CO_2 Laser Machining: A Review

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Abstract: Laser beam machining provides various advantages such as high flexibility in terms of process parameters and material type, as well as the possibility to obtain complex geometry in different dimensions with high precision. From industrial point of view, the two competitive laser cutting technologies are based on the use of CO_2 and active fiber sources, which produce samples visually different, with non-uniform surface and different depth of striations. The process parameters play an important role in the quality of the response of interest. The major process parameters that influence the responses are power, speed and number of passes of the laser probe.

***Index Terms* – CO_2 laser machining**

I. Introduction

1.1 Advance Machining Processes

Machining processes produce finished products with a high degree of accuracy and surface quality. Conventional machining utilizes cutting tools that must be harder than the work piece material. The use of difficult-to-cut materials encouraged efforts that led to the introduction of the non-conventional machining processes that are well-established in modern manufacturing industries.

Parts manufactured by casting, forming, and various shaping processes often require further operations before they are ready for use or assembly. In many engineering applications, parts have to be interchangeable in order to function properly and reliably during their expected service lives; thus control of the dimensional accuracy and surface finish of the parts is required during manufacture. Machining involves the removal of some material from the work piece (machining allowance) in order to produce a specific geometry at a definite degree of accuracy and surface quality.

1.2 Types of Advance Machining Processes

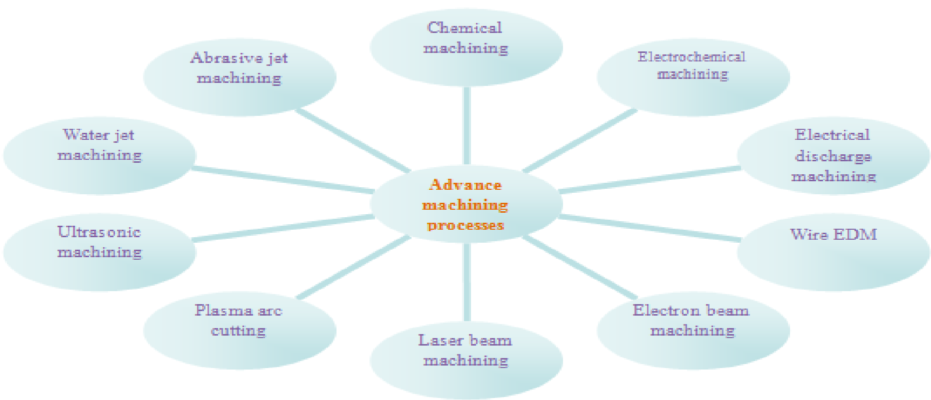

Fig: 1.1 Advance Machining Processes.

1.3 Laser Beam Machining

LASER stands for Light Amplification by Stimulated Emission of Radiation. A laser is a device which produces highly directional light. It emits light through a process called stimulated emission of radiation which increases the intensity of light. The laser beam is very narrow and can be concentrated on a very small area. This makes laser light highly directional. The laser light spreads in a small region of space. Hence, all the energy is concentrated on a narrow region. Therefore, laser light has greater intensity than the ordinary light.

Laser beam machining is thermal material removal process that utilizes a high energy, coherent light beam to melt and vaporize particles on the surface of metallic and non-metallic work piece. Laser can be used to cut, drill, weld and mark. LBM is particularly suitable for making accurately placed holes.

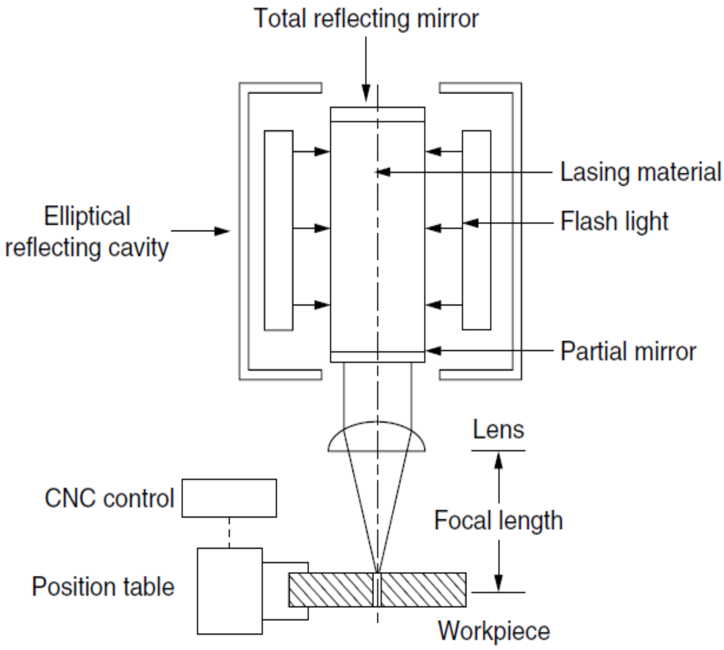

Fig: 1.2 Laser Beam Machining

Material is removed by the unreflected light is absorbed, thus heating the surface of the specimen. On sufficient heat the work piece starts to melt and evaporates.

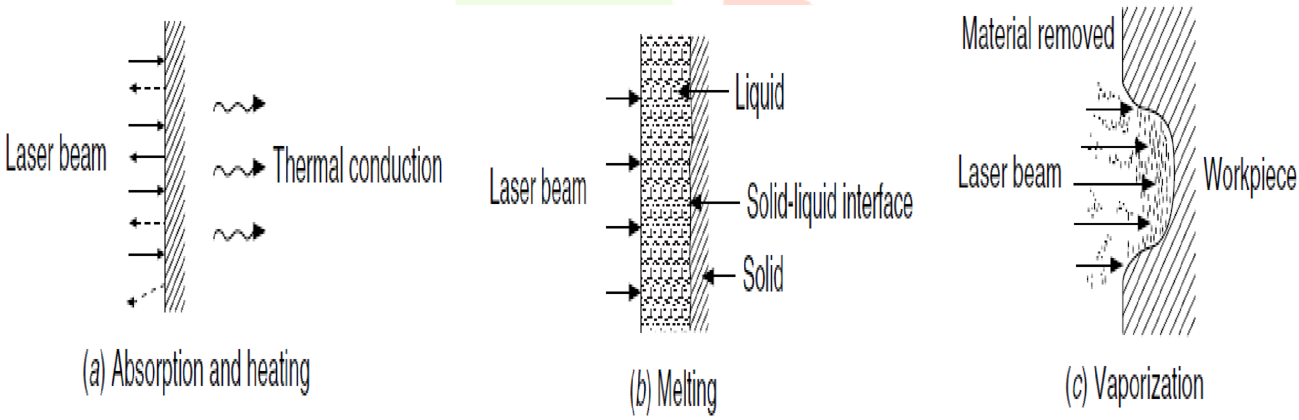

Fig: 1.3Material Removal Mechanism

1.3.1 Types of Laser

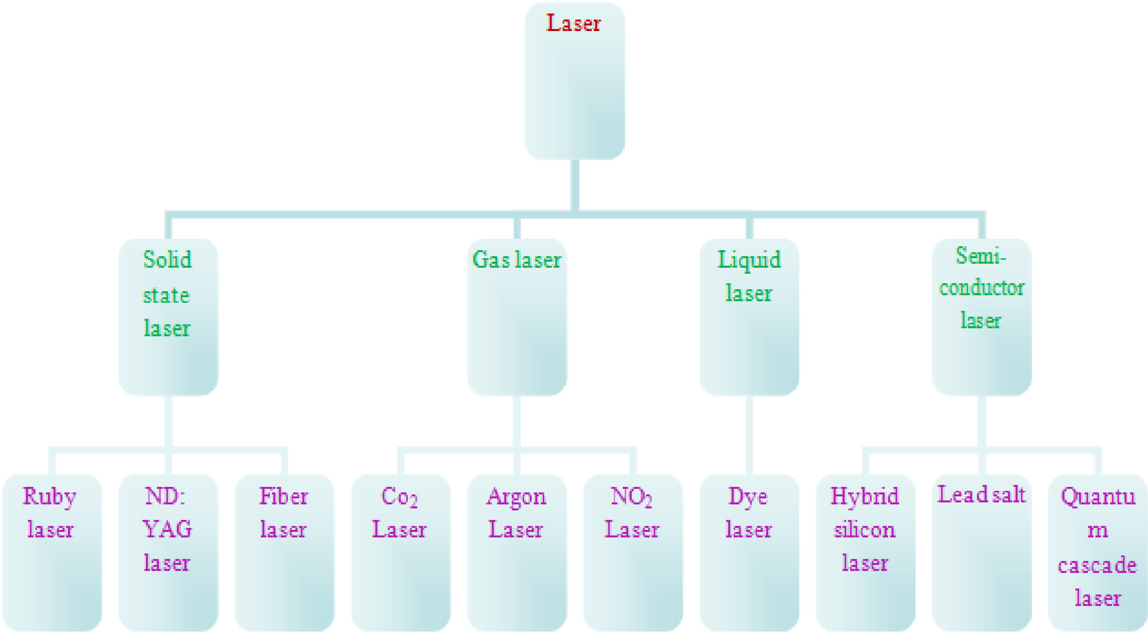

Fig: 1.4 Types of Laser

1.3.1.1 Solid-State Laser

A solid-state laser is a laser that uses solid as a laser medium. In these lasers, glass or crystalline materials are used. i.e. Ruby laser, ND: YAG laser

1.3.1.2 Gas Laser

A gas laser is a laser in which an electric current is discharged through a gas inside the laser medium to produce laser light. In gas lasers, the laser medium is in the gaseous state. Gas lasers are used in applications that require laser light with very high beam quality and long coherence length. i.e. CO_2 laser, Argon laser, NO_2laser.

1.3.1.3 Liquid Laser

A liquid laser is a laser that uses the liquid as laser medium. In liquid lasers, light supplies energy to the laser medium. A dye laser is an example of the liquid laser. A dye laser is a laser that uses an organic dye (liquid solution) as the laser medium.

1.3.1.4 Semiconductor Laser

Semiconductor lasers play an important role in our everyday life. These lasers are very cheap, compact size and consume low power. Semiconductor lasers are also known as laser diodes. From the industrial point of view there are mostly three laser use Nd: YAG, CO_2 and fiber laser.

1.2 CO_2 Laser

The carbon dioxide laser (CO_2 laser) was one of the earliest gas lasers to be developed (invented by Kumar Patel of Bell Labs in 1964), and is still one of the most useful. Carbon dioxide lasers are the highest-power continuous wave lasers that are currently available. They are also quite efficient: the ratio of output power to pump power can be as large as 20%. The CO_2 laser produces a beam of infrared light with the principal wavelength bands centering around 9.4 and 10.6 micrometers. Laser action is achieved by transitions between vibrational and rotational levels of molecules. Its construction is simple and the output of this laser is continuous. In CO_2 molecular gas laser, transition takes place between the vibrational states of Carbon dioxide molecules.

Principle

The active medium is a gas mixture of CO_2, N_2 and He. The laser transition takes place between the vibrational states of CO_2 molecules.

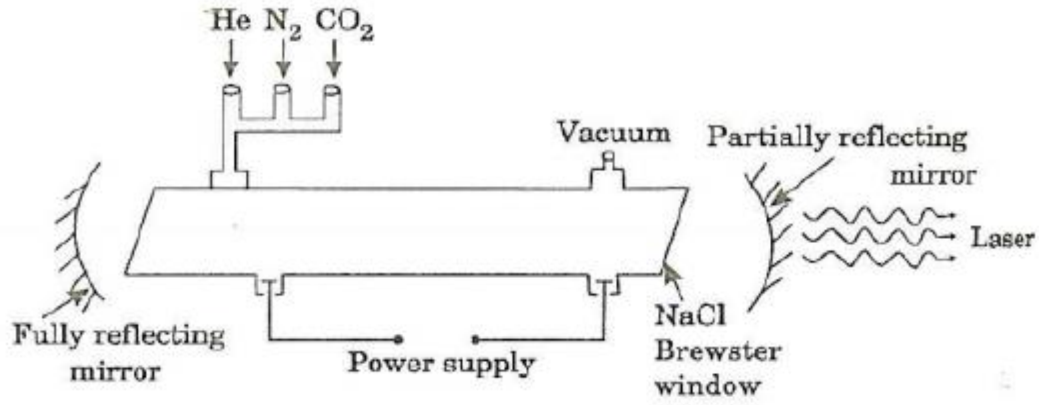

Fig: 1.1 Schematic Diagram of CO_2 Laser

Working

When an electric discharge occurs in the gas, the electrons collide with nitrogen molecules and they are raised to excited states. This process is represented by the equation

$$N_2 + e^* = N_2^* + e$$

N_2 = Nitrogen molecule in ground state e* = electron with kinetic energy
N_2^* = nitrogen molecule in excited state e= same electron with lesser energy

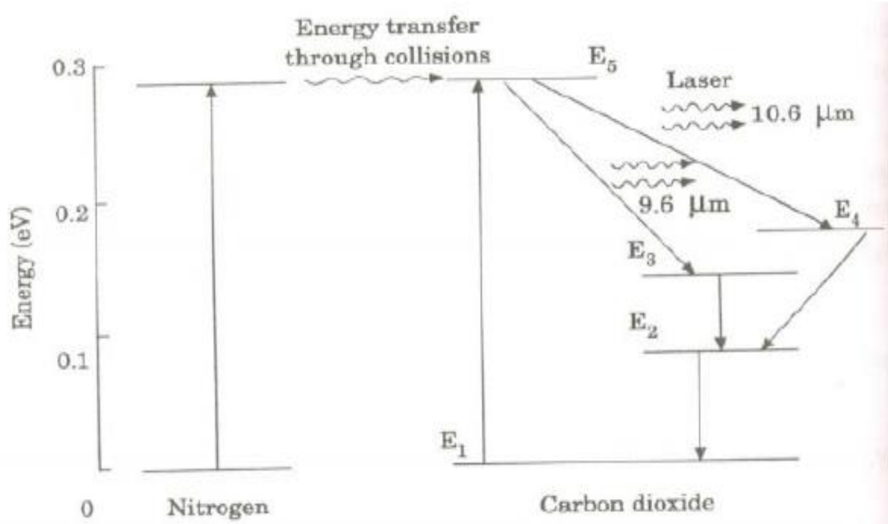

Figure 1.2 Energy Levels of Nitrogen and Carbon Dioxide Molecules.

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N_2^* = nitrogen molecule in excited state e= same electron with lesser energy

Now N_2 molecules in the excited state collide with CO_2 atoms in ground state and excite to higher electronic, vibrational and rotational levels. This process represented by

$$N_2^* + CO_2 = CO_2^* + N_2$$

N_2^* = Nitrogen molecule in excited state. CO_2 = Carbon dioxide atoms in ground state
N_2=Nitrogen molecule in ground state. CO_2^*=Carbon dioxide atoms in ground state

Since the excited level of nitrogen is very close to the E_5 level of CO_2 atom, population in E_5 level increases. As soon as population inversion is reached, any of the spontaneously emitted photon will trigger laser action in the tube. There are two types of laser transition possible.

Transition E_5 to E_4:-This will produce a laser beam of wavelength 10.6μm

Transition E_5 to E_3:-This transition will produce a laser beam of wavelength 9.6μm. Normally 10.6μm transition is more intense than 9.6μm transition.

2.1 Literature review

Sr. No.	Author	Title	Journal/Year	Material	Conclusion
1	Fattah, Abdul et. al	An investigation of laser cutting quality of 22MnB5 ultra high strength steel using response surface methodology	ELSEVIER (2017)	Boron Steel	Increment of kerf width formation happened with increasing laser power and lower cutting speeds. Similar interaction occurred in HAZ region formation, whereas high laser power with low cutting speed produced thicker HAZ region.
2	Krzysztof Jarosz, et. al	Effect of cutting speed on surface quality and heat-affected zone in laser cutting of 316L stainless steel	ELSEVIER (2016)	AISI316L stainless steel	The use of highest researched cutting speed (v_c= 16.5 mm/s) produces cut surfaces with good roughness and negligible heat-affected zone. The lower of used cutting speeds (v_c= 9.17 mm/s) produces a surface with lower roughness, but at the expense of visible heat-affected zone. Lowest researched cutting speed (v_c= 1.84 mm/s) has no practical use.
3	I.A. Choudhury, et. al	Laser cutting of polymeric materials: An experimental investigation	ELSEVIER (2010)	polypropylene (PP), polycarbonate (PC) and polymethyl methacrylate (PMMA)	It was observed that the dimension of HAZ for all polymers investigated is directly proportional to the laser power and inversely proportional to cutting speed and compressed air pressure.
4	D. J. Kotadiya, et. al	Parametric Analysis of Laser Machining with Response Surface Method on SS-304	ELSEVIER (2016)	ASTM 304 Steel	It has found that the laser power is most significant compare to cutting speed and gas pressure. Laser power and gas pressure has identified most significant interactive parameter with highest µ value of 0.64.
5	A.M. Orishich, et. al	Experimental comparison of laser cutting of steel with fiber and CO2 lasers on the basis of minimal roughness	ELSEVIER (2014)	Stainless Steel	During the fiber-laser cutting, the minimal roughness is reached at the Peclet number 0.35…0.4 and during the CO_2-laser cutting – at 0.45…0.55. In the fusion-cutting of stainless steel, the specific energy E is different when the cut surface roughness is minimal. The optimal speed corresponding to the minimal roughness coincides with the maximal speed.
6	Tomomasa Ohkuboa, et. al	Numerical simulation of laser beam cutting of carbon fiber reinforced plastics	ELSEVIER (2014)	CFRP	It was observed that the speed of thermal conduction is higher in carbon fiber than resin, decompose

					temperature of resin is lower than that of carbon fiber. Resin around carbon fiber is decomposed fast and then generated heat decompose surface of resin and resin around fiber is removed.
7	Hun-Kook Choi, et. al	Performance analysis of CO2 laser polished angled ribbon fiber	ELSEVIER (2017)	Ribbon fibbers	It was observed that the Compared to mechanically polished sharp edged angled ribbon fibers, the CO_2 laser polished curve edged angled fibers have lower probability of mechanical damage while connecting with various optical devices because of their curved structure.
8	S.K. Sahoo, et. al	Computational Modelling of Dissimilar Metal CO2 Laser Welding: Applied to Copper and 304 Stainless Steel	ELSEVIER (2015)	AISI 304	It was observed that the considered model has to extract some key features of the process such as differential heating of the dissimilar metals, development of asymmetric weld pool, and mixing of molten metal's.
9	Junke Jiao, et. al	A numerical simulation of machining glass by dual CO2-laser beams	ELSEVIER (2008)	Glass	The maximum tensile stress was 61.2MPa when the glass sample was irradiated by a single CO_2-laser beam, and 38.9MPa when machined by the dual CO_2-laser beam. These data showed that the thermal stress can be reduced when the glass sample is machined by the dual-laser-beam method.
10	Mahmoud Moradi, et. al	Enhancement of low power CO 2 laser cutting process for injection molded polycarbonate	ELSEVIER (2017)	Poly Carbonate	Results Showed that increasing laser power and position of the focal plane, increases the upper kerf width while revers condition occurs for speed of laser cutting on this response. Also increasing the cutting speed increases the kerf ratio. Obtained results also demonstrated that increasing in the cutting speed and reduction in the laser power lead to decrease the upper heat affected zone.
11	Lin-zhi Wang, et. al	Experimental investigation on densification behavior and surface roughness of AlSi10Mg powders produced by selective laser melting	ELSEVIER (2017)	AlSi10Mg	The main conclusions are summarized as, the densities of the AlSi10Mg parts fabricated by SLM are relatively high (the maximum relative density is 99%) when the point distance is 80 μm and 105 μm. Moreover, the densities decrease gradually

					with increase of the point distance. When the exposure time is 140–160 μs, the density is up to a maximum, too long or too short exposure time leads to the reduction in density.
12	F.Z. Dai, et. al	Surface & Coatings Technology A method to decrease surface roughness in laser shock processing	ELSEVIER (2016)	Aluminium alloy	It was observed that the given the initial surface topography, a final value of surface roughness is attained. This value increases with increasing laser power intensity and decreases with increasing dynamic yield strength of the contact foil. For smooth samples, the usage of higher dynamic yield strength contact foil can effectively minimize the increment of surface roughness with the increase of RCLSP impact times.
13	S. Stelzer, et. al	Experimental investigations on fusion cutting stainless steel with fiber and CO2 laser beams	ELSEVIER (2013)	Fiber	It was observed that the cut kerfs are nearly identical in size but differ qualitatively in shape for both laser types. It was found out that a sudden increase in surface roughness is present at a particular sheet thickness. Under the defined experimental conditions, this transition occurs between 4 and 6 mm in case of fiber laser cuts and between 8 and 10 mm for CO_2 laser cutting trials.
14	Fysikopoulos Apostolos, et. al	Energy Efficiency Assessment of Laser Drilling Process	ELSEVIER (2012)		Higher laser power results in improved energy efficiency. The higher pulsing frequency improves the energy efficiency. The operation of laser generation demands higher amounts of energy.
15	Ahmet Cekic, et. al	CO2 Laser Cutting of Alloy Steels Using N2 Assist Gas	ELSEVIER (2014)	Steel	Minimum values of Ra = 1.627 μm was obtained during cutting high alloy steel 1.4828 (s = 3 mm) using N_2 pressure 15.0 bar, and the position of focus fs = + 1 mm and cutting speed of 1000 mm/min. Cutting speed is inversely proportional to the thickness of the material.
16	L.D. Scintilla, et. al	Primary losses in disk and CO2 laser beam inert gas fusion cutting	ELSEVIER (2011)	Polymethyl methacrylate(PMMA)	For CO_2 laser cutting, the impact of the relative cutting speed changed with sheet thickness and became clearly smaller with increased thickness values. In the regions where both laser

					sources are able to cut, the primary losses were lower for CO_2 laser cutting than for disk laser cutting.
17	Shibing Liu, et. al	Surface roughness analysis and improvement of PMMA-based micro fluidic chip chambers by CO2 laser cutting	ELSEVIER (2010)	PMMA	The results indicate that at a preheat temperature of 70–90 °C, the surface roughness resulting from the cut would be reduced. In our experiment, the best result was that the arithmetical mean roughness is Ra = 0.10086 µm when the PMMA sheet was heated to 85 °C.
18	L. Romoli, et al	Layered Laser Vaporization of PMMA Manufacturing 3D Mould Cavities	ELSEVIER	PMMA	It has been shown that infrared laser systems could represent an effective tool for 3D machining of cavities in PMMA to be used as moulds for casting of polymeric resins, not only for the high speed of the fabrication process itself, but also for the high flexibility of the method. Results from this study showed that complex shapes can be machined even with sharp corners, due to the small radius of the focused spot (about 350µm).

3.1 Conclusion

CO2 laser machining plays an important role in manufacturing industry in terms of precision, accuracy and quality of the end products. The output of the machining depends on process parameters like power, speed and number of passes. A variety of engineering materials can be processed with minimum heat affected zone as well as smooth surface. Hence laser beam machining is a promising technique for required output.

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