Quest Journals
Journal of Research in Mechanical Engineering
Volume 7 ~ Issue 10 (2021) pp: 01-11
ISSN(Online) : 2321-8185
www.questjournals.org

Research Paper

Analysis of Laser Beam Machining Using Laser Cutting Technique

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Abstract
This prominent paper reviews the research deed carried out so far in the area of laser cutting process and also the experimental and theoretical studies on the influence of the process parameters like power, cutting speed, gas pressure, focus position etc on surface roughness, kerf width and heat affected zone (HAZ). Energy based unconventional process is an advanced machining process is called Laser cutting . The avail objective of this article is to provide a state of the art in the field of laser cutting process
Now today ,Some Technical errors faced in the field of laser machines' implementations to contour sheet cutting lie in insufficient knowledge of the laser technique in addition to the absence of both sufficiently reliable practical data and knowledge about the parameters affecting the forming process itself. The avail knowledge of the laser cutting process and its dependence on various factors will provide for a rise in forming quality as well as in its liability to manufacturing.
Key words: *Laser cutting, power, cutting speed, gas pressure, focus position ,Surface roughness, Kerf width and Heat affected zone (HAZ)*

Received 04 October, 2021; October: 16 October , 2021; Accepted 18 October, 2021 © The author(s) 2021. Published with open access at www.questjournals.org

I. INTRODUCTION

A laser beam machining is a non-conventional machining method in which the operation is performed by laser light. The laser light has maximum temperature strikes on the workpiece , due to high temp the workpiece gets melts. The process used thermal energy to remove material from a metallic surface.

HOW WAS THE FIRST LASER INVENTED?

During World War II, the physicist Charles Townes worked at the Bell Laboratories on the radar assisted bombing systems and microwaves generators. In the 50's, following an Einstein theory, stimulated emission, where energy is extracted from a transition in an atom or molecule, Townes thought about creating a photon flux, all alike, thanks to the amplification of a magnetic wave. That's how he created the first device, called Microwaves Amplification by Stimulated Emission of Radiation, i.e. "MASER". Masers were modestly useful, for scientific research mainly but not so much for military or industrial applications. Only a few scientists thought an infrared maser might be important. Moreover, infrared rays could not be manipulated like radar, and were hard to manage at all.

In 1965, the first production laser cutting machine was used to drill holes in diamond dies. So, what is the laser cutting?

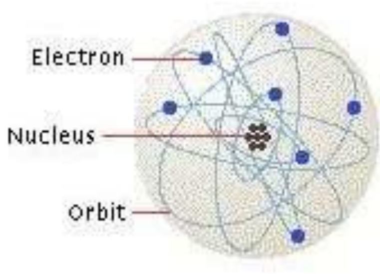
Laser cutting is a technology that uses a laser to cut materials, and is typically used for industrial manufacturing applications, but is also starting to be used by schools, small businesses, and hobbyists. Laser cutting works by directing the output of a high-power laser, by computer, at the material to be cut. The material then either melts, burns, vaporizes away, or is blown away by a jet of gas, leaving an edge with a high-quality surface finish. Industrial laser cutters are used to cut flat-sheet material as well as structural and piping materials.

Laser cutting is a type of digital manufacturing technique known as "subtractive". It uses a large amount of energy generated by a laser, concentrated on a very small area, in order to cut or engrave a material. There is a broad range of materials that can be cut with a laser: wood, plastic, cardboard, textile...

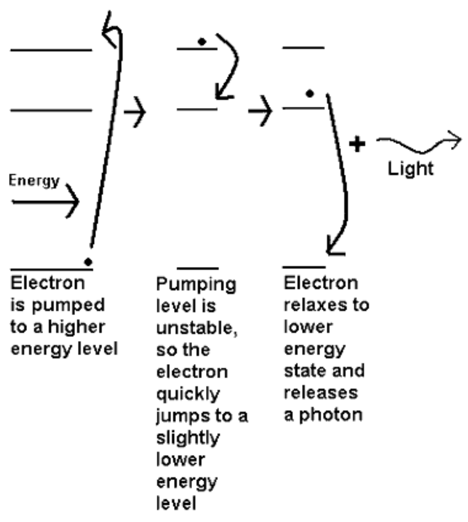
The laser-cutting technique is always evolving: materials diversification, increasing thickness of the cut, and a better-looking finished aspect made laser-cutting one of the most attractive industrial techniques of the past few years! It is now very common on the production line, to cut parts in automotive and aeronautic factories, but also to build solar panels, or to design pieces for fashion shows. It is widely used by architects, also in sign manufacturing.

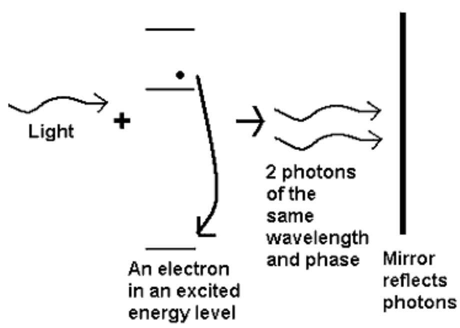
Laser Fundamentals
Acronym of Light Amplification Stimulated Emission of Radiation

Basic:
1. Atoms initially at the *Ground State*
2. The atoms go to *Excited State when a high energy is applied (called 'pumping')*
3. When atoms moves back to the ground state, photons (particle of light) are released



Laser Beam Characteristics:
a. Monochromaticity
b. Coherence
c. Very Limited Diffraction
d. Extremely high Radiance





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II. METHODOLOGY

There are many different methods in cutting using lasers, with different types used to cut different material. Some of the methods are vaporization, melt and blow, melt blow and burn, thermal stress cracking, scribing, cold cutting and burning stabilized laser cutting.

- **Vaporization cutting**

In vaporization cutting the focused beam heats the surface of the material to boiling point and generates a keyhole. The keyhole leads to a sudden increase in absorptivityquickly deepening the hole. As the hole deepens and the material boils, vapor generated erodes the molten walls blowing ejecta out and further enlarging the hole.

Non melting material such as wood, carbon and thermoset plastics are usually cut by this method.

- **Melt and blow**

Melt and blow or fusion cutting uses high-pressure gas to blow molten material from the cutting area, greatly decreasing the power requirement. First the material is heated to melting point then a gas jet blows the molten material out of the kerf avoiding the need to raise the temperature of the material any further. Materials cut with this process are usually metals.

- **Thermal stress cracking**

A beam is focused on the surface causing localized heating and thermal expansion. This results in a crack that can then be guided by moving the beam. The crack can be moved in order of m/s. It is usually used in cutting of glass.

- **Stealth dicing of silicon wafers**

The separation of microelectronic chips as prepared in semiconductor device from silicon wafers may be performed by the so-called stealth dicing process, which operates with a pulsed Nd:YAG laser, the wavelength of which (1064 nm) is well adopted to the electronic band gap of silicon (1.11 eV or 1117 nm).

- **Reactive cutting**

Reactive cutting is like oxygen torch cutting but with a laser beam as the ignition source. Mostly used for cutting carbon steel in thicknesses over 1 mm. This process can be used to cut very thick steel plates with relatively little laser power.

Table 3.2. Different ways in which the laser can be used to cut.

Method	Concept	Relative Energy
1. Vaporisation		40
2. Melt and blow		20
3. Melt, burn and blow		10
4. Thermal stress cracking	Tension	1
5. Scribing	perforation	1
6. "Cold cutting"	hν High energy photons	100
7. Burning stabilised laser cutting	oxygen burning	5

Equipment

- Laser-beam generator
- Beam delivery: Circular polarizers, mirrors, beam splitters, focusing lenses and fiber optic couplings
- Workpiece positioning
- Auxiliary devices: Laser head, safety equipment, etc.

In addition, assist gases also required

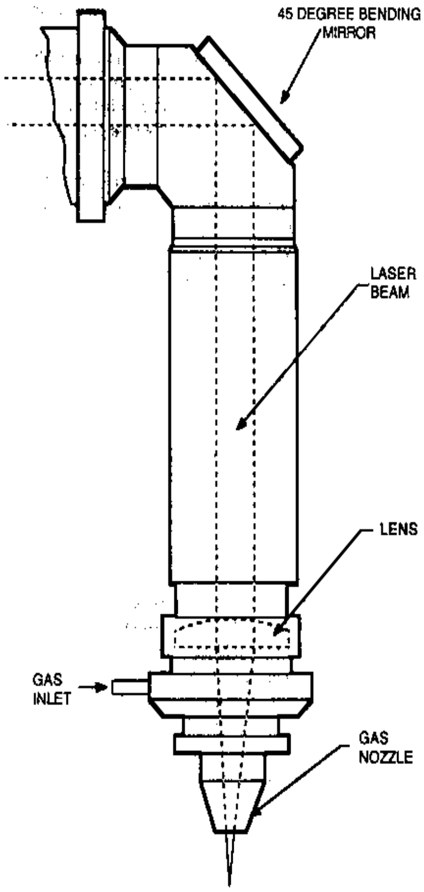


Figure 20.13 Beam delivery system for laser cutting applications.

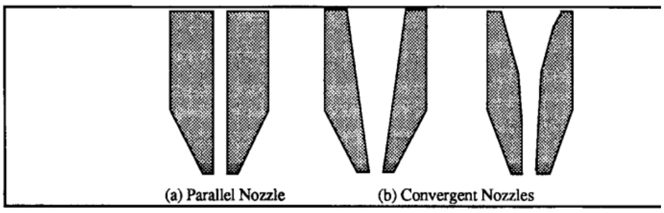


FIGURE 3.19 (a) Parallel and (b) Convergent Nozzle Designs

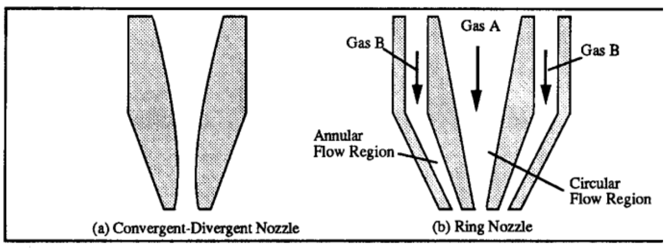


FIGURE 3.20 (a) Convergent-Divergent and (b) Ring Nozzle Designs

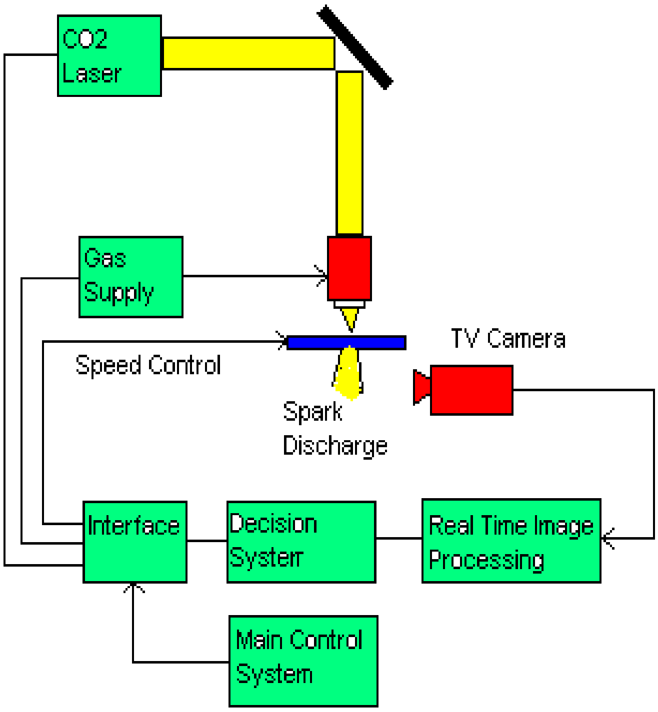
In this process, the Laser Beam is called monochromatic light**,** which is made to focus on the workpiece to be machined by a lens to give extremely high energy density to melt and vaporize any material.
The Laser Crystal (Ruby) is in the form of a cylinder as shown in the above figure or Diagram with flat reflecting ends which are placed in a flash lamp coil of about 1000W.
The Flash is simulated with the high-intensity white light from Xenon. The Crystal gets excited and emits the laser beam which is focused on the workpiece by using the lens.
The beam produced is extremely narrow and can be focused to a pinpoint area with a power density of 1000 kW/cm^2. Which produces high heat and the portion of the metal is melted and vapourises.

Tolerances and surface finish
New laser cutters have positioning accuracy of 10 micrometers and repeatability of 5 micrometers.
Standard roughness Rz increases with the sheet thickness, but decreases with laser power and cutting speed.
For example, when cutting low carbon steel with laser power of 800 W, standard roughness Rz is 10 μm for sheet thickness of 1 mm, 20 μm for 3 mm, and 25 μm for 6 mm.

We have the formula: $Rz = 12.528 \times \left(S^{0.542}\right) / \left(\left(P^{0.528}\right) \times \left(V^{0.322}\right)\right)$,

where: S: steel sheet thickness (mm);
P: laser power (kW) (some new laser cutters have laser power of 4 kW.);
V: cutting speed (m/min)
This process is capable of holding quite close tolerances, often to within 0.001 inch (0.025 mm) Part geometry and the mechanical soundness of the machine have much to do with tolerance capabilities. The typical surface finish resulting from laser beam cutting may range from 125 to 250 micro-inches (0.003 mm to 0.006 mm).

III. RESULTS AND DISCUSSION



A CO2 laser (HyperGear; Yamazaki Mazak Optronics Europe NV, Ltd.) emitting at 10.6 μm and delivering a nominal output power of 4 kW in the pulse mode with different frequencies was used to cut the workpieces. The laser beam was focused with a 7.5 inch focal lens. To aid the cutting process N2 gas A Study of the Laser Cutting Process 321 emerging from a conical nozzle supplied coaxially with the laser beam was used. The laser power and laser cutting speed were varied at four levels and the full experimental cutting conditions used are given in Case1. The workpieces used were obtained from rolled 304 stainless steel sheets of 1 and 3 mm thicknesses. The elemental composition of the stainless steel is given in Case2. After laser cutting optical microscopy was used to measure the kerf width and dross height of the resulting cuts..

Case1: Experimental CO_2 laser cutting conditions.
Feed rate (mm/min) 200 250 300 350
Power (W) 1000 1200 1400 1600
Frequency (Hz) 100 1000
Nozzle gap (mm) 1.5
Nozzle diameter (mm) 1.5
Duty (%) 100 N_2 pressure (kg/cm2)
Case 2: Elemental composition of the 304 stainless steel used in the experiments
(wt%) C 0.08
Mn 2.0
P 0.045
S 0.030
Si 0.75
Cr 18.00-20.00
Ni 8.00-12.00
N 0.10
Fe 65-71

Laser Beam Temporal Modes
Continuous Wave (CW) commonly results in the highest cutting speed & better surface finish.
Roughness is determined by thickness, alloy content, etc.

Pulsed beam results in the fewest thermal effects & least distortion of workpiece. With drilling overlapping holes (see right), it's possible to cut with smoother surface.

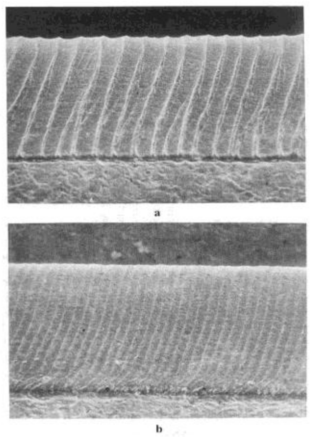
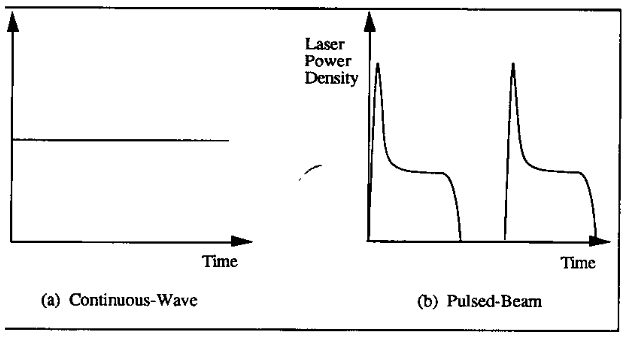


Fig. 2.18. A comparison of **a** continuous wave laser cutting and **b** pulsed laser cutting (pulse frequency 500 Hz, on : off ratio 4 : 1). All other cutting conditions were kept constant for the two samples, i.e. material thickness 1.25 mm (0.05 in), average laser power 300 W, oxygen pressure 2.0 bar, cutting speed 1.8 m/min (70 in/min). The roughness of the pulsed sample (Ra) was only 25% of the continuous wave sample.



.17 Laser Beam Temporal Modes

Comparison of Major Material Machining Lasers

Table 1.2	Efficiency of main types of industrial lasers		
Type	Wavelength μm	Quantum Efficiency %	Wall Plug Efficiency %
Carbon Dioxide	10.6	45	12
Carbon Monoxide	5.4	100	8
Nd-YAG	1.06	40	2
Nd-Glass	1.06	40	1
Diode pumped YAG	1.06	40	8
Excimer (KrF)	0.249		2

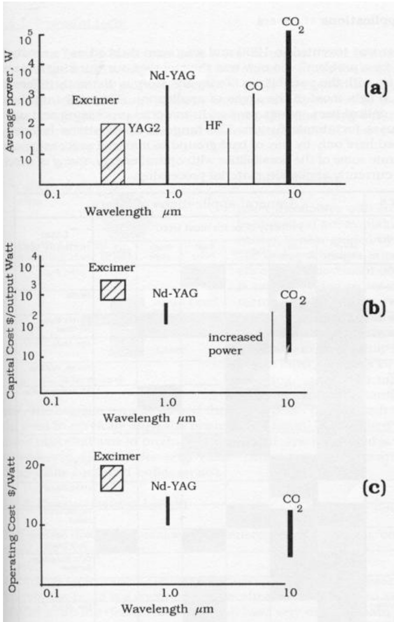


Fig.1.21. Various comparisons between the principle material processing lasers;
a) Comparison of available power vs wavelength.
b) Comparison of capital cost/output watt.
c) Comparison of operating cost/output watt.

Cutting Considerations for Different Materials

- **Ferrous Metals:**

i. High efficiency due to easy-to-remove oxide creation

ii. One approximate rule:1.5kW laser power will cut

a. 1mm thick mild steel at approx 10m/min

b. 10mm thick mild steel at approx 1m/min

- **Non-Ferrous Metals:**

i. Mostly less efficient than cutting steel, due to the higher reflectivity, thermal conductivity & less efficient oxidation reaction

ii. Similar edge qualities to SS

- **Non-Metal: Most non-metallic materials are highly absorptive at CO2 laser wavelength. Cutting process:**

i. Melt Shearing (mostly for thermoplastic): cut very quickly & high quality edges

ii. Vaporization: usually only for acrylic

iii. Chemical degradation: slow cutting, high temperature, but flat & smooth result

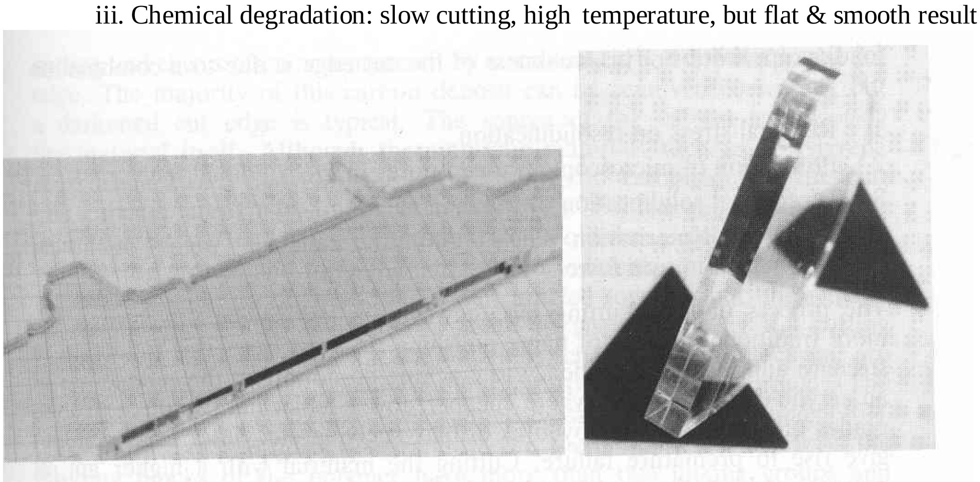


Fig. 4.4. Examples of the "polished" edge which can be produced when laser cutting acrylic with a low pressure air jet.

Cutting Speed on Mild Steel **Cutting Speed on Stainless Steel**

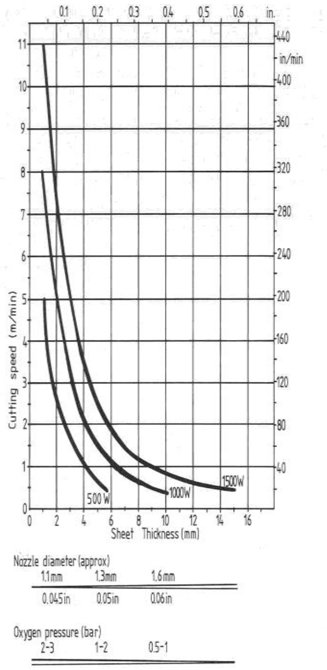


Fig. 2.3. Cutting speeds for mild steel for a number of laser powers. (Guidelines concerning nozzle diameters and oxygen pressures for each thickness are also given.)

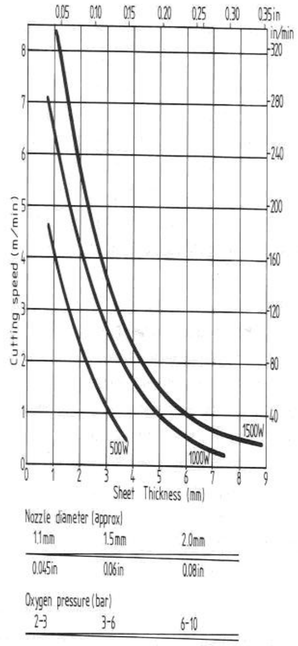


Fig. 2.20. Typical cutting speeds for stainless steels at a number of laser powers. Guidelines are also given for oxygen pressures and nozzle diameters, both of which increase with increasing material thickness.

Max Cutting Speed for Polymer:
$V=PQt^{-B}$
P = Laser Power (W) t = material thickness (mm)
Q = an experimentally derived constant for the polymer
B = an experimentally derived constant for the material

Power setting for different cutting applications

Application Requirement	Recommended Laser Power	Cutting consideration
Thin materials: Non- metals	150 Watt Average, 450 Watt peak	Up to 0.04” thick can be cut at full speed of 1200in/min with 150 watt
Thicker materials: Non-metals	250 watt to 500 watt average - up to 1500 watt peak	Up to 1”: Power ↑ →Cutting Speed ↑ , cleaner result & lower HAZ
Metals	150 watt to 500 watt average - up to 1500 watt peak	Al, Brass, SS use 500 W due to its reflectivity. As thickness ↑, also power need to be ↑

Laser Cutting Analysis
Cutting depth, s
$s = 2.a.P/(\pi^{1/2}.\rho.v.d.(cp.(Ts-To)+L))$
a = absorbtivity of the material
P = Beam power
ρ = density
v = scanning velocity
d = spot diameter (=2.R)
cp = specific heat
Ts = surface temperature
To = ambient temperature
L = latent heat of fusion

Example Typical CO_2 Laser Cutting Parameters

Table 6.1 Typical CO_2 Laser Cutting Parameters

Material	Thickness (mm)	Travel speed (m/min)	Power (W)	Assist gas
Carbon steel	0.025	0.5	30	Air
Carbon steel	0.25	1.25	80	O_2
Carbon steel	0.75	2.5	200	O_2
Carbon steel	1.5	4.0	400	O_2
Carbon steel	3	3.0	800	O_2
Carbon steel	6	2.0	1200	O_2
Carbon steel	10	1.25	1500	O_2
Stainless steel	0.5	5.0	900	N_2
Stainless steel	0.75	4.5	1200	N_2
Stainless steel	1.5	4.0	1500	N_2
Stainless steel	3	1.0	1500	N_2
Stainless steel	6	1.0	650	O_2
Stainless steel	10	0.75	800	O_2
Titanium Ti 6Al 4V	1.5	4.0	1500	Argon
Kevlar-epoxy	3	6.0	400	Air
Kevlar-epoxy	6	6.0	1500	Air
G10 glass-polyester	1.5	15	1000	Air
Boron-aluminum	1	7.5	150	Air
Silicon carbide-titanium	0.75	0.6	150	Argon

Characteristics of cuts by Laser Cutting

- Kerf Width: CO_2 laser range from 0.1-1mm
- Roughness: 0.8mm material → 1 μm
- 10 mm material → 10 μm
- Dross: undesirable; removed by extremely high assist gas or by applying antisplatter coatings (i.e. graphite)
- Dimensional Accuracy: main problem is thermal effect (distortion)

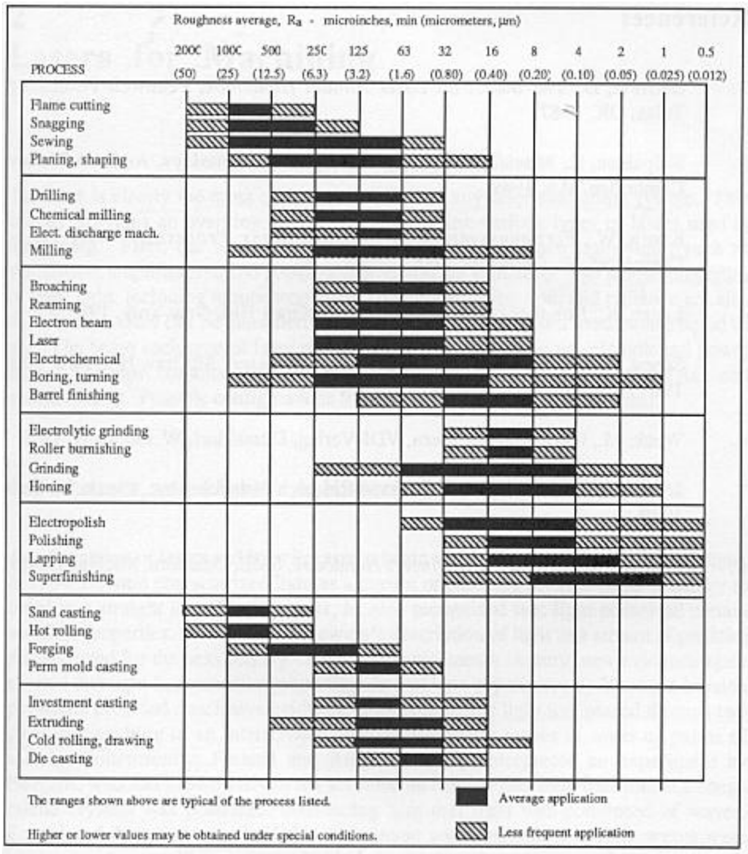


TABLE 1.4 Surface Quality for Different Machining Processes [7]

Table 3.1. Comparison of Different Cutting Processes

QUALITY	Laser	Punch	Plasma	Nibbling	Abrasive Fluid Jet	Wire EDM	NC Milling	Sawing	Ultrasonic	Oxy Flame
Rate	✓	✓	✓	✖	✖	✖	✖		✖	✖
Edge Quality	✓	✓	✖	✖	✓	✓	✓	✖	✓	✖
Kerf Width	✓	✓	✖		✓	✓		✖		
Scrap and Swarf	✓	✓		✖	✓			✖		✓
Distortion	✓		✖		✓		✓		✓	✖
Noise	✓	✖	✖		✖					✖
Metal+Nonmetal	✓		✖		✓		✓		✓	
Complex Shapes	✓	✖	✓							
Part Nesting	✓	✖			✓					
Multiple Layers	✖	✓								
Equipment Cost	✖				✖			✓		✓
Operating Cost						✖		✓		✓
High Volume	✓	✓		✖					✖	
Flexibility	✓	✖	✓	✓	✓	✖				
Tool Wear	✓	✖	✓	✖	✓		✖	✖	✖	✓
Automation	✓	✓	✓	✖	✓	✖	✓			✖
HAZ	✓	✓	✖		✓	✓	✓			✖
Clamping	✓	✖	✓		✓		✖	✖		
Blind Cuts	✓	✓	✓	✓		✖	✖		✖	✓
Weldable Edge	✓	✓	✖	✓	✓	✓	✓		✓	✖
Tool Changes	✓	✖	✓		✓					

✓ Point of particular merit
✖ Point of particular disadvantage
(Further comparisons can be found in ref 1)

Cutting Cost example

- Laser Generation: $ several hundred thousand
- Cooling system, power supply, multi-axis robot: exceed cost of laser

OPERATING COST:

- ✓ CO2 lasers cost $70-$100/watt (Nd:YAG costs 10-20%more)
- ✓ Safety devices
- ✓ Skilled operator

Example CO_2 system operating at 1500W

- Electricity at 7cent/kW-hr $2.10/hr
- Internal laser optics $2.06/hr
  (lifetimes per manufacturer)
- Focusing lens (500hr lifetime) $1.10/hr
- Laser gas $1.03/hr
- Assist gas $3.60/hr
  (based on 10ga. Carbon steel w/ O_2 assist)

TOTAL: $9.89/hr

Advantages of Laser Cutting

- Laser machining is a *thermal process*: depends on thermal and optical rather than the mechanical properties
- Laser machining is a *non-contact* process: No cutting forces generated
- Laser machining is a *flexible* process
- Laser machining produces a higher precision and smaller kerf widths results (as small as 0.005mm dia hole)
- For most industrial materials up to 10mm thick, laser cutting has a significantly higher MRR
- Laser Cutting has ability to cut from curved workpieces
- For cutting fibrous material (wood, paper, etc.) laser cutting eliminates residue and debris

Disadvantage of Laser Cutting

- Low energy efficiency
- Material damage: Heat affected zone (HAZ)
- Laser cutting effectiveness reduces as the workpiece thickness increases
- Laser cutting produces a tapered kerf shape (due to divergence)

IV. CONCLUSION

- In the laser cutting process, many factors affect the end product quality . Some of these factors include the focus setting of focusing lens and the workpiece thickness.
- This is due to the fact that the focus setting modifies the power intensity distribution across the focused spot, while workpiece thickness alters the energy required for full-depth penetration cutting.
- In the present study the CO2 laser cutting of 304 stainless steel sheet is considered and the influence of laser output power, laser cutting speed on the kerf width, stria formation and HAZ are measured

- The cutting Of CO_2 laser has been considered with the influences of laser power and cutting speed on the kerf size and dross height being examined.
- It was found that changing both parameters significantly influenced the kerf width. Increasing laser power results in increased kerf width and increasing cutting speed was seen to cause a decrease in the kerf width.
- These findings were found to be mainly because of the unavoidable presence of high temperature combustion reactions at high laser power levels. The dross height was found to increase at high laser power levels; however, this variation was not linear, but rather complex

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