Laser Material Processing(LMP)

Lecture 6

Laser Cutting

Laser Cutting Videos

- https://www.youtube.com/watch?v=K03wZbqf5AI

Laser Cutting System

1. Laser-beam generator

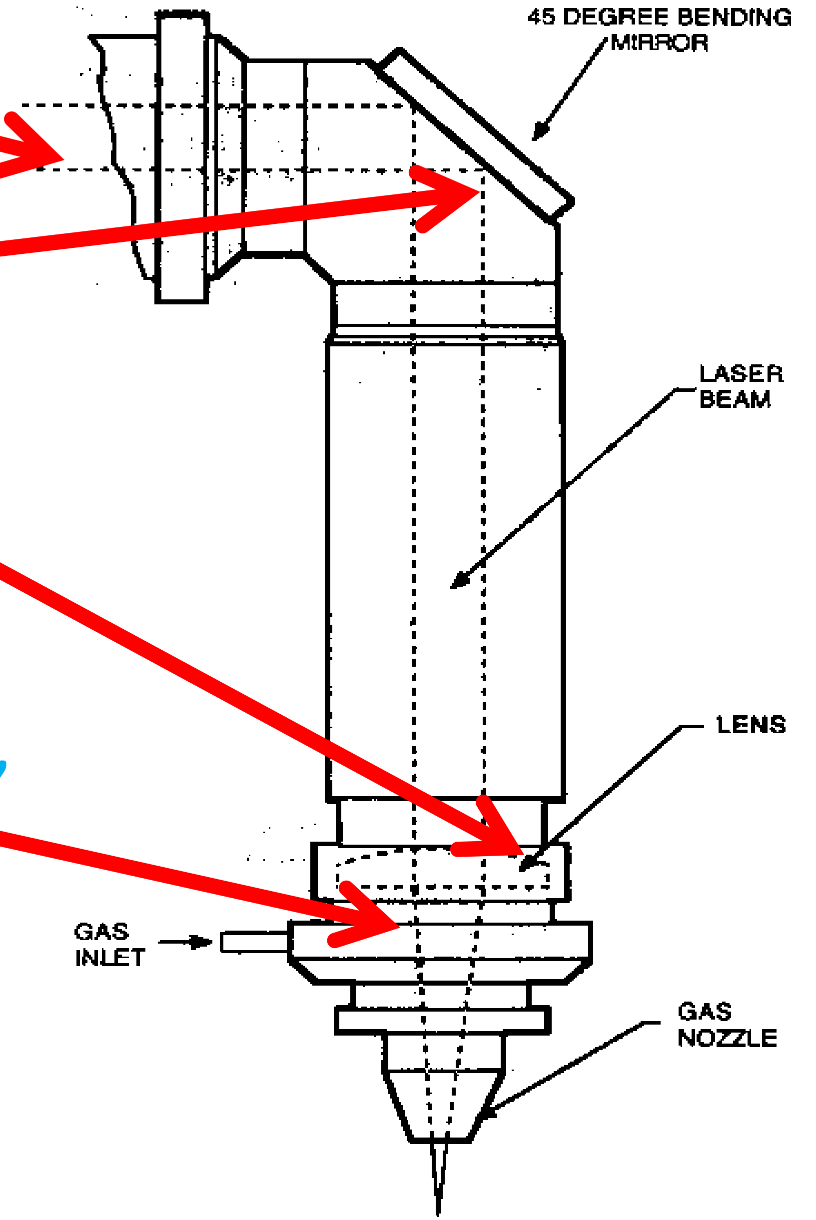
2. Beam delivery:

Circular polarizers, mirrors, beam splitters, focusing lenses and fiber optic couplings

3. Auxiliary devices: Laser head, safety equipment, etc.

4. Workpiece positioning

In addition, assist gases also required



Laser Cutting System

Gas Nozzle Designs

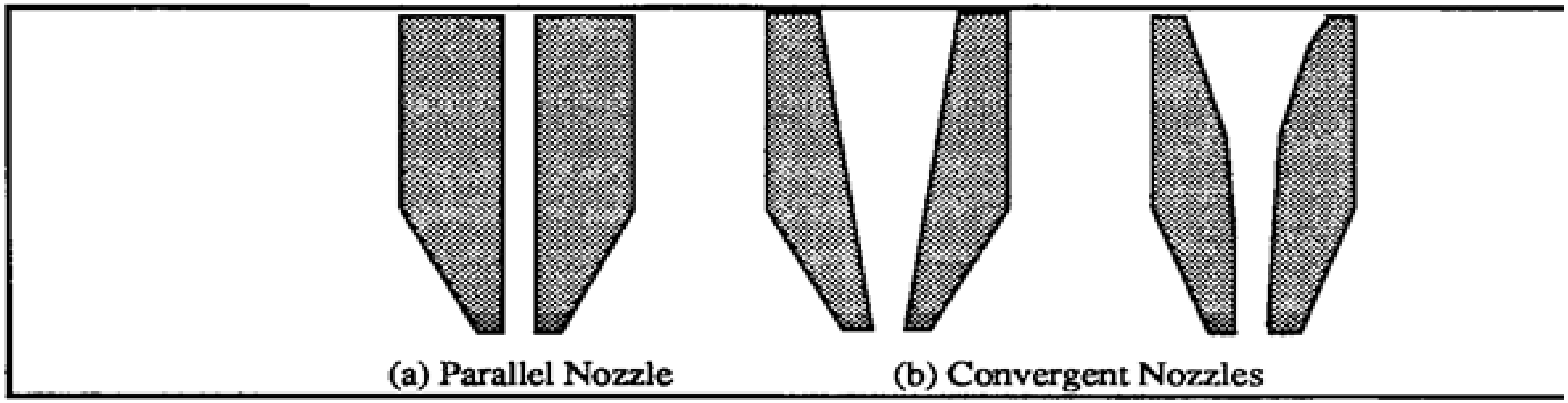


FIGURE 3.19 (a) Parallel and (b) Convergent Nozzle Designs

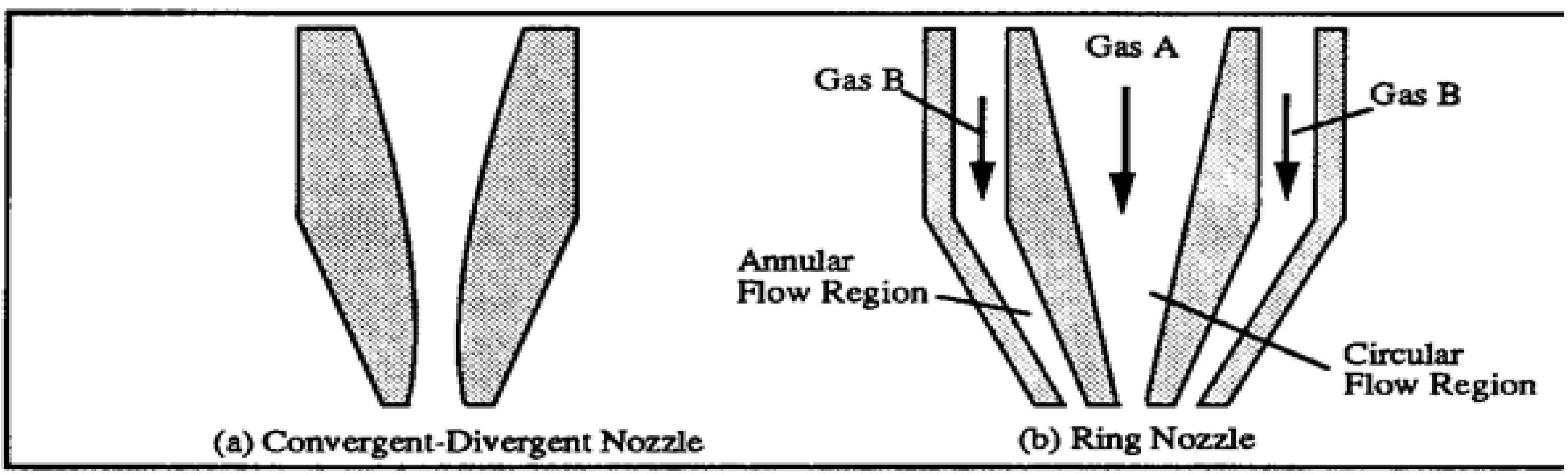
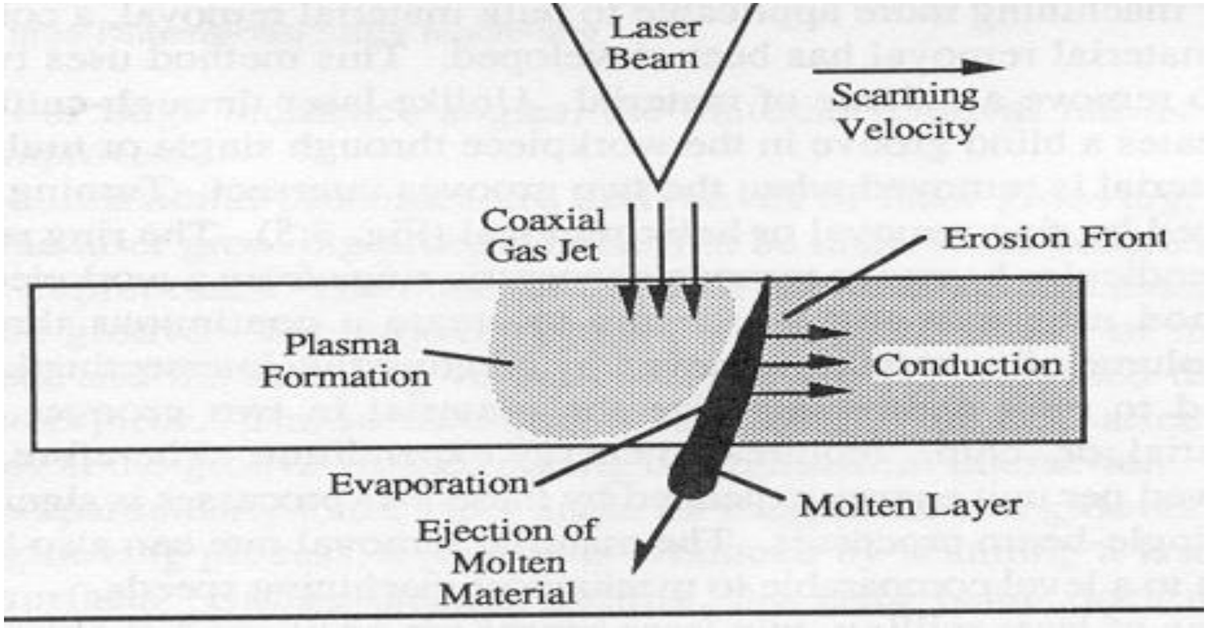
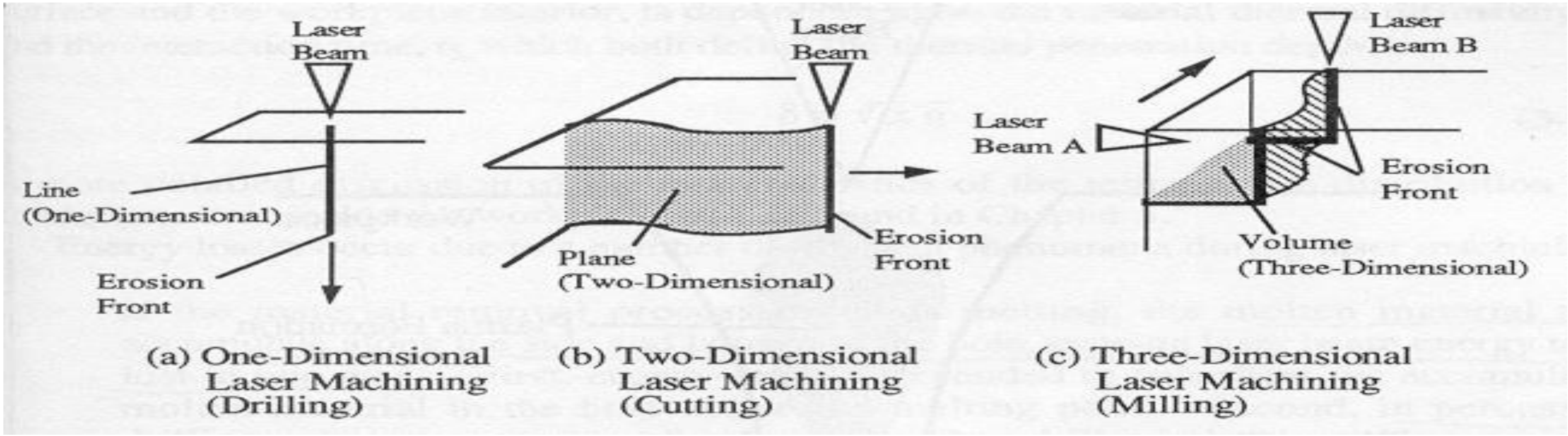


FIGURE 3.20 (a) Convergent-Divergent and (b) Ring Nozzle Designs

Laser Cutting Process

Laser Cutting





Material Removal Types of Laser Cutting

1. Vaporization: low vaporization temperature materials
2. Fusion: high vaporization temperature materials. Material is melted & ejected (by an inert gas jet)
3. Reactive Fusion:
4. Thermal stress cracking or controlled fracturing: for brittle materials
5. Scribing: Mechanical snapping along scribed line
6. Ablation (Excimer laser): breaking organic material bonds (e.g. polymer)
7. Burning in reactive gas

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

Different Type of Laser for Laser Cutting

1. CO_2 laser :

a. Have the highest Continuous Wave (CW) power
b. Capable to extract as much as 10k W
c. Have a high energy efficiency
d. Capable of both CW and Pulsed operation (5kHz)

2.Nd:YAG:

a. has the highest peak power for pulsed operation
b. May be operated in either CW or pulsed

3.Nd: Glass:

more economical but has lower thermal conductivity. Used for low pulse repetition rates & high pulse energies. Ideal for drilling.

4.Nd: Ruby:

low energy efficiency & power, Limited to pulsed laser operation

Different Type of Laser for Laser Cutting

5. Excimer:

a. High power pulsed beams

c. Used to machine solid polymer pieces, remove polymer films, micromachine ceramics, medical applications

d. Ablation material removal process

e. Higher precision & less heat affected zone vs. CO_2 & Nd:YAG lasers

f. Produces large area beams $\rightarrow$ use mask to produce series of holes. 5000 holes in a polymide sheet in 3 sec vs 50 sec using CO2 or Nd:YAG lasers.

Comparison of Major Material Machining Lasers

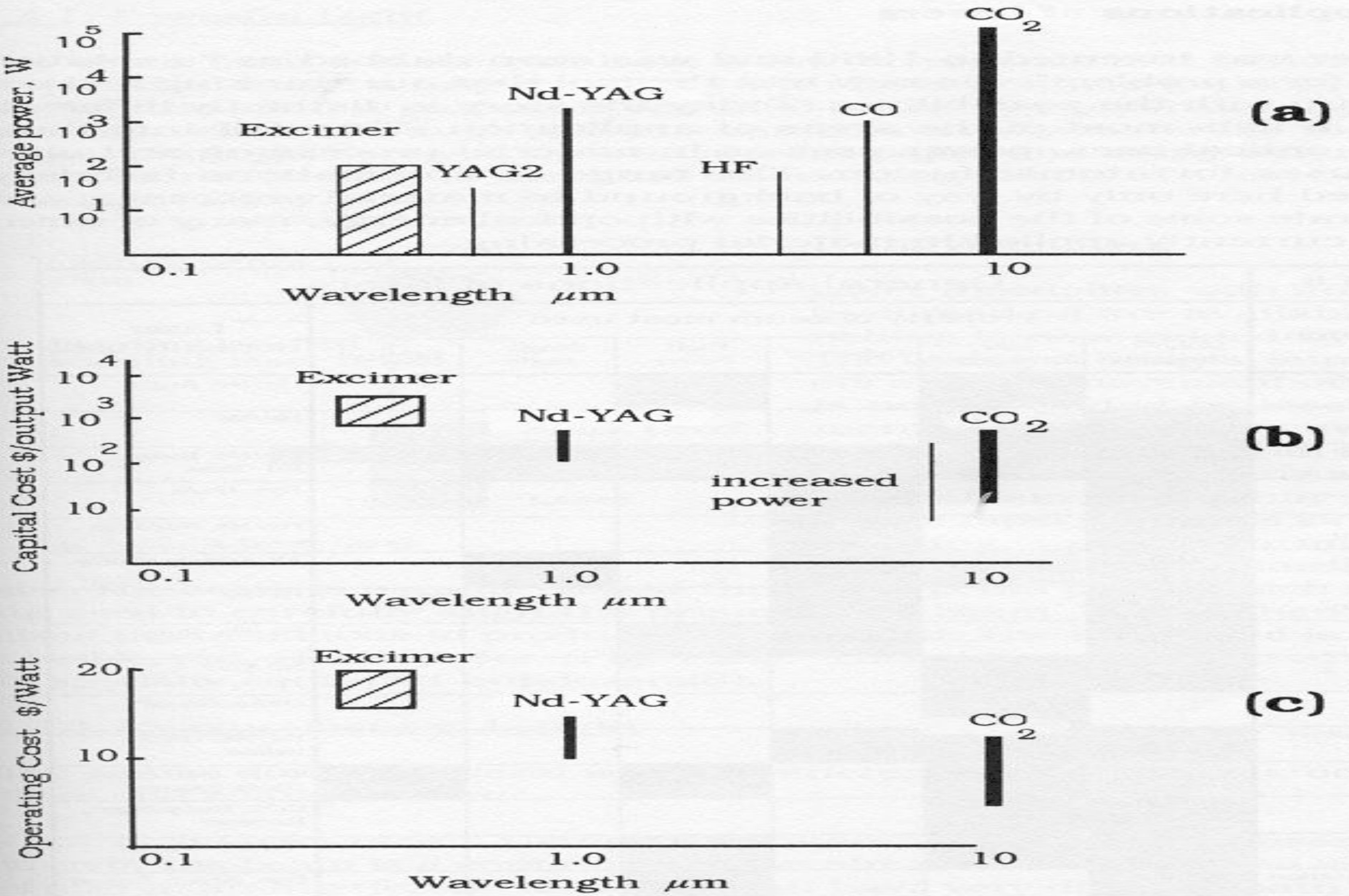
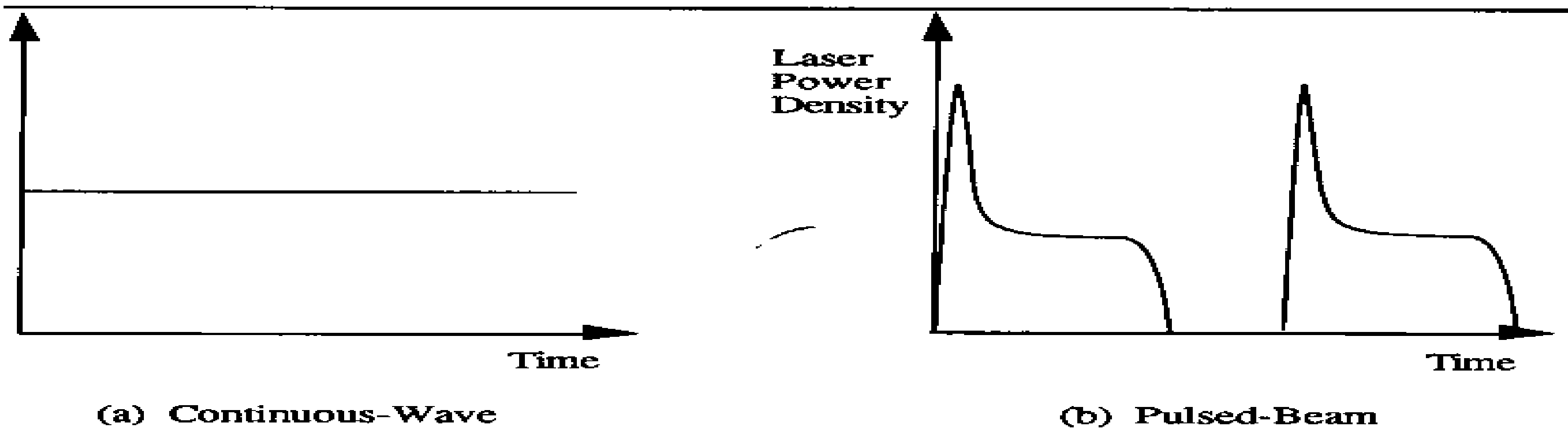


Fig.1.21. Various comparisons between the principle material processing lasers;
a) Comparison of available power vs wavelength.
b) Comparison of capital cost/output watt.
c) Comparison of operating cost/output watt.

Effect of 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.



.17 Laser Beam Temporal Modes

Effect of Laser Beam Temporal Modes

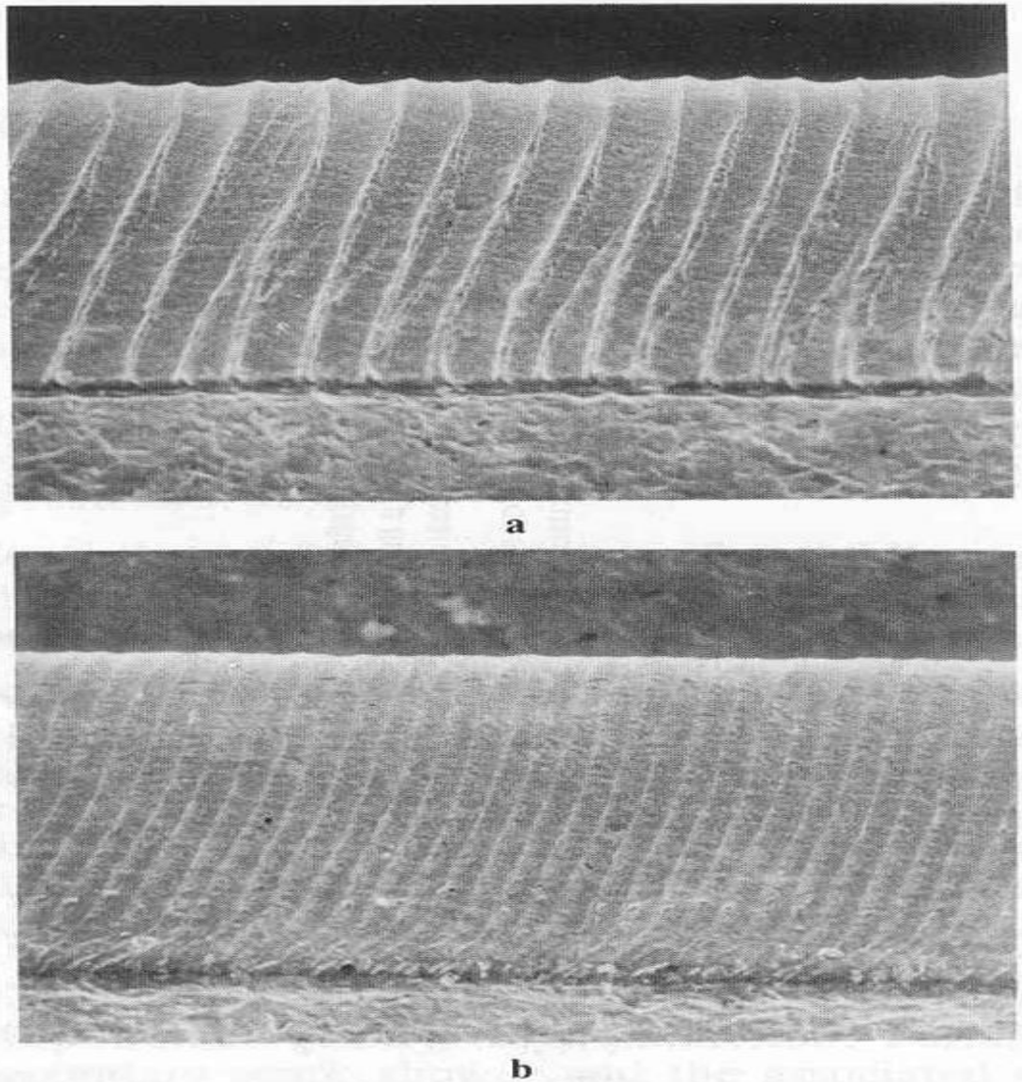


Fig. 2.18. A comparison of **a** continuous wave laser cutting and **b** pulsed laser cutting (pulse frequency 500 Hz, on : off ratio 4 : 1). All other cutting conditions were kept constant for the two samples, i.e. material thickness 1.25 mm (0.05 in), average laser power 300 W, oxygen pressure 2.0 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.

Cutting Considerations for Different Materials

A. 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

B. Non-Ferrous Metals:

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

ii. Similar cut edge qualities to SS

Cutting Considerations for Different Materials

C. Non-Metal:

Most non-metallic materials are highly absorptive at CO_2 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

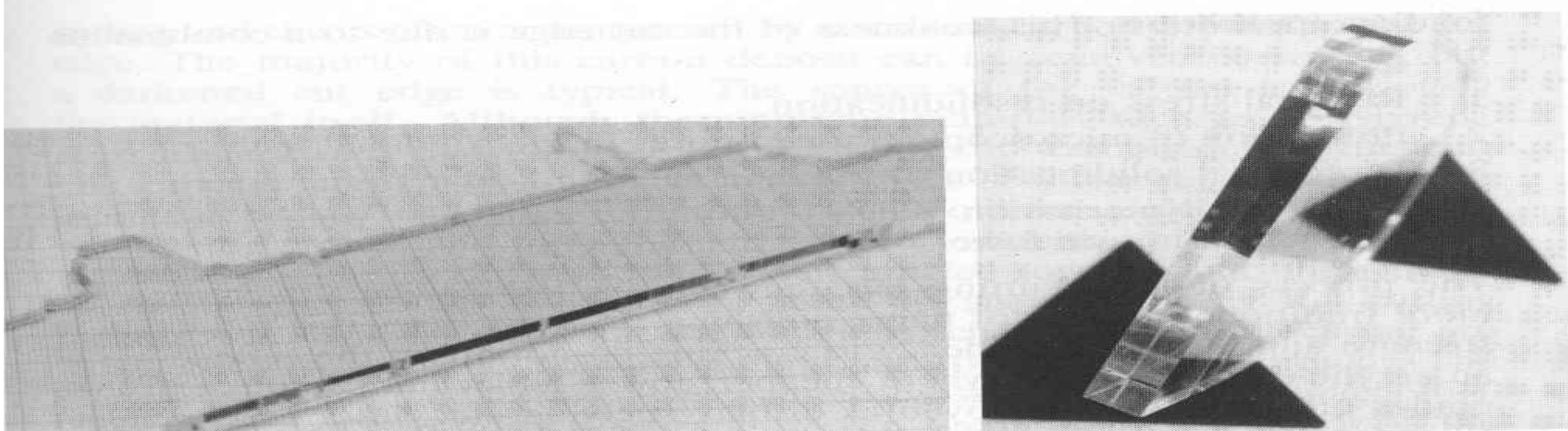


Fig. 4.4. Examples of the "polished" edge which can be produced when laser cutting acrylic with a low pressure air jet.

Cutting Considerations for Different Materials

Cutting Speed on Mild Steel

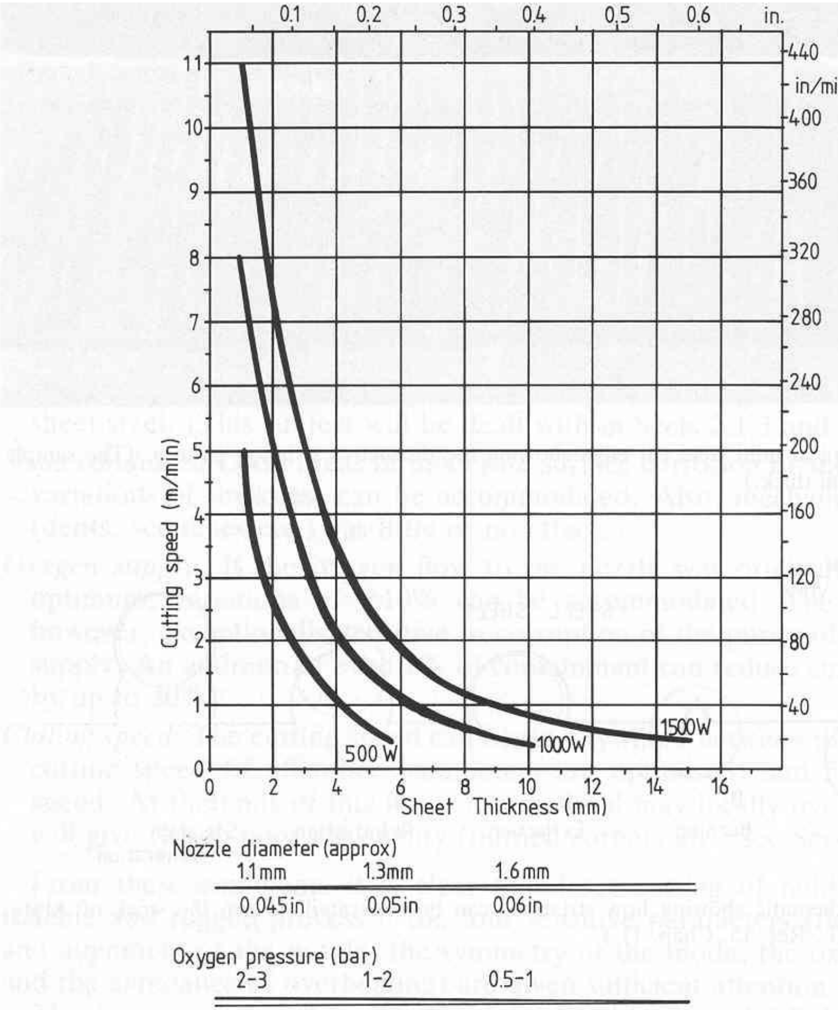


Fig. 2.3. Cutting speeds for mild steel for a number of laser powers. (Guidelir nozzle diameters and oxygen pressures for each thickness are also given.)

Cutting Speed on Stainless Steel

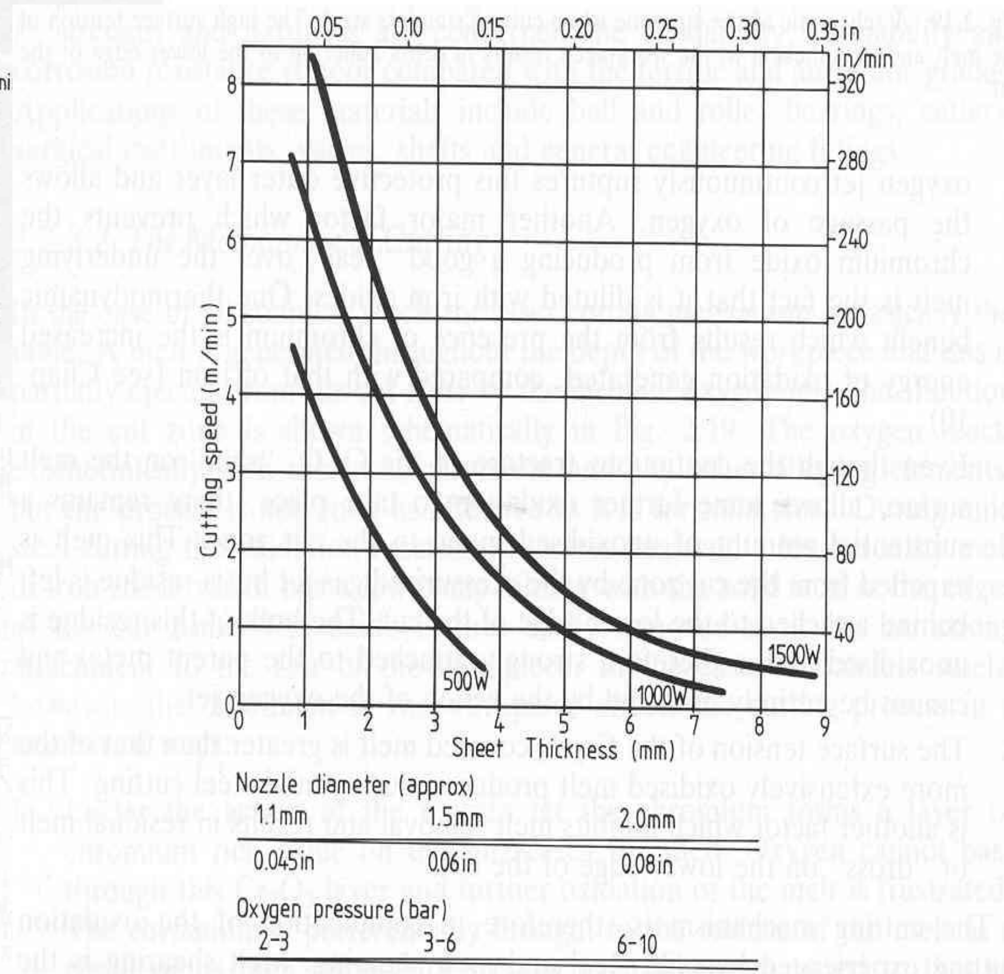


Fig. 2.20. Typical cutting speeds for stainless steels at a number of laser powers. Guidelines are also given for oxygen pressures and nozzle diameters, both of which increase with increasing material thickness.

Cutting Considerations for Different Materials

Cutting Speed on Aluminum

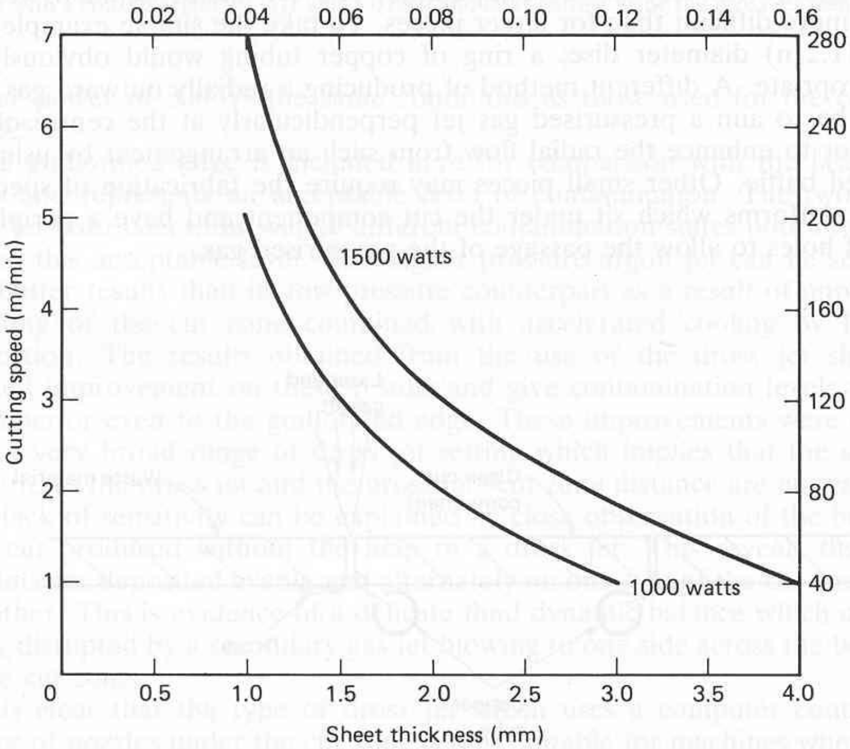


Fig. 3.8. Typical cutting speeds for aluminium alloys at laser powers of 1000 W and 1500 W. Cutting gas: oxygen at pressures of 2–6 bar. (*Note*: Anodised aluminium cuts approximately 30% faster.)

Cutting Speed on Acrylic

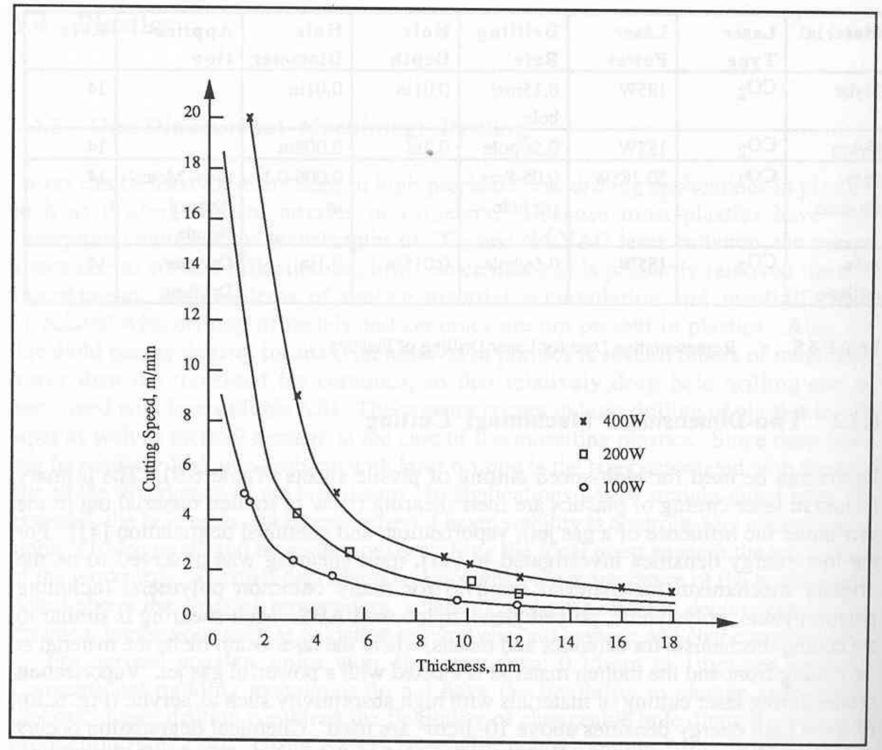


FIGURE 6.30 Cutting Speed vs. Workpiece Thickness for Acrylic

One particularly successful industrial application for plastics is laser cutting of seat belts [14], which are usually manufactured from woven nylon, which is difficult to cut mechanically. Using a 500W beam, cutting speeds of over 12m/min were achievable. The machined edge is sealed with no burring or charring. Another industrial application is the selective removal of plastic coating from a metallic film or wire. The shield material can be vaporized with no damage to the metal underneath.

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

Cutting Considerations for Different Materials

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

$$S = 2.a.P/(\pi 1/2.\rho.v.d.(cp.(Ts\text{-}To)+L))$$

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

Cutting Considerations for Different Materials

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

Comparison Of Laser Cutting To Other Methods

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)

Advantages of Laser Cutting

1. Laser machining is a *thermal process*: depends on thermal and optical rather than the mechanical properties

2. Laser machining is a *non-contact* process: No cutting forces generated

3. Laser machining is a *flexible* process

4. Laser machining produces a higher precision and smaller kerf widths results (as small as 0.005mm dia hole)

5. Laser Cutting has ability to cut from curved workpieces

6. For cutting fibrous material (wood, paper, etc.) laser cutting eliminates residue and debris

Disadvantage of Laser Cutting

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

Home Work

Compare between Continuous Wave (CW) mode laser cutting process and Pulsed mode laser cutting process