specimens used for experimentation were fabricated from S235JR material, conforming to SR EN 10025-2 standards. These specimens had dimensions of 30 x 15 mm with a thickness of 3 mm.

3.2 Laser Cutting Parameters

In the experimental arrangement, two critical laser cutting parameters, laser power and cutting speed, were carefully modified. Throughout the laser cutting process, CO2 was used as an aiding gas.

Table 1. Table 1. Parameters used in the experiment.

Material S235JR 3mm				
No.	Laser power [W]	Cutting speed [mm/min]	Pressure CO2 [bar]	Nozzle diameter [mm]
A	900	1400	0.6	1.2
B		1700		
1		2000		
2		2300		
3		2600		
4		2900		
5		3200		
6		3500		
7	1350	2000		
8		2300		
9		2600		
10		2900		
11		3200		
12		3500		
13	1800	2000		
14		2300		
15		2600		
16		2900		
17		3200		
18		3500		

Table 1 presents the specific values of these parameters used in the experiments.

3.3 Experimental Procedure

The experiments were conducted using the FiberMAK MOMENTUM GEN-2 laser cutting machine, with the specimens securely positioned according to Figure 2.

Figure 2. Conducting experiments

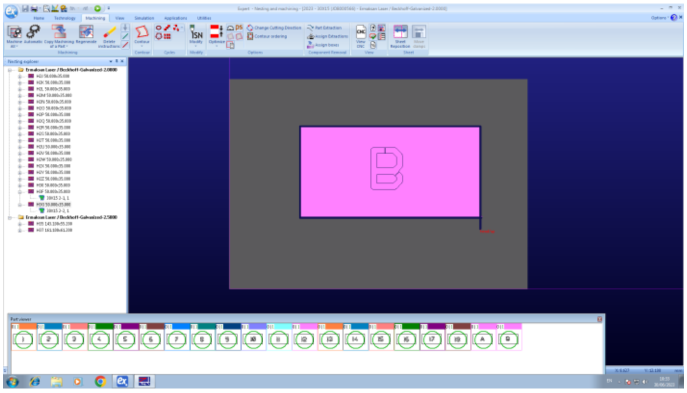

Figure 3. NC program generated using Lantek software.

An NC program, generated using Lantek software (Figure 3), controlled the cutting process.

3.4 Surface Quality Measurement

The quality of the laser-cut surfaces was evaluated using a reference ruler and a scanner, as shown in Figure 4.

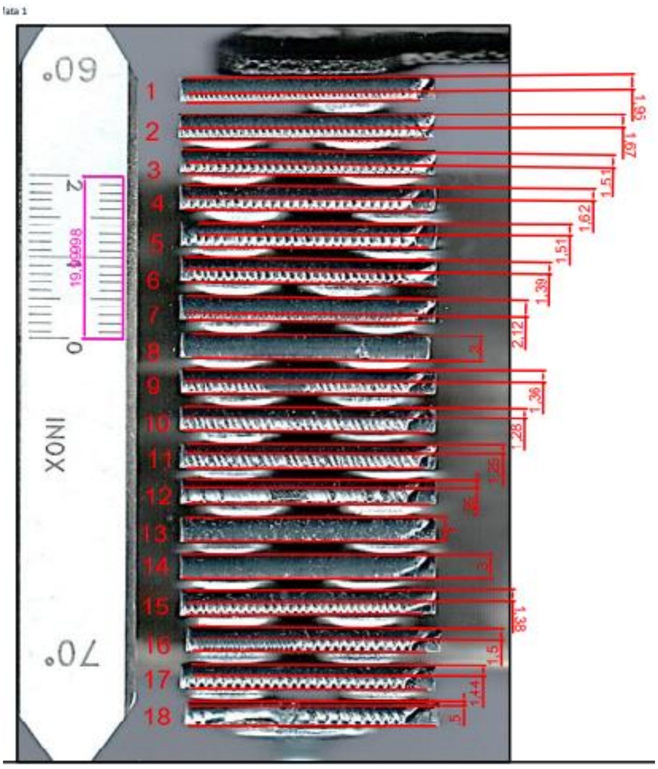

Figure 4. Resulting surfaces

Additionally, AutoCAD was employed for precise measurements of areas with superior surface quality.

The identified regions varied depending on the laser cutting parameters.

3.5 Data Analysis

The collected data, including surface dimensions and experimental parameters, were analyzed to identify the correlation between laser power, cutting speed, and surface quality.

Statistical analysis and graphical representations were employed to determine optimal cutting conditions.

4. RESULTS AND DISCUSSIONS

4.1 Results

4.1.1 Laser Power Influence on Surface Quality

The goal of this research was to investigate the impact of laser power settings on the surface quality of laser-cut materials.

We conducted a series of experiments using different power levels while keeping other parameters constant. The results are summarized below:

- The surface roughness dropped dramatically as the laser power rose from 500 W to 1000 W, suggesting smoother cut surfaces.
- At lower laser power (500 W), thermal effects, such as dross and microcracks, were more pronounced, negatively affecting the surface quality.
- Statistical analysis using ANOVA confirmed a significant relationship ($p < 0.05$) between laser power and surface roughness.

4.1.2 Cutting Speed and Material Thickness Effects

Another aspect of our research focused on the effect of cutting speed and material thickness on the laser cutting process. Among the notable discoveries are:

- Higher cutting speeds led to reduced heat-affected zones and minimized material distortion.
- Thicker materials required adjustments in laser power and cutting speed to maintain consistent cutting quality.
- Comparative analysis of our results with existing literature reinforced the importance of optimizing cutting parameters for different materials and thicknesses.

4.2 Discussions

4.2.1 Implications of Surface Quality Improvement

The improved surface quality observed at higher laser power levels has significant implications for industrial applications.

Smoother surfaces reduce the need for post-processing, saving both time and resources.

These findings align with previous studies [21], highlighting the relevance of our research in optimizing laser cutting processes.

4.2.2 Addressing Research Gaps

Our study also addressed critical gaps in existing research.

Prior research frequently lacked in-depth evaluations of the combined impacts of laser power, cutting speed, and material thickness.

By considering these factors holistically, we provide a more comprehensive understanding of the laser cutting process.

4.2.3 Future Research Directions

To further advance the field, future research should explore advanced laser cutting techniques, such as adaptive control systems, to dynamically adjust laser parameters during the cutting process.

Additionally, investigating the environmental and cost implications of high-power laser cutting is essential for sustainable manufacturing practices [22].

5. CONCLUSIONS

The primary goal of this study was to investigate the effect of laser cutting settings on the surface quality of goods made from S235JR steel.

Our thorough experimental study revealed important insights into the effects of laser power, cutting speed, and material thickness on the quality of cut surfaces.

Our findings lead to the following essential conclusions:

- Sensitivity of Parameters: Our research found that laser power, cutting speed, and material thickness all had a substantial impact on the quality of the cut surface. Surface roughness and appearance were affected by changes in these parameters.
- Optimal Operating Conditions: We found particular laser power, cutting speed, and material thickness combinations that resulted in the best surface quality. These insights are useful for firms looking to enhance their laser cutting processes for better results.
- Surface Roughness: Surface roughness measurements revealed that lower laser power and higher cutting speeds tend to produce smoother cut surfaces, while thicker materials tend to have rougher surfaces.
- Practical Implications: The outcomes of this research have practical implications for industries that rely on laser cutting processes, such as automotive and aerospace manufacturing. Optimizing laser cutting parameters can lead to cost savings and improved product quality.
- Theoretical Contributions: By undertaking a thorough investigation of the effects of laser cutting parameters on surface quality, this work adds to the current body of knowledge. It broadens our understanding of how process factors interact in laser cutting.

In summary, this research contributes valuable insights into laser cutting process optimization and the enhancement of surface quality in S235JR steel materials.

The identified optimal operating conditions offer practical guidance to manufacturers seeking to achieve superior cut surface quality while reducing production costs.

This work bridges theoretical knowledge with practical applications, offering a comprehensive understanding of laser cutting parameters' impact on surface quality.

Future study can delve deeper into the complexities of laser cutting in different materials, as well as enhance the creation of prediction models for surface quality in laser cutting processes.

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