A Review on Effect of LASER Cutting Process Parameters on Cut Quality

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ABSTRACT

In today's rapidly changing scenario in manufacturing industries, the metal cutting processes are essential for a manufacturing unit to respond effectively to severe competitiveness and increasing demand for the quality product in the market. Cutting of sheet metal is considered as an imperative process because of its importance in regular daily existence, for example, ships, aircrafts, cars, furniture and so forth. Among different sheet cutting processes, laser beam cutting is a standout, the most proficient sheet cutting process to make complex geometries with stringent plan necessities in hard-to-cut sheet materials. Optimization methods in laser cutting process considered to be a vital tool for continual improvement of output quality in products and processes. This can be achieved through modeling of input-output and in process parameters to determine optimal cutting conditions. This paper reviews the experimental analysis of laser cutting process parameters, carried out to measure the impact of laser cutting process parameters on the nature of the cut.

Keywords: Heat Affected Zone, Kerf geometry, laser cutting, Optimization, surface roughness

I. INTRODUCTION

The name LASER is an acronym for "Light Amplification by the Stimulated Emission of Radiation". There are two main types that have been used in most of all applications are the carbon dioxide (CO_2) laser and the Neodymium-doped Yttrium Aluminium Garnet (Nd-YAG) laser. Laser cutting, in general, is an effective way to reduce production and manufacturing costs. This is due to the advantage of high production rates as well as the fact that lasers can be mechanized, computer controlled and integrated into assembly lines. Many industries have been revolutionized by the application of laser equipment in their production lines. This is because of the high-quality and low distortion characteristics of the cutting action which can be achieved. Most materials can be cut by this process including metals, wood, plastics, rubber, and composites etc. except some highly reflective and conductive materials such as aluminium, gold, copper, and silver are difficult to cut using lasers and also some of the materials, such as polycarbonate, may produce dangerous exhaust gases[1-2].

1. 1 Mechanisms

There are five distinct mechanisms: inert gas melt shearing; active gas melt shearing; vaporization; chemical degradation; and scribing.

Inert Gas Melt Shearing mechanism is based on the formation of a narrow penetrating cavity that melts surrounding material, which is subsequently removed by the shearing action of a coaxial jet of inert assist gas.

Active Gas Melt Shearing by replacing the inert assist gas with a reactive gas such as oxygen or air, additional process energy may be generated through an exothermic chemical reaction. Cutting speeds can thus be increased in comparison with inert gas melt shearing. The mechanism again relies on the formation of a penetrating cavity, and so the beam must be focused to produce the required power density. Ferrous alloys and some thermoset polymers are cut by active gas melt shearing.

Vaporization mechanism normally used with pulsed lasers, and for continuous wave (CW) cutting of materials that are not easily melted. A high power density is used, material is heated rapidly to the vaporization temperature before extensive melting though thermal conduction occurs. Material is removed by vaporization and the ejection of liquid by an inert gas jet.

Chemical Degradation relies on the action of the laser beam to break chemical bonds and form new compounds, and is an important mechanism in the cutting of wood, thermoset polymers, elastomers and some composites. Cutting rates are generally lower than melt shearing, and cut edges are of relatively high quality, although residue may require cleaning.

Scribing the objective of scribing is to create a groove or a series of blind holes at the workpiece surface. Low energy, high power density pulses cause vaporization with a restricted heat affected zone (HAZ). The notches serve to raise stress locally such that the material can be fractured along a defined line under subsequent bending. The mechanism is used for some ceramics, notably alumina, as well as some glasses and composites [1].

1.2 Principle

Laser cutting is a thermal, non-contact and highly automated process well suited for various manufacturing industries to produce components in large numbers with high dimensional accuracy and surface finish. It is also stated that high power density beam when focused in a spot melts and evaporates material in a fraction of second and the evaporated molten material is removed by a coaxial jet of assisted gas from the affected zone as shown in fig.1.

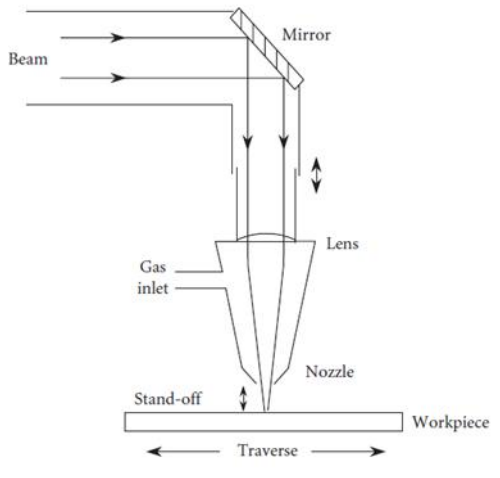

Figure 1. Schematic diagram of laser beam cutting [1].

Laser cutting is a thermal separation process. Herein, a focused beam of high energy photons is bombarded on the material to be cut. This beam simply melts the material, and high-pressure gas is used to blow off the molten material out of the kerf.

2. Process Parameters and Response variables in laser cutting

Laser cutting process has always been a major research area for getting the exceptionally good quality of cut. The laser cutting parameters are dependent on the composition of the material to be cut, its thickness, the beam characteristics, the cutting rate required, and the desired edge quality that is reduced surface roughness, kerf width and heat affected zone (HAZ). As shown in fig. 2

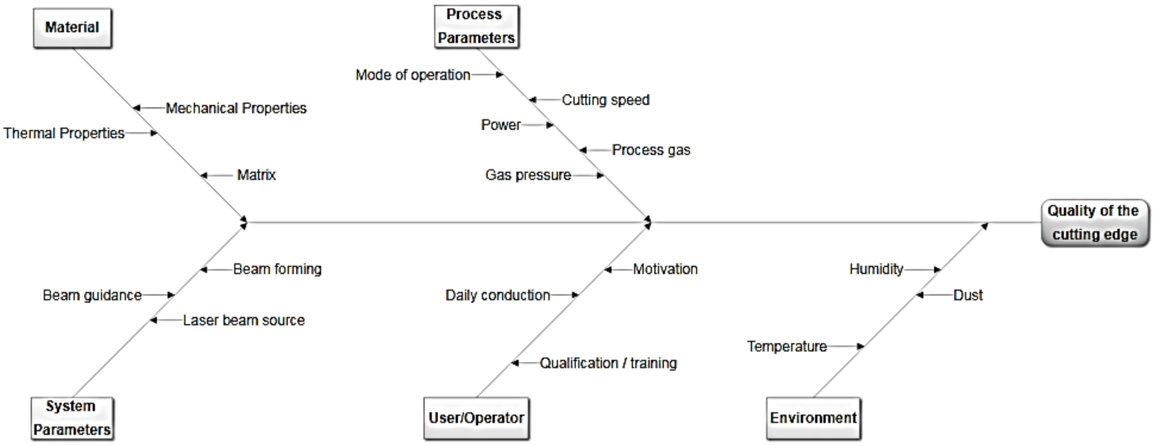

Figure 2. Cause and effect diagram of laser beam cutting.

2.1 Process Parameters

2.2.1 Continuous wave (CW) or pulsed laser operations

The highest cutting speeds can be obtained at high power levels in CW-mode operation. Continuous wave means that the laser power output is constant, without interruption over time.

2.2.2 Laser power and intensity

Laser power is the total energy emitted in the form of laser light per second. The intensity of a laser beam is equal to its power divided by the area over which the power is concentrated. The high intensity causes the material to heat up rapidly so that little time is available for heat to dissipate into the surrounding material. This produces high cutting rates and an excellent quality of cut.

2.2.3 Cutting Speed or Feed Rate

In the laser cutting process, the cutting speed or feed rate is also an important parameter which decides the heat input in the cutting front and interaction time of laser beam and workpiece.

2.2.4 Focal length of the lens

The focal length of the lens defines the shape of the focused laser beam. A lens with a short focal length produces a small spot size and a short depth of focus, generally resulting in high speed and good cutting quality of thin sheet metal. However, careful control of the distance between the lens and the workpiece is necessary.

When thicker materials are cut, the depth of focus must be adapted to the material's thickness by selecting a longer focal length. As the longer focal length also results in greater focal spot power, it must be increased in order to maintain intensity and cutting speed.

2.2.5 Wavelength of the laser beam

The absorption in the material being cut is dependent upon the wavelength of the laser beam.

2.2.6 Laser beam mode

A laser beam's mode refers to the distribution of energy through its cross section. The mode affects the cutting process, because it affects the size of the focused spot and the intensity of the focused beam and also it affects intensity distribution in the beam and focus and, as a result, cut quality a good mode is therefore essential in laser cutting.

2.2.7 Nozzle size and standoff distance

Gas assistance is essential in laser cutting. Therefore, nozzle geometry and standoff distance are important. Nozzle design and flow dynamics through the nozzle differ substantially from other thermal cutting processes. This is mainly due to the compactness and diameter of the nozzle, which is always larger than the kerf produced below it. As a result, only a portion of the gas jet formed by the nozzle penetrates the kerf. Nozzle standoff distances depend on the design of the nozzle.

2.2.8 Gas type and gas pressure

The cutting gas used is crucial to the cutting result. Oxygen generally yields good cutting performance in carbon steels and low alloyed steels. However, oxygen reacts with the base metal, and the cut edge is covered with an oxide layer. These are the reasons why high-alloy steels are being cut with nitrogen more and more often whenever sufficient laser power is available.

2.2 Response variables

2.2.1 Surface roughness

Surface roughness is an effective parameter representing the quality of a machined surface.

2.2.2 Kerf width

Kerf is a groove or a slit or a notch usually the lower and upper part of the cut is usually not parallel, it will be narrow at the bottom than the top. Kerf width is measured along the whole cut line of the width. It is the difference of starting width of the top profile to the ending width of the top profile. This same applies to the bottom surface.

2.2.3 Heat Affected Zone (HAZ)

The thermal heat of laser cutting produces a heat affected zone (HAZ) next to the cut edge. The heat affected zone is the part of the material whose metallurgical structure is affected by heat but is not melted.

III. LITERATURE REVIEW

Wandera et al. [3] investigated on inert gas-assisted laser cutting of 10 mm stainless steel plate and 4 mm aluminum sheet performed with a 5 kW fiber laser. The effects of laser power, cutting speed, focal point position, and assist gas pressure on the cutting performance and cut quality were investigated. Clean cut surfaces without or with minimal dross were achieved with some combinations of process parameters.

Ghany and Newishy [5] presented experimental results containing the effect of different pulsed and CW laser operation parameters on the cutting quality of 1.2 mm thick austenitic stainless steel and discussed the relation of each parameter to the optimum cutting quality. It was shown that the laser cutting quality depends mainly on the cutting speed, cutting mode, laser power, and pulse frequency and focus position. The cutting parameters provided dross-free and sharp cut surface during pulsed laser mode.

Adelmann and Hellmann [6] have used a fast algorithm to optimize the laser parameters (FALCOA) to get a burr-free laser cut. The algorithm includes the design of experiments and one-factor-at-a-time methods. The algorithm describes the whole optimization from the first to the optimum cut.

Gadallah and Abdu [7] studied and optimized the process parameters of laser beam cutting process for stainless steel (316L) considering the effect of input parameters such as power, oxygen pressure, frequency, and cutting speed over process responses such as average kerf taper, surface roughness, and heat affected zones. The experiments were conducted on a 200 W pulsed Nd: YAG laser beam machining system with CNC work table. Power and assist gas pressure significantly affect the kerf quality in the operating range of process parameters.

Stelzer et al. [8] investigated cutting capabilities of a fiber and a CO_2 laser beam with similar Rayleigh length and compared as a function of material thickness with respect to achievable maximum cutting speed, cut edge surface roughness and cut kerf geometry. The most interesting finding achieved so far concerns the observation that the cut kerfs are nearly identical in size but differ qualitatively in shape for both laser types. Fiber and CO_2 laser cutting results in AISI 304 stainless steel were compared. In this study, they found out that a sudden increase in surface roughness is present at a particular sheet thickness. In 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. Furthermore, they observed cut kerf shapes were nearly identical in size but they differed qualitatively in shapes, for both laser types.

Pocorni et al. [9] in their work investigated the morphology of the laser cut front generated by fiber lasers by observation of the ‘frozen’ cut front. In addition, high speed imaging (HSI) was employed to study the fluid dynamics on the cut front while cutting. During laser cutting, the morphology and flow properties of the melt film on the cut front affect cut quality parameters such as cut edge roughness and dross. The results presented in this paper suggest that the cut front produced when cutting stainless steel with a fiber laser and a nitrogen assist gas is covered in slow-moving humps which themselves are covered by a thin layer off aster moving liquid. The results here indicate that the decrease in cut edge quality, when processing thicker section steel with fiber lasers, could be a consequence of sporadic hump generation (as opposed to smooth flow) in addition to multiple reflections of the laser beam inside the cut kerf.

Löschner et al. [10] studied the effect of cutting speed on HAZ and surface roughness in laser cutting of AISI316L stainless steel. Test samples of 10 mm thickness were cut with varying cutting speeds, while other process parameters remained constant. The study shows with the decrease in cutting speed, HAZ width increases. An optimized cutting speed (16.5 mm/s) produces cut surfaces with good roughness and negligible HAZ.

IV. CONCLUSION

The work presented here is a glance of research work carried out in laser cutting process. From the above discussions, it can be concluded that:

i. Laser cutting process is fit for cutting complex profiles in most of the materials with a high level of exactness and precision.

ii. The performance of laser cutting process depends on the attributes such as laser power, cutting speed, and assist gas pressure etc. which ultimately govern the process parameters like surface roughness, HAZ and kerf width.

iii. This paper just presents an overview of the recent experimental investigations in laser cutting of various engineering materials concerned with cut quality like surface roughness, HAZ and kerf width and identifies the most common process parameters and cut quality characteristics.

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