© April 2024| IJIRT | Volume 10 Issue 11 | ISSN: 2349-6002

Review on Process Parameters of Laser Cutting Machine

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Abstract: Here is a review paper based on the process parameters of laser cutting machines. Laser beam cutting is a versatile and efficient technique used in various industries for the precision in profiling for different sheet materials. We have included all the possible parameters needed to enhance the quality of the product with the help of previously published research papers. Our paper also cover's the study of the impact of material type, workpiece thickness, and gas pressure on the quality of laser cuts using a CO2 laser. There are many different types of lasers cutting machines, but we have covered only CO2, YAG, and fiber-based laser cutting machines. Laser cutting offers versatility and effectiveness for precise material processing, but achieving optimal results requires understanding parameter influencing on different materials, Laser cutting offer's versatility and effectiveness for accurate material processing, but achieving optimal results requires understanding parameter influencing on distinct material's, Laser cutting offers versatility and effectiveness for precise material processing, but to achieve better results one need to have proper understanding on various parameter influencing on different materials. Further research should conducted to explore the influence of additional parameters, material variations, and process dynamics across diverse materials and applications. By harnessing this knowledge, manufacturers can unlock the full potential of laser cutting, achieving superior cut quality, reduced costs, and enhanced product functionality in various industries.

Keywords: laser cutting machine, parameters, kerf width, cutting speed, heat affected zone, surface roughness.

INTRODUCTION

Laser cutting, a well-established technique for diverse materials, has seen continuous advancements. This process shines a high-powered, focused laser beam onto a specific area, melting or vaporizing the material for precise cuts. Primarily used in machining and welding within the manufacturing industry, laser cutting shines for its versatility. It tackles ferrous and non-ferrous metals, stone, plastic, and even ceramics, all while offering distinct advantages over mechanical cutting. Since the laser does the work, no physical contact occurs, eliminating contamination and impurities. Key benefits include high cutting speed, minimal material waste, clean edges, low surface roughness, minimal distortion, and easy integration. CO2 and Nd:YAG lasers are the dominant players, each with distinct wavelengths and operating parameters. Laser power, beam diameter, cutting speed, feed rate, and depth of cut are crucial parameters influencing outcomes like edge roughness and surface hardness. Balancing productivity, quality, and cost is a constant struggle for manufacturers. However, due to limited knowledge, parameter selection often relies on guesswork, leading to subpar results and wasted resources. Understanding the significant impact of these parameters on cut quality is crucial for achieving optimal results. This research delves deeper into this very topic, aiming to shed light on how parameter selection influences cut quality and empowers manufacturers to make informed decisions. Laser Beam Cutting (LBC) is a versatile tool for industry, offering advantages like automation and high-quality cuts compared to plasma cutting. This research explored how different parameters affect cut quality for various metals. They studied the impact of material type, thickness, cutting speed, and gas pressure on aluminum, stainless steel, and structural steel, using nitrogen and oxygen for assistance. Their analysis focused on factors like kerf geometry, surface roughness, and edge quality. This research is valuable because it examines LBC across different metals, filling a gap in existing knowledge. It opens doors for further exploration of how to optimize LBC for specific applications while minimizing thermal damage.

CO2 Lasers: Powerhouse for Non-Metals:
CO2 lasers reign supreme in the realm of non-metallic material processing. Their high power and efficiency

translate to rapid cutting and engraving on wood, acrylic, plastics, and textiles. With their mature technology and reliable performance, CO2 lasers have earned a well-deserved spot in various industries. However, their longer wavelength makes them less effective on metals, and their larger size and maintenance requirements necessitate careful consideration.

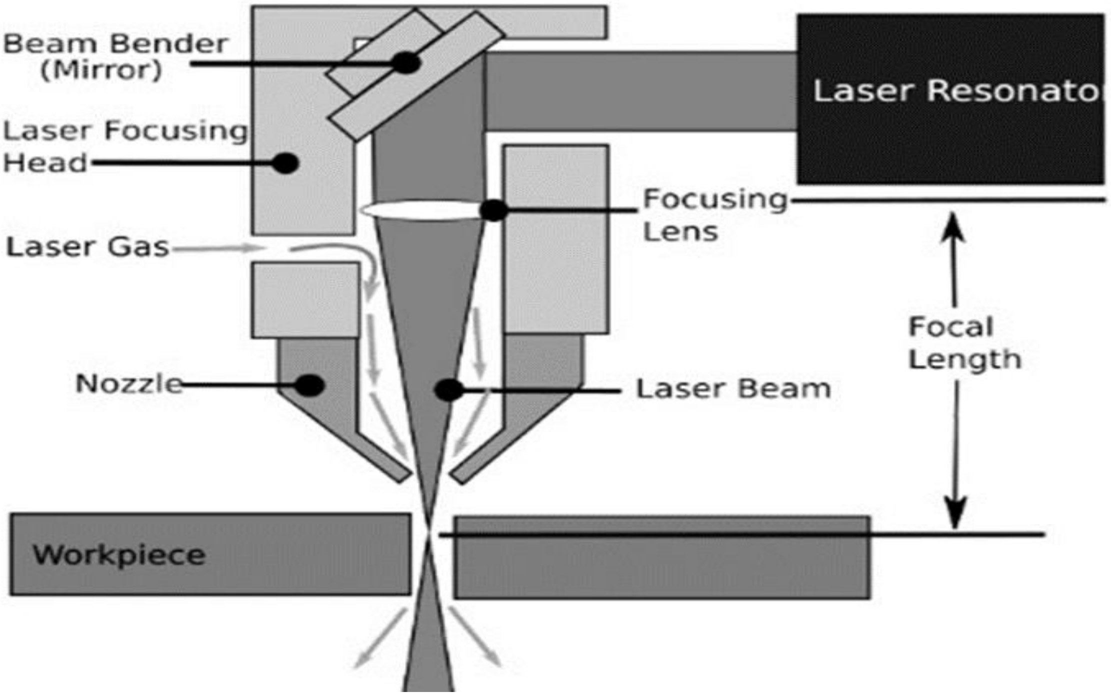

FIG.CO2 laser cutting

Fiber Lasers: Compact Champions of Versatility:

Fiber lasers represent the cutting edge of laser technology. Packed into a compact and lightweight package, they boast immense efficiency and reliability. Their excellent beam quality and small focal diameter enable precise material interactions, making them ideal for cutting and marking across metals, plastics, and even some reflective materials. While their initial cost might be higher, their low maintenance and long lifespan provide long-term value. Remember, expertise might be needed to unlock their full potential in specific applications.

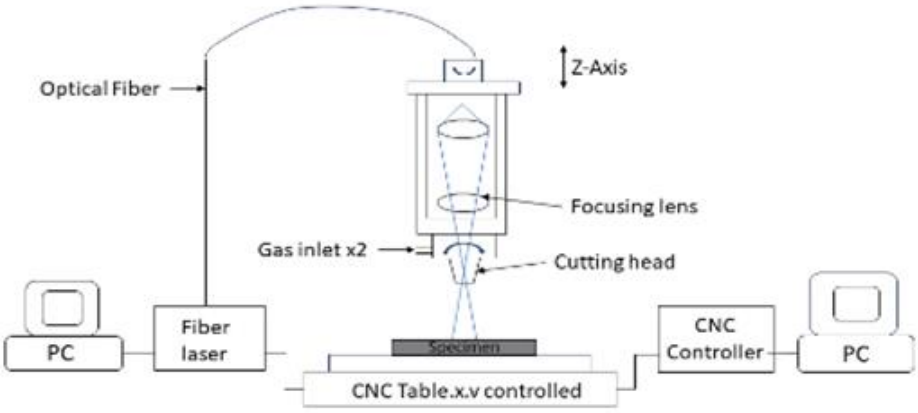

FIG. Fiber laser cutting

YAG Lasers: Flexible Mark-Makers:

Don't underestimate the humble YAG laser. Its ability to operate in both pulse and continuous modes makes it suitable for marking and engraving a wider variety of materials compared to CO2 lasers, including some metals. It offers compact and mobile options, making it versatile for on-the-go tasks. Although less powerful and efficient than fiber lasers, it has good overall efficiency and moderate maintenance costs. However, its limited cutting capabilities mainly suit thin sheet materials.

By understanding the strengths and weaknesses of each type, you can confidently choose the laser that aligns perfectly with your needs. Remember, consulting with a laser expert can provide invaluable guidance for a seamless laser journey.

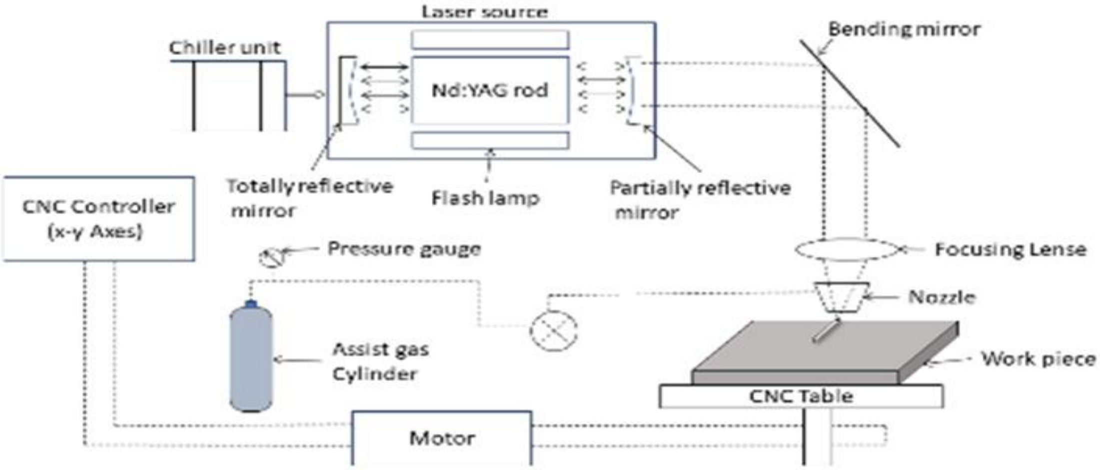

FIG. YAG laser cutting

1.LITERATURE REVIEW

1) B.adelmann,R.hellmann describes a fast laser cutting optimization algorithm for obtaining burr-free laser cuts in aluminum using a 500W single mode fiber laser .The algorithm includes design of experiments and one-factor-at-a-time methods for optimization .The burr height, which is the target value in the study, is measured using a self-designed LED module and an optical stereo microscope .The algorithm is evaluated and described in detail for cutting 1 mm aluminum sheets, as well as other materials such as stainless steel and electrical sheets .A comparative study is conducted using a 1 kW multi-mode fiber laser to cut 1 mm aluminum.
2) Karim kheloufi ,EI Hachemi explains transient numerical model to study the temperature field and kerf shape during laser cutting process .The model incorporates the Fresnel absorption model to handle the absorption of the incident wave by the surface of the liquid metal and the enthalpy-porosity technique to account for the latent heat during melting and solidification of the material .The VOF method is used to track the evolution of the shape of the kerf, and physical phenomena occurring at the liquid/gas interface, including friction force and pressure force exerted by the gas jet and the heat absorbed by the surface, are incorporated into the governing equations as source terms .They investigate the temperature and velocity distribution, as well as the kerf shape .The simulation parameters used in the study include laser power, cutting velocity, gas velocity, and laser beam radius .The paper also discusses the heat transfer at the volume fraction interface and the melting process of the material .The absorption coefficient, intensity of the incident laser beam, and angle of incidence are considered in the formulation of the absorbed laser radiation intensity, which is described by the Gaussian distribution .
3) J.powell, A.F.H.kaplan presents CO2 laser cutting machines as the main workhorse of the laser cutting world since the 1970s, with typical power ranging from 4 to 5kW. They are used to cut various materials such as stainless steel, aluminum, mild steel, wood, and plastics. Fiber

and Disk lasers are more efficient and powerful versions of Nd:YAG lasers, which have been used since the 1980s for fine detail cutting and applications where space is limited. Fiber lasers are faster and provide good edge quality when cutting metals thinner than 3mm. The choice between CO2 and fiber lasers depends on the thickness of the metal being cut and the specific application. Fiber lasers are recommended for manufacturers of metal cabinets, air ducting components, and point of sale display racks, where metal thicknesses are within the range of the fiber laser's capabilities.

4) A Mahrle, E Beyer discusses the theoretical aspects of fiber laser cutting and compares it with CO2 lasers for cutting applications .It provides theoretical estimates of the effective absorptivity at the cut front for fiber lasers and CO2 lasers, highlighting the advantages of fiber lasers for thin sheet metal cutting .The paper suggests solution strategies for improving the efficiency of fiber laser cutting of thicker metal sheets, indicating the need for further research in this area .The paper also mentions the importance of controlling the cut front inclination during the cutting process and proposes the use of beam oscillation technique for achieving this control .It emphasizes the need for improvements in system technology to achieve higher oscillation frequencies for steady-state conditions at the laser-induced cut front.

5) Goncalo costa Rodrigues, Vitalii vorkov,joost R. Duflou provides an overview of possible techniques for optimizing laser beam configurations for laser cutting of metal sheets, discussing their practical implications. The authors use advanced modeling tools to explore the limitations and opportunities of individual laser beam parameters, aiming to maximize laser beam absorption. The work presented in the paper highlights the gap between the optimal efficiency of laser material interaction and the current status of industrial laser cutting processes. The paper proposes different strategies, such as wavelength, polarization, and beam shape, to address this gap and discusses their respective opportunities and limitations. The modeling tools and laser beam parameters used in the paper are fully described in a previous work by the authors.The paper emphasizes the increasing relevance of this topic for both academia and industry, as solid state lasers become established as industrially relevant technology and the opportunities for shaping laser beam properties mature.

6) Peter Rauschera, Michael Schlossera, Thomas Pindera, Christoph Leyensa,Peter Rauschera, Michael Schlossera, Thomas Pindera, Christoph Leyensa,discusses the importance of capacity optimization in Industry 4.0 and the trade-off between capacity maximization and operational efficiency. It presents a mathematical model for capacity management based on different costing models (ABC and TDABC) and analyzes idle capacity to design strategies for maximizing organization's value. The paper also mentions the concept of idle capacity, which refers to unused capacity or production potential, and highlights the need for measuring and managing it effectively in modern production systems. It discusses the limitations of cutting speeds in 2D contour cutting and presents two alternative laser cutting concepts that overcome these limitations. It provides examples to demonstrate the chances and limitations of these concepts.

7) Silvio Genna,Erica Menna,Gianluca Rubino,and Vincenzo Tagliaferri investigates the effect of material type, workpiece thickness, cutting speed, and assistant gas pressure on cut quality in laser beam cutting of different engineering materials, including AlMg3 aluminum alloy, St37-2 low-carbon steel, and AISI 304 stainless steel, using a 5000 W CO2 industrial laser .The evaluation of cut quality is based on kerf geometry (kerf width and taper angle), surface roughness, and cut edge quality .The study aims to enhance the understanding of the mechanisms through which laser cutting parameters and workpiece parameters interact to identify general criteria and well-optimized process parameters that guarantee the kerf quality .The experiments are performed using a systematic experimental design approach based on Design of Experiments, and the results are validated via Analysis of Variance .The study involves an analysis of both phenomenological and practical issues.

8) Catherine Wandera,Veli Kujanpaa investigates the rate of melt removal from the cut kerf during laser cutting of thick-section stainless steel using

an inert assist gas jet .The authors model the melt flow velocity and melt film thickness by applying the principles of conservation of mass and momentum to the boundary layer flow. The effects of process parameters, including assist gas pressure, nozzle diameter, nozzle standoff, focal point position, and cutting speed, on the depth of flow separation and the dross attachment on the lower cut edge are investigated .The assist gas pressure, nozzle diameter, and focal point position are found to significantly affect the efficiency of melt removal from the cut kerf .The calculated melt flow velocity and melt film thickness are correlated with the depth of flow separation on the 10 mm stainless steel AISI 304 laser cut edge. The model results are correlated with the cut quality obtained in the experimental investigation of laser cutting of 10 mm stainless steel AISI 304 plate with nitrogen as assist gas.

9) I.A. Choudhury, S. Shirley investigates the CO2 laser cutting of three polymeric materials: polypropylene (PP), polycarbonate (PC), and polymethyl methacrylate (PMMA) .The study aims to evaluate the effect of laser cutting parameters on the quality of the cut, including heat affected zone (HAZ), surface roughness, and dimensional accuracy .The experiments were conducted using a central composite design and response surface methodology (RSM) to develop predictive models for HAZ and surface roughness .The results show that PMMA has the least HAZ, followed by PC and PP, and PMMA also has better surface roughness compared to PP and PC .The study concludes that the developed models can be used by the manufacturing industry for practical purposes.
10) Teeraphat Kongcharoen, Maturose Suchatawat presents an experimental study on the effects of process parameters on laser cutting of 3 mm thick mild steel plates .The parameters investigated include laser power, gas pressure, and cutting speed .The study uses a continuous wave CO2 laser with a maximum power of 4 kW .The results show that as the laser power increases, the average kerf width increases .Oxygen gas pressure also has a remarkable effect on the cut edge roughness, with an increase in gas pressure leading to increased roughness .Increasing the cutting speed gives a narrower average kerf width and a smoother cut surface. The study also measures the kerf width and cut edge roughness using an optical microscope and a roughness tester. The experimental setup includes a FANUC C4000 laser and a CNC system for moving the laser beam.
11) H. Golnabi, M. Bahar investigates the optimum conditions for laser cutting, specifically focusing on power level and cutting gas pressure, to achieve an optimum kerf width .The study analyzes the kerf width for a range of laser power (50-170 W) and gas pressure (1-6 bar) for steel and mild steel materials .The experimental results show that the minimum average kerf width for steel is 0.2 mm at a laser power of 67 W, cutting rate of 7.1 mm/s, and an oxygen pressure of 4 bar .For mild steel, the minimum average kerf width is 0.3 mm at the same laser power, cutting rate, and an oxygen pressure of 1 bar .The estimated focused beam diameter is 0.27 mm, which is close to the experimental average kerf width of 0.3 mm .The study also compares the theoretical cutting rate with the experimental results, showing good agreement .The experiment involved 338 cases and 400 runs under different cutting conditions, with the average kerf width measured directly .The maximum laser power used in the experiment was 173 W, and the cutting rate ranged from 4 to 9.5 mm/s .The quality of the laser cut was determined qualitatively from recorded images of the cut area.The study provides valuable insights into the optimization of laser cutting parameters for achieving desired kerf widths in steel and mild steel materials.
12) O. KEles andU. One present study focuses on the CO2 laser cutting of 304 stainless steel sheets and examines the influence of laser power levels and cutting speed on cut quality. It assesses the quality through measuring the dross height attachment to the cut edges and the kerf width variation using optical microscopy. Laser power levels were found to have a significant effect on the resulting cut kerf size, with increasing power intensity causing an increase in kerf width size and sideways burning through thermal erosion. Factors that affect the end product quality in laser cutting include the focus setting of the focusing lens and the workpiece thickness. The focus setting modifies the power intensity distribution

across the focused spot, while workpiece thickness alters the energy required for full-depth penetration cutting. The study also measures the influence of laser output power and cutting speed on kerf width, stria formation, and heat-affected zone (HAZ). Increasing laser power results in increased kerf width, while increasing cutting speed causes a decrease in kerf width. The presence of high-temperature combustion reactions at high laser power levels contributes to these findings.

13) Suraj S Patel,Viraj H Patel,Ketul M Patel,Bhaumik A Patel,Aseem A Patel,Saumil C Patel Performs Experimental analysis and optimization of CO2 laser cutting process. - Multi-objective optimization of cut quality characteristics using ANNs. - Effects of laser power, cutting speed, gas pressure, and focus position. - Use of the weighting sum method and CSA for multi-objective optimization. - Impact of different gasses on material roughness and surface finishing. - Unevenness in kerf width during pulsed mode of LBC. - Optimization of kerf deviation and kerf width using Taguchi quality loss function.
14) Dr J. Powell1 and Dr A. Kaplan2 provides an overview of laser cutting, covering topics such as laser-materials interactions, different laser types, the technical and commercial growth of laser cutting, and the state of the art. they discusses the basic mechanism of laser cutting, where a high-intensity beam of infrared light is generated by a laser and focused onto the surface of the workpiece, creating a localized melt .They mentions the use of CO2 laser cutting for applications where the heat-affected zone would be problematic, and alternative machining methods like mechanical machining, abrasive water jet, or electric discharge machining might be used .It also highlights the drawbacks of laser cutting, such as the production of an oxidized melt with low viscosity that does not adhere well to the solid steel, resulting in the liquid being easily blown out of the cut zone and no residual melt attached to the lower edge of the cut.
15) Amit Sharma, Vinod Yadava The paper focuses on the modeling and optimization of cut quality during pulsed Nd:YAG laser cutting of thin Al-alloy sheets for straight profiles .The hybrid approach of Taguchi methodology (TM) and response surface methodology (RSM) is used for modeling the laser cutting process .Multi-objective optimization is performed using the hybrid approach of TM and gray relational analysis (GRA) coupled with entropy measurement methodology .The study highlights the application of the hybrid approaches for modeling and optimization of the laser cutting process, which can be useful in the aerospace and automotive industries .The results indicate that the hybrid approaches applied for modeling and optimization of the laser cutting process are reasonable.
16) B.S. Yilbas explains Laser cutting process improves cut quality with increased scanning speed. First law efficiency improves with increased scanning speed and workpiece thickness. Second law efficiency is lower than first law efficiency due to entropy generation. Laser output power, scanning speed, and workpiece thickness affect cutting quality. Main effects of parameters and their interactions influence waviness and out of flatness.
17) I Uslan Previous studies have investigated laser cutting of engineering materials. Some studies focused on modeling the cutting process and assessing end product quality. Optimization of the laser-cutting process for metallic coated surfaces was investigated. The effect of high-pressure assisting gas flow on kerf geometry was studied. Stria patterns and parameters were analyzed for quality assessment. The influence of oxygen content on the cut surface was examined. Pulsed mode laser cutting of sheet metals was investigated. A mathematical model for kerf width variation with laser power was introduced.
18) A. Stournaras, P. Stavropoulos, K. Salonitis, G. Chryssolouris Few investigations on CO2 laser cutting of aluminum alloys Low absorption of aluminum by laser radiation at 10.6 mm Laser power and cutting speed play important role in cutting quality Pulsing frequency and assist gas pressure affect surface roughness and morphology Laser power affects cutting edge morphology, low power levels result in rough surface.
19) Lv. Shanjin, Wang Yang The paper investigates the influences of laser cutting parameters on

surface quality factors. Laser cutting of titanium alloy leads to the formation of a heat-affected zone (HAZ).Different assist gasses have different effects on surface morphology and corrosion resistance. Argon-assisted laser cutting produces unaffected surface quality and is suitable for subsequent welding.

20) N. Rajaram, J. Sheikh-Ahmad, S.H. Cheraghi Most literature focuses on one or two laser cut surface properties. Cutting speed and power have a combined effect on cut quality. Feed rate affects surface roughness and striation frequency. Kerf width and HAZ decrease with increasing cutting speed. Power has a major effect on kerf width, while feed rate has a minor role. Feed rate has a major effect on surface roughness and striation frequency. Regression models were developed to predict the effect of power and feed rate. The laser machine parameters can be adjusted to maintain cut quality.

2.TYPES OF MATERIALS USED

Stainless steel, aluminum, mild steel, wood, and plastics, AlMg3 aluminum alloy, St37-2 low-carbon steel, and AISI 304 stainless steel, three polymeric materials: polypropylene (PP), polycarbonate (PC), and polymethyl methacrylate (PMMA), 304 stainless steel sheets, titanium alloy.

3.TABLES USED

Table1: chemical composition of the adopted materials

Material	Standard	Composition
Aluminum	UNI EN 573-3	AI 94.2% min, 97.4% max, Mg 2.6% min, 3.6% max, Mn 0.5% max, Si 0.4% max, Cr 0.3% max, Zn 0.2% max, Ti 0.15% max, Cu 0.1% max, Fe 0.4% max, Residuals 0.15% max
Steel	UNI EN 10025	Fe 98.13% max, C 0.21% max, Mn 1.50% max, S 0.055% max, P 0.055% max, Residuals 0.05% max
Stainless Steel	UNI EN 10088-1	Fe, C 0.07% max, S 0.15% max, P 0.045% max, Mn 2% min, Si 1% min, N 0.11% min, Cr 17% min, 19.5% max, Ni 8% min, 10.5% max, Residuals 0.05% max

Table:2 main properties of adopted materials

Properties	AlMg3 (UNI EN 1706)	St37-2 (UNI EN 10025)	AISI 304 (UNI 6900-6901)	Units
Density	2.7	7.85	7.9	g/cm³
Solidus temperature	600	1420	1450	°C
Liquidus temperature	650	1460	1400	°C
Latent heat of fusion	-	-	-	J/g
Specific heat	900	470	480	J/kg K
Thermal conductivity	130-140	51	16	W/m K
Tensile strength	140-240	360-510	490-685	MPa
Yield strength (at 0.2%)	80-130	235	185	MPa
Elongation (at 50 mm)	1	20-26	45	%
Young's modulus	68	206	193-200	GPa
Brinell Hardness	52-88	130	170-360	-

Table 3. Laser parameters adopted in experimental tests.

Material	Thickness (mm)	Nozzle Diameter (mm)	Focus Position (mm)	Gas Flow (m/min)	Pressure (bar)	Gas Type

AlMg3	2	1.7	0	8.6	10	N2
	4	2	-1.5	4.2	8	
	6	2.7	-7	2.2	9	
	2.5	0.8	2.5	5.2	0.8	
St37-2	5	0.8	0.5	3.7	0.8	O2
	6	1	2.5	3.3	0.7	
AISI 304	1	1.4	1.5	8.9	9	N2
	3	1.7	1	5.2	9	
	6	2.3	-2.5	2.3	4.5	

Table4: Cutting parameters table

Property	Units	Value
Laser power	kW	2–5
Cutting speed	m/min	0.2–1.8
Nozzle diameter	mm	1.0–2.5
Gas pressure	bar	4–20

Table5: Physical properties of stainless steel and nitrogen gas table

Property	Stainless Steel (AISI 304)	Nitrogen Gas	Units
Density	7900	1.185	kg/m³
Viscosity	10.26 (at 20°C)	0.0165 (at 1439°C)	mPa·s
Specific Heat Capacity	500 (at 20°C)	1.040 (at 20°C)	J/(kg·K)
Thermal Conductivity	16.2 (at 20°C)	0.257 (at 20°C)	W/(m·K)
Electrical Conductivity	1.12 x 10^6 (at 20°C)	0 (insulator)	S/m

Table6: Mechanical and thermal properties of the polymers

Polymer	Tensile Strength (MPa)	Density (g/cm³)	Temperature (°C)	Service Temperature (°C)
PC	62.1	1.2	270	-40/+120
PP	31 - 37.2	0.906	170	-07/+135
PMMA	53.8 - 73.1	1.19	160	-30/+770

Table7: Levels of independent input machining parameters.

Variables	Symbol	Unit	Coded levels 1	Coded levels 0	Coded levels +1
Laser power	P	Watt	200	300	400
Cutting speed	V	m/min	0.2	0.3	0.4
Air pressure	p	Bar	2.5	3	3.5

Table8: Design of experiments with experimental conditions.

Experiment No.	Laser Power (W)	Cutting Speed (m/min)	Air Pressure (bar)
1	200	0.2	2.5
2	400	0.2	2.5
3	200	0.4	2.5
4	400	0.4	2.5

5	200	0.2	3.5
6	400	0.2	3.5
7	200	0.4	3.5
8	400	0.4	3.5
9	300	0.3	3
10	300	0.3	3
11	300	0.3	3
12	300	0.3	3

Table 9:

Parameter	Values
Material	Mild steel
Thickness	3 mm
Laser power	2000, 2200, 2400 W
Gas type / pressure	O2 / 0.07, 0.12, 0.17 MPa
Cutting speed	3100, 3400, 3700 mm/min
Nozzle diameter	0.8 mm
Nozzle standoff distance	0.7 mm

Table10: Powers for CO2-assisted laser cutting of steel

Thickness (mm)	Power (W)	Average Width (mm)	Highest Rate (mm/s)	O2 Pressure (bar)
1	67	0.3	6.4	2
1	67	0.2	7.1	1
1	67	0.25	6.7	4
6	1.5	104	0.375	5.5
6	1.5	104	0.35	6.7
6	1.5	104	0.3	7.1
6	2	146	0.4	6.4
6	2	146	0.3	6.4
6	2	146	0.4	7.1

Table11: Threshold powers for O2-assisted laser cutting of mild steel

Thickness (mm)	Power (W)	Average Width (mm)	Highest Rate (mm/s)	O2 Pressure (bar)
1	53	NC	NC	2
1	53	0.3	5.9	4
1	53	0.3	4.7	6
1.5	88	0.425	7.1	2
1.5	88	0.4	7.1	4
1.5	88	0.4	7.1	6
2	123	0.3	7.1	2

2	123	0.5	8	4
2	123	0.5	8	6

Table12: Optimum experimental conditions for steel laser cutting

Thickness (mm)	Average width (mm)	Power (W)	Cutting rate (mm/s)	O2 pressure (bar)
1	0.2	67	7.1	4
1.5	0.3	104	7.1	6
2	0.3	146	6.4	4

Table13: Optimum experimental conditions for mild steel laser cutting

Thickness (mm)	Average width (mm)	Power (W)	Cutting rate (mm/s)	O2 pressure (bar)
1	0.3	67	9.5	1
1.5	0.35	97	9.5	1
2	0.3	123	7.1	2

Table14: Experimental observations

Experiment No	Laser Power (kW)	Cutting Speed (m/min)	Material Thickness (mm)	Gas Pressure (bar)	Ra (mm)	Rz (µm)
1	1.2	1	12	13	9.8	74.68
2	1.4	1.4	12	13	8.21	61.78
3	1.8	2	12	13	6.51	48.23
4	2.4	3	12	13	5	36.36
5	2.6	4	12	13	4.38	31.78
6	2	4.4	12	13	4.78	35.39

Table15:

Parameters and their respective levels	Units	Level 1	Level 2	Level 3
Laser power	Watts	1500	1650	1800
Cutting speed	m/min	2	3	4
Pulsing frequency	Hz	8	9	10
Gas pressure	Bar	10	12	14

Table16:

Parameter	Units	Thickness = 1 mm	Thickness = 2 mm
Laser power (P)	W	500, 750, 1000, 1250, 1500	500, 750, 1000, 1250, 1500
Cutting speed (v)	m/s	0.01, 0.02, 0.03, 0.04, 0.05	0.01, 0.02, 0.03, 0.04, 0.05
Kerf width	m	6.00E-04, 1.20E-03, 1.80E-03, 2.40E-03, 3.00E-03	6.00E-04, 1.20E-03, 1.80E-03, 2.40E-03, 3.00E-03

Table17:

Experiments	Kerf width (µm)	Cutting edge surface roughness (µm)	HAZ (µm)
1	207.8	2.28	119.44

2	182.4	2.54	116.66
3	172.8	3.42	75
4	194.5	2.3	263.88
5	190	1.35	180.55
6	176	1.6	175
7	202.6	1.23	333.33
8	188.8	0.9	250
9	192	1.74	166.66

Table 18: Optimized parameters' combination for obtaining the optimum kerf width, heat affected zone and surface roughness and corresponding results.

Characteristic	Laser	Cutting	Pulsing	Gas	Result
Power level	LP2	CS3	PF3	GP3	178 µm
Power level	LP1	CS3	PF3	GP1	81 µm
Roughness	LP3	CS3	PF1	GP2	0.83 µm

4. LASER CUTTING PARAMETERS

4.1 kerf width:

Cutting speed has an impact on the formation and shape of the kerf during laser cutting. The effect of cutting speed on the formed kerf and identifies different stages during the cutting process. Higher cutting speeds can result in a wider and less precise kerf, while lower cutting speeds can lead to a narrower and more precise kerf. The specific relationship between cutting speed and kerf shape is not explicitly mentioned in the provided sources. However, it can be inferred that the cutting speed affects the dynamics of heating and kerf formation, potentially influencing the width and quality of the kerf[1].Nonvalid cuts were excluded from the analysis, resulting in the omission of incongruous kerf widths. The kerf width decreased with decreasing thickness, as more material needed to be removed in laser cutting of thick sections. Different shapes of kerf profiles were observed, with most exhibiting slight v-profile or parallel-sided sections[7].Kerf width decreases with decreasing laser power or increasing cutting speed. for Kerf Width Measurement, Instrument Used: Optical microscope (Olympus UTV1X-2) with 50x magnification, Location Upper and lower kerf widths measured at three locations along the cutting lines. Analysis of Average kerf width determined for each sample[10].Kerf size depends on power intensity, spot size, focus setting, and material thickness[11]. The kerf width in laser cutting refers to the width of the slot formed during cutting, which is narrower at the bottom surface of the workpiece than at the top surface, and it is determined by the laser beam quality and focus optics[14].Decreases with increasing cutting speed at all laser power levels and workpiece thicknesses. Increases slightly with increasing workpiece thickness. Increases with increasing laser power, especially at high power levels. Experimental results agree well with predicted values at low scanning speeds, but discrepancies occur at higher speeds due to factors like coupling effect and exothermic reaction contribution[16].as increasing Power Intensity Increases kerf width almost linearly. Higher gradients at lower intensities, meaning small power variations significantly affect kerf width[17].

4.2 Cutting Speed:

Cutting speed can indirectly affect burr height through its interaction with other parameters. For example, increasing speed often requires higher laser power to maintain cut quality. As discussed in the article, higher power can lead to increased burr height due to focus shift and changes in melt viscosity. The study is restricted to a fixed cutting speed of 50 mm/s. Analyzing burr height across different speeds wasn't part of the investigation[4].Cutting speed has an impact on the formation and shape of the kerf during laser cutting. The paper discusses the effect of cutting speed on the formed kerf and identifies different stages during the cutting process. Higher cutting speeds can result in a wider and less precise kerf, while lower cutting speeds can lead to a narrower and more precise kerf. The specific relationship between cutting speed and kerf shape is not explicitly mentioned in the provided sources. However, it can be inferred that the cutting speed affects the dynamics of heating and kerf formation, potentially influencing the width and quality of the kerf[1].cutting speed alone is not enough to determine overall productivity. Other factors like: Acceleration and deceleration: The time it takes for the laser to reach and slow down from its cutting speed significantly impacts the time for each cut. Piercing time: The time it takes for the laser to pierce through the material at the beginning of each cut also affects overall productivity. Sheet changeover time: The time it takes to switch between sheets of material can be a major factor, especially for large sheets. Complexity of the cut: More intricate cuts require more movements and direction changes, reducing the effective cutting speed. Therefore, when comparing laser cutting systems, it's crucial to consider these additional factors along with the advertised cutting speeds[2].High-speed linear cutting: Fiber lasers enable cutting speeds up to 150 m/min for various materials like electrical steel, aluminum, and high-strength steel. Cutting speed depends on laser power, optical setup, and material thickness. Dross-free cutting is achievable even at high speeds. Applications include slitting and trimming of band material[3].Flow separation moves closer to the bottom cut edge as cutting speed increases, resulting in higher dross attachment. Lower cutting speeds lead to high power loss, lower melt temperature, high melt viscosity, reduced melt removal rate, and high dross attachment on the lower cut edge. Increasing cutting speed reduces power loss, increases melt temperature, lowers melt viscosity, improves melt removal, and reduces dross attachment[8].Increasing Cutting Speed: Generally decreases roughness for all laser powers. Roughness converges to ~10µm at high speeds[10].The cutting speed must be matched to the type and thickness of the workpiece to avoid roughness, burr formation, and large drag lines.The energy balance in laser cutting involves energy used in generating the cut and energy losses from the cut zone. Increasing cutting speed decreases energy losses and improves cutting efficiency. In mild steel cutting with oxygen, too low cutting speed can result in excessive burning of the cut edge and degradation of edge quality. Laser power should be adjusted based on the type and thickness of the workpiece, and reducing power may be necessary for high accuracy on complex or small parts. High beam intensity achieved through focusing the laser beam to a small spot is desirable for cutting applications[14].

4.3 Surface Roughness:

The effect of process parameters on surface roughness in cutting is observed through the presence of finely grooved surfaces with regular patterns or drag lines. Three different zones can be distinguished in the cutting direction: the upper edge of cut with lower surface roughness, the lower edge of cut with higher surface roughness and possible slug formation, and the middle of the edge of cut with intermediate roughness. Parameters such as amplitude, spacing, arithmetic mean surface roughness (Ra), surface roughness depth (Rz), and mean width of profile elements (RSm) are commonly used to evaluate the surface roughness of the cut edge[7].Surface roughness is an important factor in determining the quality of manufactured parts, affecting corrosion, fatigue life, friction, and wear and tear. The arithmetic mean surface roughness is commonly used to measure surface roughness, and it was measured using a contact-type stylus Mahr Perthometer. Laser cutting of plastics like PP and PC resulted in rough surfaces, while PMMA had excellent cut quality with a surface roughness in the range of 7-10 mm. A model equation was developed to relate surface roughness to input variables, showing that it is inversely proportional to laser power, cutting speed, and compressed air pressure. Cutting speed and compressed air pressure have a more pronounced effect on surface finish than laser power. Previous research has also shown that increasing cutting speed and air pressure can decrease surface roughness, supporting the findings of this study[9].for Roughness Measurement Instrument: Mitutoyo SJ-310 roughness tester. Procedure: Samples cut apart after kerf width measurement. Mean roughness (Rz) used to estimate average cut edge roughness. Roughness tester traces taken along the center of the cut surface. Assessment length set to 4.8 mm with 0.8 mm cut-off length[10].

4.4 Laser Power:

Not the same as power density: Unlike power density, which focuses on energy concentrated in a specific area, laser power solely deals with the total energy emitted per second. A high-power laser can deliver more energy overall, but if its beam is more diffuse, it might not have the same cutting or burning power as a lower-power laser with a highly focused beam. Impact on performance: Laser power directly influences the laser's effectiveness in various applications. Higher power lasers can: Cut thicker materials Weld deeper joints Engrave with more precision and depth Generate hotter temperatures for ablation or material removal Application-specific needs: Different applications require different laser power levels. For instance, delicate eye surgery might use low-power lasers for precise tissue removal, while industrial metal cutting utilizes high-power lasers for efficient material processing. Examples: A laser pointer usually has a very low power, measured in milliwatts (mW), enough to create a visible dot but not cause harm. A laser engraver used for marking wood or plastic might have a power of around 10-20 watts. High-power industrial lasers employed in metal cutting can reach hundreds of watts or even kilowatts. Additional notes: Laser power is just one factor in determining a laser's performance. Other parameters like wavelength, pulse duration, and beam quality also play important roles.[1]Kerf width increases with increasing laser power (2000 to 2400 W).Higher power provides more energy, melting more material and widening the kerf. This aligns with findings from references 2-4[10].Laser power must be adjusted based on the type and thickness of the work-piece, with a reduction in power sometimes necessary for high accuracy on complex or small parts. High beam intensity achieved by focusing the laser beam to a small spot is desirable for cutting applications, resulting in high cutting speeds and excellent cut quality. The reflectivity of metals is higher at low beam intensities but lower at high intensities, and cutting thicker materials requires higher intensities. The focus ability of the laser beam is an important factor to consider for achieving high power and intensity[14].Power Intensity: Increases kerf width almost linearly. Higher gradients at lower intensities, meaning small power variations significantly affect kerf width[17].

4.5 Heat affected zone(HAZ):

The heat affected zone (HAZ) in laser cutting of thermoplastics varies for different materials, with PP having the highest HAZ followed by PC and PMMA. Equations were developed to relate the HAZ to laser processing parameters, such as cutting speed, laser power, and compressed air pressure. The analysis showed that HAZ increases with laser power and decreases with cutting speed and compressed air pressure. Laser power was found to be the most important variable affecting the HAZ .The HAZ size can be controlled by adjusting the laser power and cutting speed, with a reduction in HAZ achieved by increasing cutting speed and decreasing laser power[9].The heat affected zone (HAZ) in laser cutting refers to the area surrounding the actual cut where the surrounding material is heated but not melted. This heating zone experiences changes in its properties due to the heat exposure, which can be positive or negative depending on the specific material and desired outcome. Key points about HAZ: Size varies: It depends on the material being cut (PP being more susceptible), the laser power used (higher power = larger HAZ), cutting speed (faster = smaller HAZ), and compressed air pressure (higher pressure = smaller HAZ).Impacts: Changes in the HAZ can affect factors like strength, flexibility, and resistance to cracking. In some cases, these changes are beneficial (e.g., annealing), but in others, they can be detrimental (e.g., warping).Control: Optimizing laser power and cutting speed is crucial for managing the HAZ. Increasing speed and decreasing power minimize the affected area[11].Mechanical cutting generates heat that affects the lifespan of tools and the metal being cut, with HAZ width increasing with higher gas pressure and cutting speed. Laser power and stand-off distance have a smaller impact on HAZ width compared to cutting speed and gas pressure[14]. Size of heat-affected zone (HAZ): The area surrounding the cut where the steel experiences high temperatures, altering its microstructure and properties. Higher power creates a larger HAZ[20].

4.6 Assisted Gas Pressure:

Different gasses have different properties that affect how they interact with the melted material and the cutting process. For example, nitrogen is commonly used as an inert gas that helps prevent oxidation and improve cut quality, while oxygen can be used for reactive cutting of certain materials. Pressure: Higher gas pressure typically leads to Increased cutting speed As the pressure increases, the gas flow rate increases, which can remove molten material more quickly and lead to faster cutting. Reduced dross formation. The higher pressure helps to blow away molten material and prevent it from re-solidifying on the cut edge, leading to less dross. Reduced burr formation Depending on the material and other parameters, higher pressure can assist in reducing burrs at the edge of the cut. The effect of pressure depends on the position of the focal point of the laser beam relative to the workpiece. When the focus is inside the material, higher pressure can lead to deeper penetration and potentially rougher surfaces. When the focus is on the surface, higher pressure can lead to cleaner cuts but potentially wider Some materials are more sensitive to pressure changes than others. In many cases, using the right gas and pressure can lead to cleaner cuts with smoother surfaces and less dross formation. The gas flow can help to cool the workpiece and reduce heat distortion, which can improve the overall accuracy of the cut. In some cases, high pressure can cause the gas to create turbulence, which can lead to a rougher surface finish[4].The position of the boundary layer separation point moves closer to the bottom cut edge with an increase in assist gas pressure due to an increase in the Reynolds number of the melt flow. Higher inertial force exerted by the assist gas leads to a thinner boundary layer thickness and sustained laminar flow over a longer distance down the cut edge. Low assist gas pressure results in sluggish melt flow, significant viscous forces in the boundary layer, and rapid increase in boundary layer thickness, leading to a transition from laminar to turbulent flow. Viscous forces and pressure drop in the thick-section cut kerf reduce the melt removal rate, causing flow separation and dross attachment on the lower cut edge. Flow separation occurs when the melt flow regime transitions from laminar to turbulent flow in the boundary layer, and surface tension retards the melt from clearing the lower cut edge, resulting in dross attachment[8].The assist gas helps cool the material and remove molten material. Higher pressure contributes to narrower kerfs and reduced HAZ due to better cooling. Understanding the interaction between these parameters is crucial for optimizing the cutting process. The research shows that different combinations of settings can achieve desired outcomes, such as minimizing kerf width or surface roughness[18].

5.CONCLUSIONS

- A 3D model for laser melt cutting process was presented. Different stages during the cutting process were identified. The effect of cutting speed on the formed kerf was discussed.
- The paper presents a mathematical model for capacity management based on different costing models (ABC and TDABC) and discusses the trade-off between capacity maximization and operational efficiency.
- The paper also discusses laser cutting concepts in modern production systems. It presents two alternative laser cutting concepts that overcome the limitations of traditional 2D contour cutting.
- The FALCOA algorithm successfully optimized laser fusion cutting processes for burr-free cuts.
- CO2 laser is more versatile for jobshops, while fiber laser is better for manufacturers of thin sheet metal products.
- Good overall quality and limited presence of laser cut imperfections observed.
- Good correlation between melt flow velocity and depth of flow separation.
- CO2 laser can be used for cutting polymeric materials.
- Kerf width decreases with decreasing laser power or increasing cutting speed.
- Optimum conditions for steel cutting identified.
- Laser cutting has experienced continuous growth since its beginnings in the early 1970s.
- The hybrid approach of Taguchi methodology (TM) and response surface methodology (RSM) was used for modeling the cut quality.
- Laser cutting process depends on input parameters like laser power, cutting speed, and gas pressure.
- The study concludes that the laser power levels and cutting speed have a significant influence on the kerf width and dross height.
- Laser beam scanning speed and laser output power affect kerf width.
- Laser power intensity significantly influences the kerf width size.
- CO2 laser beams can be used to process aluminium alloys.
- Pulsed laser cutting of titanium alloy sheet is a complex thermal process.

- Power has a major effect on kerf width and size of HAZ.

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