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Review Article

An extensive review of the effects of laser cutting parameters on metal surface and kerf quality

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Abstract

The aerospace, marine, automotive, construction, and military industries, as well as ordinary consumer items, place a great deal of significance on sheet metals such as titanium alloys, steel alloys, and aluminum alloys. Understanding how laser cutting parameters affect cutting quality is crucial since laser cutting has become a top non-conventional technology for precision sheet metal cutting. This thorough analysis explores the complex link between the parameters used in laser cutting and the final surface quality and kerf characteristics, identifying the parameters that have the biggest influence on cutting quality. This review also provides a detailed comparison that emphasizes the benefits of laser cutting over conventional machine methods. It also explores the nuances of laser cutting, differentiating between different laser sources and their unique properties in terms of material thickness and advantages. Moreover, it offers a thorough analysis of the characteristics and range of uses of the materials being studied. The review provides a methodical classification of the examined literature by carefully defining performance parameters with the use of graphical representations and equations, and by arranging research analysis and discussions with the use of detailed tables and graphs. In order to produce the best results in terms of low surface roughness, minimal heat-affected zone (HAZ) width, narrow kerf width, and ideal kerf angle, it is crucial to use certain parameters, which include low laser power, high cutting speed, moderate gas pressure, adequate standoff distance, intermediate pulse frequency and width, small nozzle diameter, decreased material thickness, and nitrogen as an assist gas.

1. Introduction

An improvement in machining methods is the laser cutting process, which uses heat energy to cut materials without making physical touch. A monochromatic coherent light beam is produced by a laser, which stands for "light amplification by stimulated emission of electromagnetic radiation." Because of their coherent nature, lasers are excellent for focusing on small regions, which is useful in a variety of industrial and medical applications. Lasers are widely used in manufacturing, from precisely drilling tiny holes to precisely completing welds and even cutting thick metal sheets with exceptional accuracy and tolerance. One of the main benefits of lasers is their adaptability; unlike other types of light sources, they don't require particular environments to function, such vacuum or gas shielding [1, 2]. A wide variety of materials, including metals, ceramics, polymers, composites, and both conductive and non-conductive materials, may be cut with great potential

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using laser cutting [3]. Because of their remarkable mechanical qualities, materials including composites, ceramics, steel, aluminum, and titanium alloys in particular present difficulties [4-6].

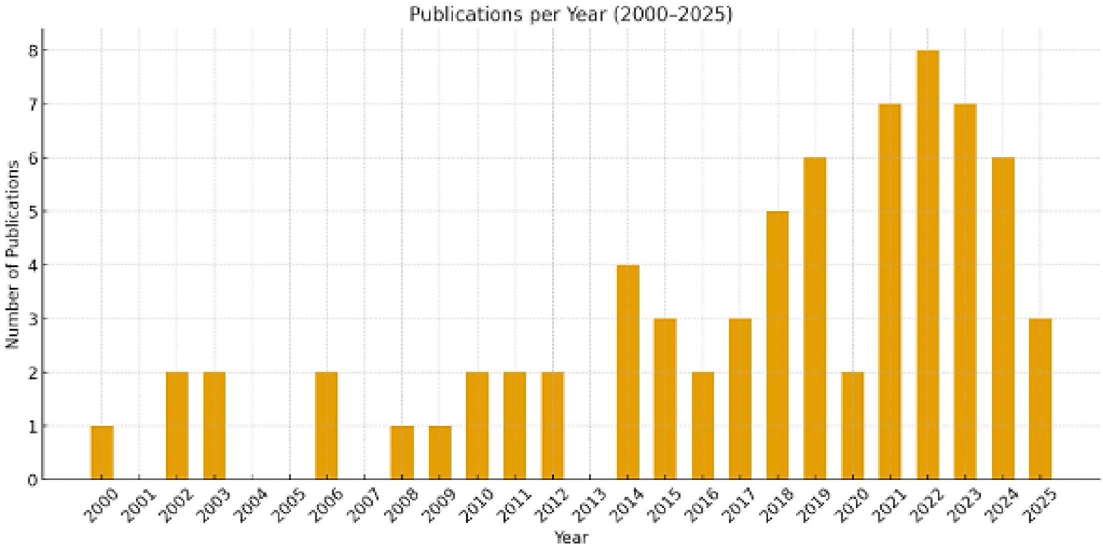


Fig.1. Based on the publications chosen for this review, the total number of published papers in laser cutting from 2000 to 2025

Based on the papers chosen for this study, Figure 1 shows the quantity of published papers or reviews on laser cutting from 2000 to 2025. The increased trend suggests that the use of laser cutting methods to cut sheet metals of the materials under study has been steadily increasing. Increased production rates and better industrial processes are the result of the high degree of precision attained in the cut surface and the shorter machining time. Therefore, when compared to other cutting-edge techniques and conventional ways of metal cutting, laser cutting techniques have many benefits and few negatives. This comparison will be covered in more detail later. Moreover, the data indicates a change in the focus of laser machining techniques from mainly studying medium-hard materials to hard materials. This shift ensures better precision in comparison to other non-traditional machining techniques and offers increased efficiency by reducing the time-consuming mistakes associated with old processes. Surprisingly, from 2017 to the first part of 2025, research on laser cutting techniques increased significantly to 47 articles that were published in just 5 years, as opposed to 45 papers over the course of 16 years, from 2000 to 2016. This exponential rise highlights how laser cutting techniques are becoming more and more important in modern research. As a result, these results point to a positive future trend in which laser cutting techniques are expected to come under even more scrutiny and attention.

1.1 Description of the Laser Cutting Method

One thermal cutting technique that is widely used in industrial manufacturing is laser cutting. As seen in Figure 2, this procedure makes use of a laser beam, which is normally produced by a laser cutting machine (LBC). The apparatus aims a monochromatic, high-power, coherent laser beam with wavelengths ranging from infrared to ultraviolet onto the workpiece's surface. The laser beam transfers energy to the workpiece when it impacts, which causes the material's targeted spot to rapidly heat up. Apart from the increased temperature, the characteristics of the material being sliced and the laser beam's intensity also have an impact on the surface of the cut. This mixture produces a very hot region that is highly concentrated. As a result, the substance melts and evaporates, and occasionally it may also go through chemical changes before being released with the use of a high-pressure support gas [7–13].

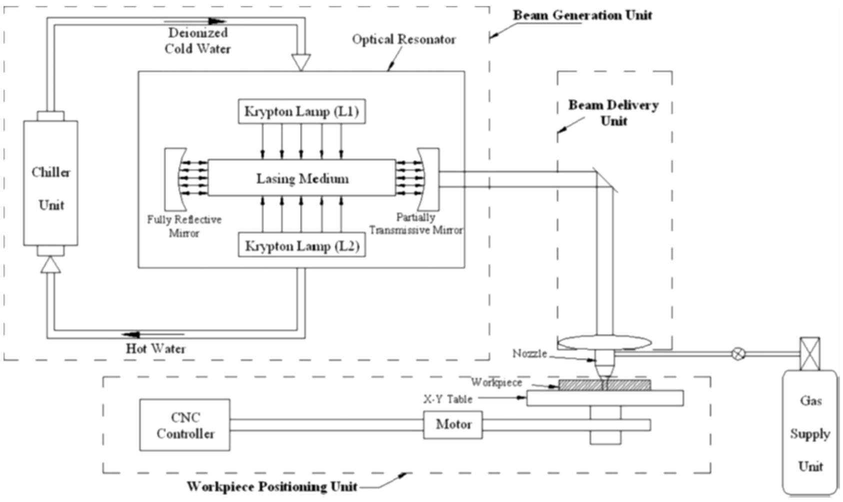


Fig. 2. Laser cutting machine schematic diagram [14]

1.2 The Benefits and Drawbacks of Laser-Assisted Machining and Laser Cutting Processes in Relation to Other Traditional Machining Techniques

When it comes to cutting, laser cutting has several benefits over traditional techniques like drilling, milling, and turning. These advantages include the achievement of precisely cut surfaces, reduced material waste, and higher cut quality [1]. However, standard machining processes encounter substantial problems because of the high mechanical qualities inherent in materials such as steel alloys and titanium alloys [15, 16]. These difficulties can take many different forms, including increased machining pressures, asymmetrical dimensions, high machining temperatures, shortened tool life from wear [17], and worse surface finish. As such, it presents a problem for cutting effectiveness [16, 18]. However, some research has tried to mitigate this problem by preheating titanium alloys before cutting, which shortens processing time and reduces cutting problems [19]. In order to improve cutting quality and extend tool life by reducing cutting pressures, researchers have since looked at using the laser source as a heat source [20, 21]. Additionally, Inconel 718 was milled using a laser-assisted method, which demonstrated a direct relationship between the cutting speed and the size of the melted region, as well as an inverse relationship between the laser beam's power [22]. Furthermore, this method was applied once more to predict surface roughness values during the milling of Inconel 718 [23]. Further evidence that laser-assisted machining performs better than conventional methods come from a number of research that compared the two techniques [9, 24].

However, even with its automated benefits, the laser cutting technology has several significant disadvantages. These disadvantages include the high cost of the machine's initial investment and continuous operation. Furthermore, a variety of input elements have a substantial influence on the cut's quality. As a result, achieving high-quality cuts requires adjusting process parameters—a task that changes based on the material qualities. Furthermore, it's critical to keep an eye on any changes in the cut material surface's microstructure since quick cooling can have unfavorable impacts that could cause failure [25].

1.3. Benefits and Drawbacks of The Laser Cutting Process in Relation to Other Unconventional Machining Techniques

As a result, several research have focused only on non-traditional machining methods, as ultrasonic machining (USM) [28, 29], abrasive water jet machining (AWJM) [27], laser machining (LM) [26], and abrasive water jet–assisted laser machining (AWJALM) [30]. These substitute procedures are acknowledged for their increased velocity and effectiveness over traditional techniques. Of these, laser cutting machining is the most popular option since it has a number of benefits over abrasive water jet and plasma machining, such as shorter operating times and lower energy costs, as well as the ability to cut without hardening the metal beforehand [31].

1.4. Types of Lasers Cutting Sources and Their Respective Uses

1.4.1 CO_2 Laser

CO_2 laser as shown in Fig. 3, is one of the most well-known kinds of lasers used in the mechanical industries to cut metallic materials. It has the capacity to cut metals with a range of thicknesses while preserving excellent cut quality [34]. Because of its high temperature, significant output power, and excellent beam quality, the CO_2 laser is the most widely used kind of laser source in laser cutting applications [10, 35, 36].

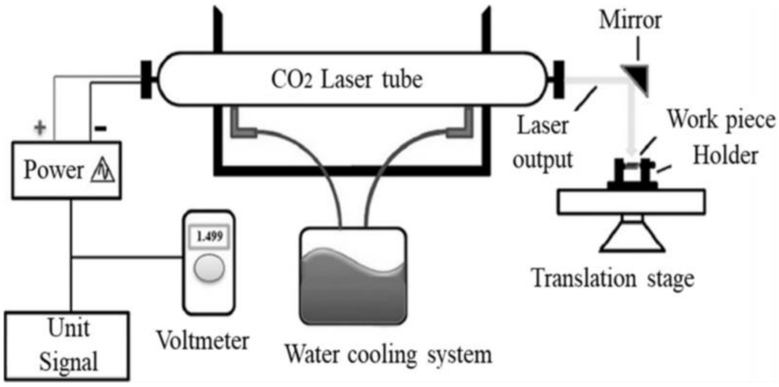


Fig. 3. Diagram of CO_2 LBC [37]

1.4.2 ND: YAG Pulsed Laser

Figure 4 shows a solid-state pulsed Nd-YAG machine that is widely used for sheet metal cutting. Its increased peak power and shorter pulse length allow it to cut larger materials, demonstrating its applicability beyond only thinner sheet metal [38]. It also finds use in welding and precision cutting of thin sheet metals, as well as in micro welding procedures such seam welding of small electromechanical components [39, 40].

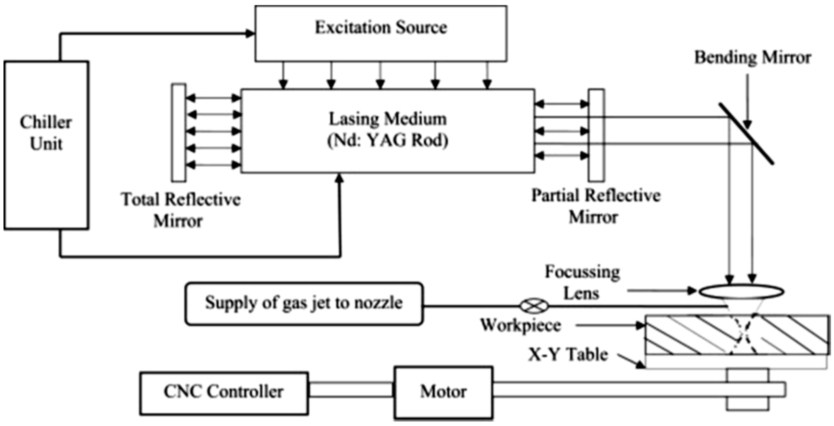


Fig. 4. Diagram ND:YAG LBC [41]

1.4.3 Fiber Laser

Superior cutting qualities of the fiber laser machine, shown in Fig. 5, allow for quicker and more accurate cutting of thin sheets, including steel sheets up to 4 mm thick. Fig. 6 shows that, for thicknesses more than 4 mm, the cut surface quality achieved by fiber laser cutting at the same cutting speed is not as good as that achieved by CO_2 laser cutting. This picture shows the AISI 304 material's cut surfaces that were produced at different thicknesses over 4 mm utilizing fiber laser and CO_2 laser sources.

One may directly measure the previously indicated cut quality by looking at surface roughness [34]. As a result of its low absorption at the metal surface, fiber laser cutting big portions is less advantageous [42]. Because of the fiber laser's high focusing power, the kerf width is narrowed, which causes the assist gas flow inside the kerf to separate close to the lower cut surface. This separation increases uncontrolled burning and molten material removal in close proximity to the bottom surface by causing flow instability at the lower cut surface. In the end, this results in a lower-quality cut surface and a thicker bottom kerf width [43].

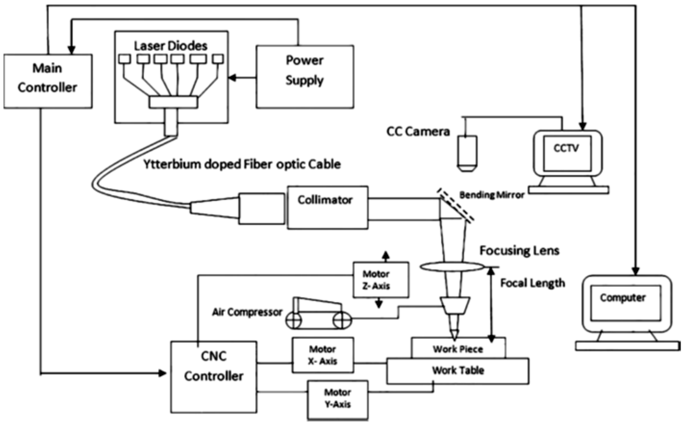
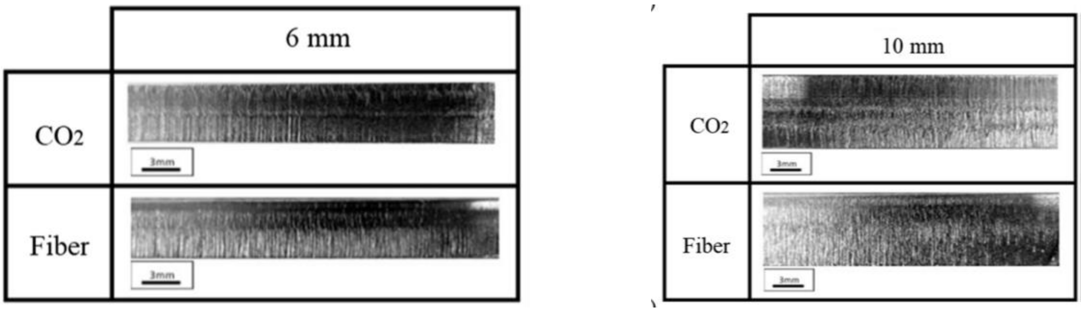


Fig. 5. Diagram of fiber LBC [44]



(a) (b)

Fig. 6. Pictures of the AISI 304 material's sliced surfaces produced at varying thicknesses utilizing Two distinct laser sources, such as CO_2 and fiber laser: Thickness: (a) 6 mm; (b) 10 mm [45]

An overview of previous review articles and an explanation of the latest developments Table 1 presents the material included in this review article as well as the contributions made by previous review studies.

Table. 1. A comparison between this review paper's contribution and that of earlier review articles

Ref.	Summary	Current Contribution
11	The study examined steel alloy behavior under CO2 laser cutting, examining variables like thickness, material type, and optimization strategies, and highlighting the use of various researchers in the field.	The table of steel alloy studies in this review discusses three types of alloys: titanium, steel, and aluminum. Titanium alloys are high strength, steel alloys are medium strength, and aluminum alloys are low strength.
9	The study investigated the processes of material removal rate and laser cutting for conventional machining of hard materials such as ceramics, nickel alloys, and titanium alloys.	To demonstrate how cutting parameters affect MRR, the material removal rate is introduced as a performance metric in the discussion. A thorough analysis and discussion of various alloys are also included.
10,36	The experiments looked at how different cutting settings affected how well different technical materials are performed when machined using CO2 lasers.	This work offers a thorough analysis of metal alloys, enhancing the text with a wealth of illustrations and graphs, in-depth input and output parameters, and further research.
12	The paper provides useful parameters for the laser cutting process and examines the background, uses, and parameters of laser-	This review enhances the quality of the material offered by presenting the latest research and

	assisted machining with an emphasis on mechanical and metallurgical qualities.	offering thorough information through tables, figures, and graphs.
14	The ND-YAG laser technology for cutting complicated geometries, its experimental applications, and the processes behind material removal rate are all examined in this paper.	This article examines the effects of MRR mechanisms and the ND-YAG laser technique on laser beam production, with particular attention to how these effects affect the cutting characteristics of three distinct materials.
37	The research looked at how different aluminum alloys were made with a CO2 laser beam, determining a number of variables and their impacts.	A thorough table of aluminum alloy research is included in this study, along with a discussion of how these studies affect the laser beam input parameters when utilizing different laser sources other than CO2.

1.5. The purpose of this Research

Recently, a lot of experimental research has been done to increase the laser cutting process. Thus, this paper offers a thorough analysis with the goal of determining which laser cutting parameters have the most effects on metal surface quality and how they affect metal surface quality in general. A summary of the benefits of laser cutting over alternative machining techniques is also included, along with some information on the quantity of articles that have been published throughout the last 22 years. This research also provides a thorough explanation of the laser cutting process, lists the many laser sources, and clarifies the range of material thicknesses that are appropriate for each source, as well as each source's benefits. The examination also explores the characteristics and uses of the materials being studied. Graphs and equations are used to offer a thorough grasp of the procedure, the properties of the laser beam, and the performance parameters of the laser cutting method.

Tables and graphs are used to convey the study analysis and debate in an orderly fashion, offering a thorough categorization of the examined publications. The articles are categorized in these tables and graphs according to a number of factors, such as the authors, the year the work was published, the thick material, assist gas, kind of laser source, input parameters, performance parameters, and each paper's main conclusions. Bullet points are used in the discussion section to show how various cutting parameters affect the cutting method's performance. The relationship between these impacts and performance metrics such dross height, kerf breadth, kerf taper, heat-affected zone, and surface roughness is examined.

2. Materials and Their Characteristics

The distribution of examined articles among the chosen papers for this review, broken down by material type, is shown in Figure 7. Because steel is used in so many different applications, the figure shows that studies in the subject of laser cutting are primarily concerned with the investigation of steel alloys.

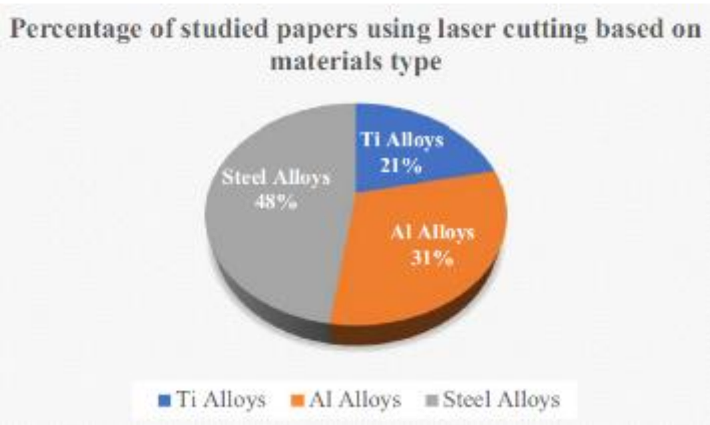


Fig. 7. Depending on the kind of material, the laser cutting procedure for the examined papers

Furthermore, given that titanium alloys have received relatively less study attention than steel and aluminum alloys, the chart indicates that titanium alloys constitute a viable field for future laser cutting research. This is perhaps because cutting titanium alloys with a laser cutting process presents some difficulties. Response surface methodology to optimize fiber laser cutting of AZ31B magnesium alloy, identifying nozzle distance and laser power as key factors influencing temperature variation and surface roughness. The results provide precise parameter settings for improved cut quality while revealing oxidation effects on kerf edges [87].

2.1 Titanium Alloys

Titanium alloys in particular, Ti-6Al-4V have extraordinary mechanical and chemical characteristics, such as excellent resistance to heat, oxidation, and corrosion. They also have notable toughness, excellent tensile strength, and a high strength-to-weight ratio. Ti-6Al-4V typically exhibits a tensile strength of about 900–950 MPa, a yield strength of 830–880 MPa, and a hardness of approximately 350, along with excellent corrosion resistance, making it ideal for high-performance applications [92]. Due to their qualities, they are widely sought-after materials for usage in a wide range of sectors, such as the chemical, petrochemical, automotive, offshore oil and gas, water desalination, power generation, and biomedical industries [15, 16, 46–50]. Titanium alloys are usually produced from wrought bar stock or by CNC machining after casting. Advancements in laser cutting of titanium alloy plates, covering process parameters, auxiliary gas effects, and their influence on microstructure and mechanical properties. It effectively links martensitic phase transformation, residual stresses, and surface features to performance degradation, while highlighting predictive modeling for process optimization [86].

Nevertheless, despite Ti Alloys' advantageous properties in real-world applications, tool damage is frequently seen, mostly as a result of temperature increase, stress, and vibration in the machining area [51, 52]. In addition, Ti alloys are very difficult to machine because of their great strength, low heat conductivity (about 80% lower than that of steel), and high temperature chemical reactivity with tool materials. These elements increase the risk of cutting tool damage and significantly shorten tool life. The quality of the cut surface is further compromised by chatter and spring-back caused by the comparatively low Young's modulus of titanium alloys [53, 54].

2.2 Steel Alloys

Steel is combined with other elements, including silicon, boron, vanadium, chromium, nickel, manganese, and molybdenum, to create steel alloys. This combination improves qualities like hardness, wear resistance, and toughness. The range of alloying element proportions is 1 to 50%. Low alloy and high alloy are the two primary categories into which alloy steels are divided. It is commonly known that a 5% alloying element often indicates the barrier that separates low alloy steel from high alloy steel. Low alloy steel is the main type of alloy steel used in the oil and gas sector [55]. Furthermore, steel alloys are difficult to cut for the reasons listed below [9, 56]: (i) Because of the material's extreme strength and hardness, the cutting tool broke during the machining process. (ii) Steel alloys have a high dynamic shear strength, which frequently forms during cutting coupled with abrasive saw teeth and localized stress. (iii) The instrument transfers heat far more quickly when temperatures are raised to about 1000°C. (iv) The majority of tool materials react with steel alloys at high temperatures, which accelerates tool wear. Optimizes laser cutting parameters for AISI 304 stainless steel, showing cutting speed as the dominant factor in reducing surface roughness and kerf width. The Taguchi and variance analyses provide clear guidelines for achieving superior surface quality with minimal dimensional deviation [85].

2.3 Aluminum Alloys

Aluminum alloys find applications across various industries such as aerospace, machinery, automotive, and food manufacturing. The weight-saving properties of aluminum have become increasingly crucial, particularly in the development of fully electric vehicles. Additionally, aluminum's ability to absorb energy in collisions enhances the safety of vehicles constructed with this material compared to those made of traditional steel. However, cutting aluminum presents several challenges compared to cutting steel due to the following reasons [57–62]:

- Aluminum has a thermal conductivity of 205.0 W/mK, which is almost four times greater than that of steel (50.2 W/mK for steel). This causes a quick dissipation of heat, which causes the heat-affected zone to absorb laser energy. As such, the main methods of cutting are vaporization and superficial removal.
- Because aluminum alloys absorb less laser beam energy than other materials, they have high reflectivity and require more laser power to cut effectively.
- Aluminum oxide, or Al2O3, is formed during cutting when oxidation takes place in the cutting region. Alumina is another name for this substance. At 2072°C, alumina has a very high melting point. Furthermore, alumina provides thermal isolation because of its low thermal conductivity of 30 W/mK. This low thermal conductivity prevents heat from being transferred to the metal plate while it is being sliced.
- The two most popular industrial laser sources for cutting aluminum are fiber lasers and continuous wave sources, which have a constant laser output strength. Nitrogen is also commonly used as a cutting aid gas [59].

3. Parameters for Laser Cutting

The input parameters for laser beam cutting are divided into two main categories: beam parameters and process parameters, as shown in Fig. 8 and described in Table 2 [7, 8, 63].

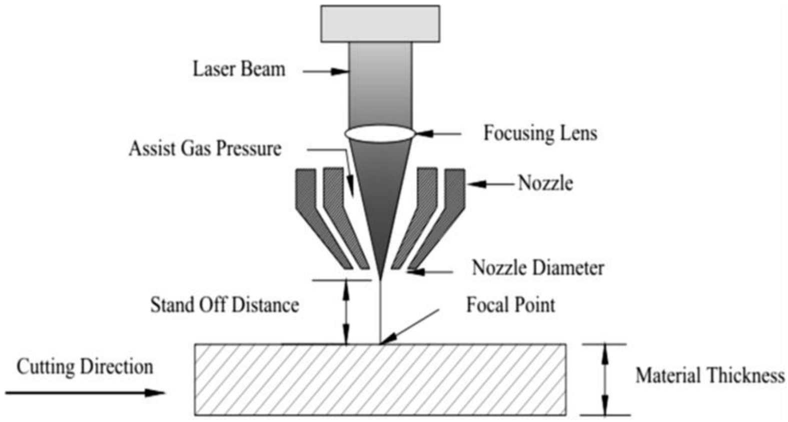


Fig. 8. Diagram of laser cutting with the specified parameters

Table 2. Categorization of laser cutting parameters

Laser cutting parameters	
Beam Parameters:	Process Parameters:
Wavelength	Focusing of laser beam
Power intensity and spot size	Process gas and pressure
Pulsed laser power	Nozzle diameter
Beam polarization	Stand of distance
Types of beams	Cutting speed

3.1 Beam Parameters

The laser beam's power intensity, wavelength, spot size, polarization, continuous wave or pulsed power, kinds, characteristics, and mode are all described by its parameters.

3.2 Process Parameters

Standoff distance, cutting speed, alignment, nozzle diameter, assist gas type and pressure, beam focusing, use of dual focus lenses, and focal position are among the laser process parameters (Fig. 9). In order to maximize the observed surface quality outputs, researchers typically focus on adjusting the laser beam intensity, cutting velocity, and assist gas pressure among these parameters because they are easily modifiable. This work effectively demonstrates how laser power, cutting speed, and assist gas pressure influence surface finish and kerf characteristics in thick Ti–6Al–4V sheets, identifying optimal parameters for minimizing roughness, dross, and taper. The results provide practical benchmarks for precision cutting of high-performance titanium alloys [80]. This research highlights cutting geometry as the dominant factor influencing kerf width in laser machining of AISI 1040 steel, with high-accuracy quadratic regression modelling providing precise guidance for minimizing kerf variation. Complementarily, experimental trials combined with ANN and ANFIS models in CO_2 laser cutting of PMMA offer valuable insights for parameter optimization, enhancing process control and cutting quality in both metal and polymer machining applications [81, 82].

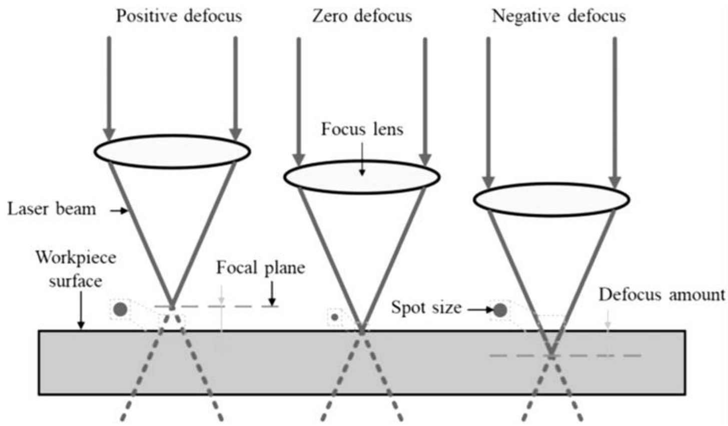


Fig. 9. Diagram for representing focal point [64]

The valuable insights into how cutting geometries and parameters influence surface roughness and kerf width in fiber laser machining of API 5L X60 steel, highlighting optimal settings for improved quality. The findings offer practical guidance for achieving stable kerf ratios and enhanced surface finish in industrial applications [65].

4. Laser Metrics of Performance

Performance characteristics, which are indications of surface quality, have been reviewed in this section and are shown in Fig. 10. Drawing on prior research, surface roughness and kerf width—two frequently used measures of surface quality—come up as the most investigated parameters. Consequently, the following analysis has been done on eight observed parameters.

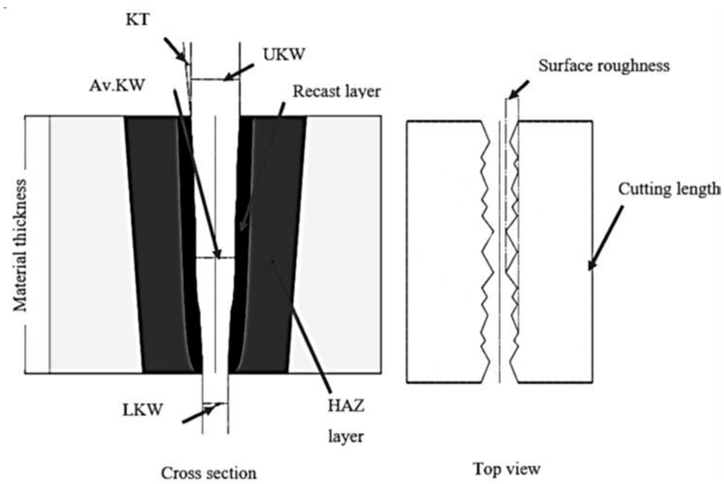


Fig. 10. Diagram showing the characteristics of laser performance

4.1 Surface Roughness

Surface roughness is a measurement of how far an actual surface deviate from its ideal shape in the direction of its normal vector. If these variations are significant, the surface is categorized as rough;

if they are minor, it is categorized as smooth. Thus, surface roughness serves as an indicator of surface quality and the need for additional surface polishing. Studies show that cutting speed and laser beam strength have the biggest effects on the roughness of the cut surface. Surface finish is lowered by melting more material at high power and low speed. Additionally, argon tends to produce surfaces of higher caliber than other gases when utilized as an assist gas. Figure 11 illustrates examples of both smooth and rough surfaces.

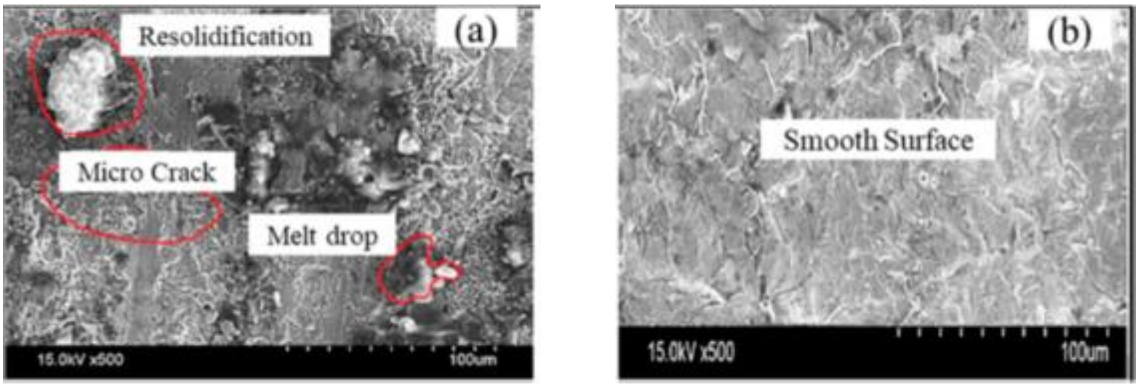


Fig. 11. User Distinction between titanium alloy surface roughness and smoothness using SEM [65]

This review offers a thorough evaluation of laser beam cutting process models, covering geometrical, metallurgical, mechanical, and defect-related aspects to enhance kerf quality prediction. By comparing theoretical, numerical, regression, and machine learning approaches, it identifies research gaps and outlines future directions for advancing LBC process modelling [83].

4.2 Kerf Width

The width of the cut path produced by laser cutting is known as the kerf width, as illustrated in Fig. 12. Its two parameters are the top and bottom kerf widths of the cut surface cross-section. The upper kerf thickness is typically greater than the bottom kerf thickness because the top face receives more force than the lower. Kerf width is the second performance metric found in the publications under review. These results show that the kerf thickness has a direct relationship with laser beam strength and an inverse relationship with cutting speed.

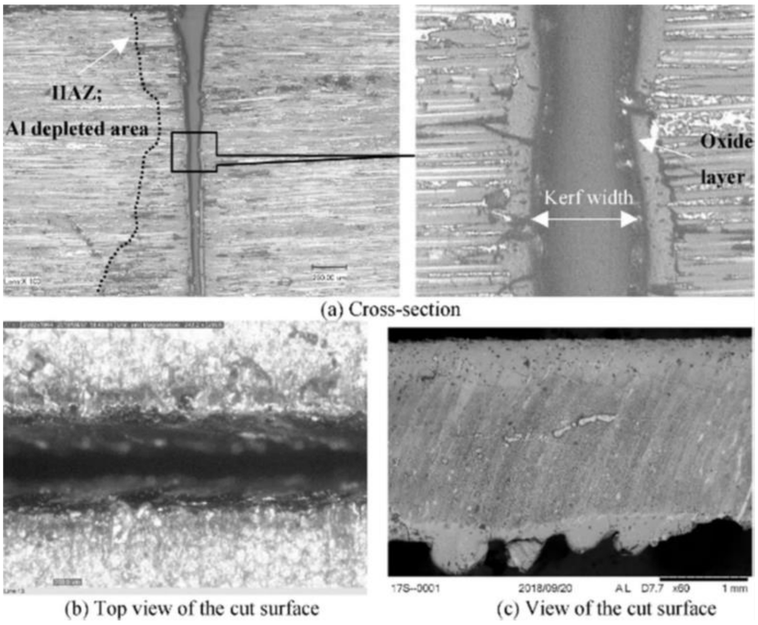


Fig. 12. Representation of the kerf width of a sample sliced by a laser beam [66]

4.3 Kerf Taper, Heat-Affected Zone and Hole Profile

The difference between the top and lower kerf widths, or the kerf taper, is said to be more than twice as thick as the material [44]. Kerf taper is ranked third among performance parameters for steel and aluminum alloys in the studied articles; it is ranked fourth for titanium alloys. Research indicates that the relationship between cutting speed and kerf taper is inverse and directly proportional to power. The term "heat-affected zone" (HAZ) refers to the region where a material's microstructure shifts during laser cutting without melting. The material's thickness can be used to gauge how much its properties have changed. HAZ is ranked fourth for titanium and aluminum alloys, but third for steel alloys when compared to other criteria in the publications that were evaluated. Research indicates that the laser power is directly proportional to the heat-affected zone's breadth, while cutting speed is inversely related to it. While the kerf and hole profiles are similar, the kerf width is associated with linear cutting, while the hole profile is crucial to circular profiles. As such, its kerf width and kerf taper are comparable to those of the linear profile. The hole kerf width is determined by the upper- and lower-hole sizes. The hole kerf taper, which is expressed in radians, is obtained by dividing the difference between the higher and lower diameters by twice the thickness of the material. Furthermore, the most significant factors are cutting speed and laser power. It takes high speed and low power settings to get the best hole kerf quality.

4.4 Kerf Hardness and Material Removal Rate

The hardness of a substance can varies, ranging from very hard materials like ceramics, boron carbide, and diamond to softer metals, polymers, and soft tissues. The ability of a material to withstand localized plastic deformation is known as its hardness. Microhardness is directly related to power and has a negative correlation with cutting speed, according to research on C45 steel alloy [71]. However, power and cutting speed do not appear to have an effect on Al alloy microhardness [72]. The material removal rate is calculated by dividing the weight difference of the material that has been cut by the amount of time required to cut it [73]. Laser cutting makes use of a number of machining mechanisms [6]. A high material removal rate is desirable over other performance metrics because it reduces cut time and costs while increasing cutting efficiency. Therefore, factors that favor low speed and high power are preferred in order to achieve this performance criterion in laser cutting. Additionally, using oxygen as an aid gas is preferred because it accelerates the removal of material by increasing heat creation through contact with the material. Systematically examines kerf width and its variation in CO_2 laser cutting of straight and curved profiles, highlighting the influence of severance energy and nitrogen pressure. The developed predictive models and contour analyses provide valuable guidance for optimizing cutting conditions across different profile geometries [84].

5. Analysis and Discussion of The Research

Enhancing the critical characteristics that must exist in the cut result—such as dross, surface polish, hardness, heat-affected zone, kerf width, kerf taper, and kerf deviation—is the aim of continuing research on laser cutting. Some of the key factors influencing the quality of the cut are laser power, cutting velocity, assist gas pressure, gas type, laser beam diameter, pulse frequency, focal length, standoff distance, and nozzle diameter. The literature makes it abundantly evident that in order to achieve the proper degree of cut surface quality, these cutting parameters need to be optimized [25, 75, 76]. A hybrid gas-assisted laser cutting and wire electrochemical machining approach for Inconel-718, achieving a 90% improvement in surface finish and eliminating thermal damage. The method offers a cost-effective solution for producing high-precision slits in aerospace-grade materials [89].

In laser beam machining, surface quality plays a critical role in determining kerf quality, heat-affected zone (HAZ), hardness, and surface roughness. Although materials with better surface quality can be cut by laser beam machining, most research is focused on sections with modest thicknesses. Experimental research uses techniques such as factorial analysis, artificial neural network modeling, Taguchi, or generic algorithm optimization to examine how input process parameters affect these parameters.

Three metals—titanium, steel, and aluminum alloys—that are widely employed in a variety of sectors, including sheet metal, welding, hydraulics, automotive, and aerospace, are the subject of this review article's examination. The content is presented in an orderly and thorough way in the paper, which facilitates rapid information retrieval for scholars. The thickness of the cut sheet, the kind of assist gas, the laser source, the input and output parameters, and significant details from particular articles are among the variables included in the study. For example, the quality of the cut surface of Ti6Al4V alloy is dependent on the laser beam strength and speed, which have values of 3000W and 2400 mm/min, respectively. According to the study, there is a 27.39% improvement in kerf width and kerf deviation when pulse width is greatly increased. The optimal kerf thickness and taper values for Ti6Al4V alloy were 0.033 mm and 0.001 mm when paired with laser power and cutting speed. The greatest influencing element on material removal rate (MRR) was wait time. Key factors affecting taper were laser power and pulse frequency. Because of the improved ejection of molten metal and increased thermal energy, higher MRR is the consequence of higher gas pressure and pulse width. On the other hand, longer pulse intervals result in longer non-cutting times, which lower MRR. Further taper, more thermal energy, and more metal loss are likewise caused by stronger and more frequent pulses. A study using CO_2 and fiber lasers to cut AISI 304 at 1-10mm thicknesses found that surface roughness increased between 8-10mm thicknesses in CO_2 laser cutting, while it increased in the 4-6mm thickness range in fiber laser cutting. The cutting speed reached around 7000 mm/min, and kerf profile alterations were observed between the two laser sources [70].

The study found that the combination of cutting speed and laser power significantly affects the width of the kerf, longitudinal, surface, and volume energies for Hardox 400 and Hardox 450 alloys at different thicknesses. Thickness was found to be the most important factor for specific surface energy, while low thickness, high speed, and medium power settings yielded the best results for volume-specific energy [71]. The study reveals that CO_2 offers better cut quality than fiber lasers for cutting 6mm thick AISI 304 sheets, while comparing different laser sources for 6mm and 10mm thicknesses. However, for 10mm thickness, neither method is significantly superior in terms of quality [43]. The study examines the impact of input parameters on response parameters in aluminum alloys, specifically Al-2024-T3 alloy. It considers factors like cut sheet thickness, assist gas type, laser source, input parameters, output parameters, and effective parameters. Results show no cutting at 3500 mm/min cutting velocity and 1500W laser beam power, indicating no significant impact on the cut surface. The study found that the HAZ's breadth is directly related to laser power and inversely proportional to cutting speed, with cutting power or speed not significantly affecting hardness [72].

The study examined the impact of cutting parameters on surface roughness and cut kerf width on an Al_2O_3 alloy sheet. Results showed that the breadth of the cut kerf was negatively related to cutting speed and highly related to power, with no significant increase in kerf breadth [81]. The kerf width and surface roughness of an Al 6351 alloy sheet were found to be mostly influenced by the cutting velocity during the machining process. This observation was observed when cutting speed, laser power, and assist gas pressure were all combined. The settings that yielded the lowest surface roughness and kerf width were determined to be 3200W, 7390 mm/min, and 7.7 bar, respectively [76]. Furthermore, when a combination of laser beam power, cutting speed, assist gas pressure, and frequency were utilized as input parameters to examine their impact on the surface roughness, width, and taper of the cut kerf while milling the Al6061/SiCp/Al_2O_3 composite alloy, it was found that the best cutting parameters were 2970.94W, 1196.4 mm/min, 8.42 Hz, and 12 bar. This implies that the laser power and cutting speed had the greatest effects on the output characteristics [77]. While a combination of laser beam power, cutting speed, assist gas pressure, and frequency was utilized as input parameters to study their effect on the surface roughness, width of the heat-affected zone (HAZ), and width of the cut kerf when milling the AA5083 alloy, it was also found that these factors had the greatest influence on the output values. It was demonstrated that surface roughness was influenced by assist gas pressure and pulse frequency. It was found that the relationship between cutting speed and HAZ and kerf width was inverse and proportionate to power. Higher assist gas pressure results in an increase in the melting material removal rate (MRR) [78].

For instance, it was found that the optimal cutting parameters for the fiber laser were 250 W, 6000 mm/min, 0.3 mm for the stand-off distance (SOD), 0.3 mm for focus, and 12 bar while cutting an Al_2O_3 alloy sheet utilizing the same set of input parameters for both CO_2 sources and fiber lasers. On the other hand, 180 W, 7200 mm/min, -0.25 mm for focus, 0.4 mm for SOD, and 12 bar were the optimal CO_2 laser cutting parameters [79]. Furthermore, when four different types of assist gas—argon, air, nitrogen, and oxygen—were used to examine their impact on the surface roughness and the width of the HAZ, it was discovered that oxygen (O_2), nitrogen (N2), and air created various values of dross, HAZ width, and microstructure alterations in the Al-Cu alloy. Argon has been demonstrated to be the best assist gas when considering cost-effectiveness in order to achieve the highest cutting quality. These points can be used to sum up this review:

- Research shows that sheet metal thickness significantly impacts output characteristics, with larger sheets requiring higher laser power levels and lower cutting rates, leading to higher surface roughness and kerf taper. This is due to the increased heat concentration, resulting in higher surface roughness. Figures 13 illustrate this impact, highlighting the significant impact of thickness on output metrics.

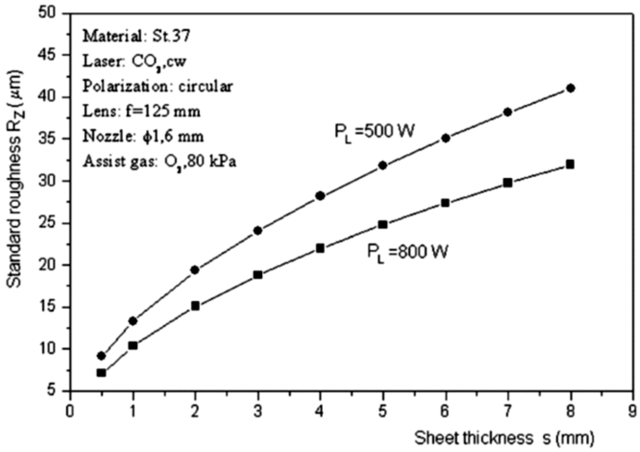


Fig. 13. Standard roughness vs sheet thickness [78]

- The quality of the cut surface is directly impacted by several cutting factors. As seen in Figures 13, for example, increased laser power intensifies heat at the cutting spot and may result in a worse finish, whereas increasing cutting speed disperses concentrated heat and produces a smoother surface. However, because of a harsher striation pattern brought on by a shift in form from straight to inclined, extremely high velocity values may increase surface roughness.

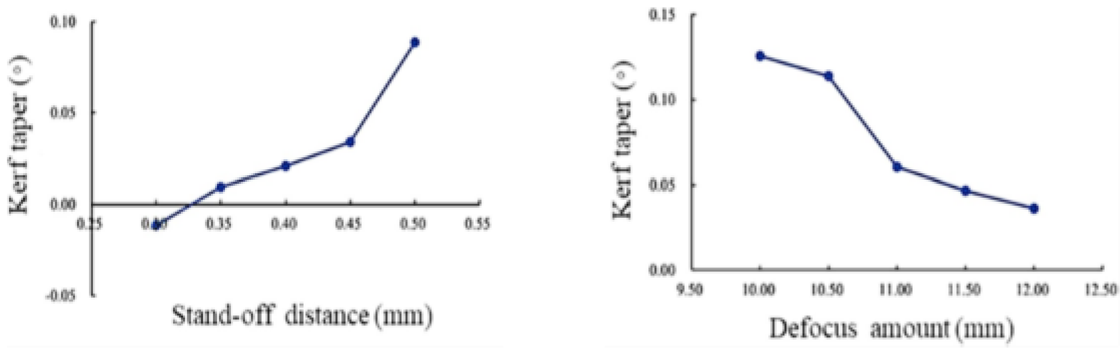


Fig. 14. Kerf taper connection with defocusing amount and standoff distance [64]

Kerf width is a crucial factor in evaluating the overall quality and efficacy of the laser cutting process. It has been shown that the kerf's breadth is directly proportional to power and inversely related to cutting speed. A broader kerf results from greater power because it raises the temperature in the cutting region, which melts more metal, especially at low cutting speeds. Evaluation fiber laser cutting of high-volume SiCp/Al composites, identifying specific energy thresholds for complete penetration and analyzing defect formation mechanisms. The findings provide critical insights for optimizing laser parameters to improve kerf quality and surface morphology in advanced automotive and aerospace applications [90].

- The kerf taper is affected by the kind and thickness of the material being cut, as well as by the cutting speed and assist gas pressure. Stronger mechanical properties or thicker materials frequently result in a larger taper angle. Conversely, using high pressure and velocity with moderate power can help minimize the taper angle by reducing the concentration of heat at the cutting point. Increasing the standoff distance and defocusing amount typically results in an increase in the kerf taper, as seen in Fig. 14.
- The measurement of dross height is a crucial factor in evaluating the efficacy of the laser cutting procedure; a lower dross height signifies superior cutting quality attained by means of ideal cutting parameters. Studies investigating the effects of different laser cutting process parameters on metal kerf taper values have shown that the values of assist gas pressure and laser power are the main determinants of dross height, with cutting velocity and power also being important factors.
- Kerf width (KW) and surface roughness (SR) are the two most often measured measurements used to evaluate surface quality. Surface roughness offers information regarding dross growth and dross height, whereas kerf width provides information about the geometry of the kerf profile. Knowing the thickness of the sheet and taking measurements of the kerf width from both the upper and lower sides can help you determine the taper value.
- The composition of the assist gas also affects the oxidation layer's thickness, as Fig. 15 shows. Because nitrogen is less expensive than argon and may produce a higher-quality surface than oxygen, researchers commonly employ it as an assist gas. Nevertheless, the ideal assist gas will depend on the specific requirements of the application. For instance, oxygen is chosen for thicker materials because it may generate more heat, which increases the material removal rate (MRR) at the point where surface cleanliness is less crucial. On the other hand, because argon offers the optimum assist gas pressure for achieving high accuracy, it is suggested for precision applications that need excellent surface quality in thin materials.

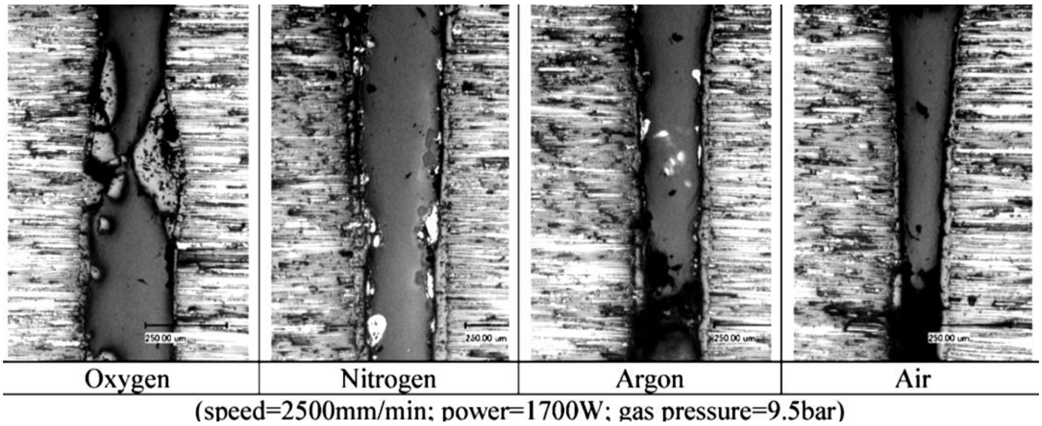


Fig. 15. The impact of the gas composition on the oxidation layer thickness during laser beam machining [66]

According to the study, laser power, pulse width, and pulse frequency are directly correlated with heat-affected zone, material removal rate, kerf width, kerf taper, and surface roughness, whereas cutting speed and standoff distance are negatively correlated with these variables. A smaller nozzle-cut surface distance, low cutting speed, and increased laser power, pulse frequency, and breadth result in a greater amount of molten metal, dross, a prolonged HAZ, and a higher material removal rate. Surface quality isn't the main concern for material removal rate optimization, but these conditions may be beneficial. Steel microhardness is inversely related to cutting speed and directly correlated with power, while aluminum hardness remains unaffected by laser power and cutting speed, despite their impact on sheet metal properties. The investigation of kerf open deviation in CO_2 laser cutting of various polymers demonstrates the superior predictive accuracy of a hybrid ANN–humpback whale optimizer model, providing a highly reliable tool for optimizing cutting parameters across multiple polymeric materials [88]. Similarly, the use of an artificial neural network for predicting kerf width in CO_2 laser cutting of mild steel achieved average errors below 2%, effectively correlating laser power, cutting speed, and gas pressure to support precise process optimization [91].

6. Conclusion

Numerous experts have examined a great deal of study to investigate the use of laser beam machining. Following a thorough examination and debate, the following conclusions may be made:

- The parameters such as the heat-affected zone (HAZ), kerf width, surface roughness, kerf taper, and material removal rate (MRR) demonstrate a direct correlation with power, pulse width, and pulse frequency. Conversely, there is a negative correlation with cutting speed and standoff distance.
- The microhardness of steel shows a negative correlation with cutting speed and is inversely proportional to laser power. However, it's worth mentioning that the hardness of aluminum appeared unaffected by these parameters. This observation seems illogical, considering that sheet metal properties are typically influenced by both of these factors.
- The type of assist gas is a critical factor to consider, with researchers typically exploring five different options. Among these, argon, nitrogen, and oxygen are the most important. Despite nitrogen's widespread use due to its lower cost and superior surface quality compared to oxygen, the study recommends opting for oxygen as an assist gas. This recommendation is based on oxygen's capacity to interact with the material during laser cutting, resulting in an increase in material removal rate (MRR). This proves particularly advantageous when surface quality is not the primary concern, and higher rates of material removal are desired.
- In conclusion, it is recommended to utilize a small nozzle diameter, thin material thickness, high cutting speed, medium gas pressure, high standoff distance, moderate pulse frequency, and moderate pulse width, with nitrogen as the assist gas. This combination of settings is suggested to achieve objectives such as low surface roughness, minimal width of the heat-affected zone (HAZ), narrow kerf width, and reduced kerf angle, thereby improving the quality of laser cutting processes.

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