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Effect of Process Parameters on Laser Cutting Process: A Review

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Abstract: *Laser cutting is energy based unconventional process used to cut complicated shapes of various types of materials. The objective of this paper is to investigate the effect of parameters associated with the laser cutting process. The quality of laser cut is of the most importance in laser cutting process. All cutting parameters might have significant influence on the resulting quality of work. In general, cutting parameters are adjusted and tuned to provide the quality of cut desired. But this consumes exhaustive amounts of time and effort. Therefore, it is important to investigate the impact of cutting parameters on quality of cut. The relations between the input parameters and the response were investigated. The result showed that the parameters like power, cutting speed and stand-off distance have major impact over surface roughness and kerf width.*

1. Introduction

Laser cutting is a thermal based non-contact process capable of cutting complex contour on materials with high degree of precision and accuracy. It involves process of heating, melting and evaporation of material in a small well defined area and capable of cutting almost all materials. The word LASER stands for Light Amplification by Simulated Emission of Radiation. Laser has a wide range of applications, ranging from military weapons to medical instruments. In industries laser is used as an unconventional method for cutting and welding. The main advantage of laser cutting is that, it is a non-contact operative method from which a good precise cutting of complicated shapes can be achieved. Also laser can be used to cut variety of materials like wood, ceramic, rubber, plastic and certain metals. Extensive research work is being done in laser cutting for improving the quality of cut. The quality of cut depends upon many control factors or parameters such as laser beam parameters (laser power, pulse width, pulse frequency, modes of operation, pulse energy, wavelength, and focal position); material parameters (type, optical and thermal properties, and thickness); assist gas parameters (type and pressure) and processing parameters (cutting speed). The laser cutting is a very complex and nonlinear process due to involvement of many process parameters. Many researchers have investigated the effect of these process parameters on different quality characteristics such as material removal rate (MRR), kerf quality characteristics (kerf width, kerf deviation and kerf taper), Surface quality (cut edge surface roughness, surface morphology), metallurgical quality characteristics (recast layer, heat affected zone, oxide layer and dross inclusions) and mechanical properties (hardness, strength).

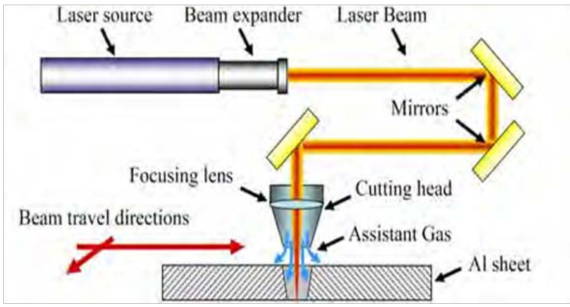

Figure 1. Basic laser cutting process [06]

Laser cutting offers several advantages over conventional cutting methods such as plasma cutting. The advantages of laser cutting include high productivity thanks to the high cutting speeds, narrow kerf width (minimum material lost), straight cut edges, low roughness of cut surfaces, minimum metallurgical distortions, and easy integration.

In the early 1980's, laser cutting had a limited application, being mostly used in high technology industries such as aerospace and the available commercial equipment could only cut light sheet (1-2 mm) because of their limited power output. Laser technology has continued to develop over the years and now many types of lasers are commercially available. With the development of high power lasers, laser materials processing is now being used as part of the production route for many items such that the laser is finding increasing commercial use as a cutting tool. The laser development trends indicate that there are more tendencies towards smaller and more efficient semiconductor lasers. The beam quality and available power output of a particular laser cutting system affects the cut quality obtained, the quality of the cutting process and the range of thickness that can be satisfactorily cut.

2. Literature Review

Rajaram et al. (2003) have found the influence of laser power and feed rate (cutting speed) on the kerf width in the laser cutting of 1.27 mm thick 4130 steel. The laser power has a major effect on kerf width while the feed rate effect is secondary. As the laser power increases, the kerf width also increases and smallest kerf width is obtained at the lowest value of laser power and moderate feed rate.

Yilbas (2004) has also obtained similar results for the laser cutting of 1 mm and 2 mm thick mild steel sheets. They have observed that the kerf width increases by increasing the laser power and decreases by increasing cutting speed

Karatas et al. (2006) have found that the Kerf width can also be changed by varying the focal position of laser beam and thickness of the workpiece. For the workpiece thickness of 1.5 mm in laser cutting of steel sheet, the minimum kerf width is obtained at nominal focus setting of focusing lens (nominal beam waist position) but as the thickness of workpiece increases from 1.5 to 3.5 mm, the focus setting for minimum kerf width changes, i.e. the nominal beam waist position of the focusing lens moves into the workpiece.

Pfeifer et al. (2010) have applied the laser cutting process for the cutting of 1 mm thick NiTi shape memory alloys and the effects of cutting speed, spot overlap, pulse width and pulse energy on kerf geometries (top and bottom kerf widths) have been discussed. They have shown that the top and bottom kerf widths decrease linearly with increasing cutting speed or decreasing spot overlap. The top kerf width is marginally affected with pulse width but bottom kerf width decreases by increasing pulse width.

Sivarao, Ammar, T.J.S. Anand has worked on stochastic modeling and optimization of laser machining by response surface methodology. The response optimization was capable to predict the parameter setting for the desired output. This is very useful in machining process where, by using this tool the cost and also the machining time can be optimized to reduce unnecessary waste. As observed the model produced is a linear empirical model for the surface roughness. The results of this study show that kerf width is highly affected by the cutting speed. For the kerf width, when looking at the parameters itself, high cutting speed value is always necessary in order to obtain an optimal kerf value. The duty cycle and frequency however have some interaction effect. When a high frequency is used, is most advisable to use a high value of duty cycle also and vice versa. This shows that the duty cycle is directly proportional to the frequency. Therefore, when setting up the machine, it is advisable to use high cutting speed and match the duty cycle with the frequency used if kerf width is an important outcome.

Ghany and Newishy (2005) have compared both modes of operation (pulsed and continuous) and shown that the maximum cutting speed of 8 m/min is obtained in the continuous wave of Nd:YAG laser cutting of 1.2 mm austenitic stainless steel sheet. The effects of laser power, pulse frequency, cutting speed, focus position and types of gases on the kerf width have been investigated. Kerf width is decreased by increasing the pulse frequency and cutting speed while it is increased by increasing the laser power, focus position and gas pressure. Compared to oxygen, nitrogen gives brighter and smoother cut surface with smaller kerf but it is not economical as compared to the oxygen.

Yusof et al. (2008) have found that at all cutting speeds, the kerf width increases by increasing the laser powers while sideline length and percentage over length decreases by increasing laser power. Increasing the cutting speed in pulsed mode led to rough surface and incomplete cutting while in CW mode, increasing the cutting speed with equivalent increase in power, led to better quality and smoother cut surface upto 8 m/min cutting speed. The SR also increases by increasing the peak power, gas pressure, pulse frequency and duty cycle. The surface roughness of the cut specimen can also be changed by changing spot over lap and pulse width

3. Laser Cutting Parameters

A] Surface Roughness (Ra)

Surface roughness is an effective and commonly adopted parameter representing quality of a machined surface in general engineering practice. It gives a good general description of the height variations in the surface

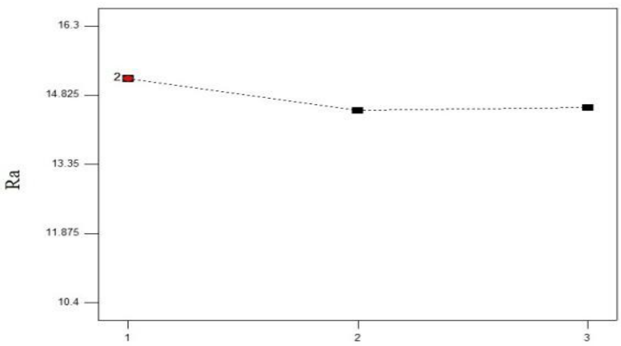

Figure 2. Surface Roughness vs Power [02]

The surface roughness decreases and remains same as the power increases as shown in Figure

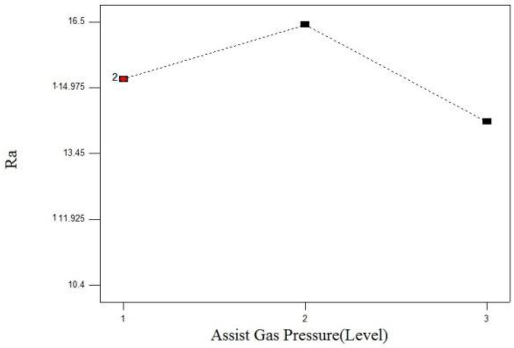

Figure 3. Surface Roughness vs Assist Gas Pressure [02]

Roughness increases and then decreases as the assist gas pressure increases as shown in Figure

B] Kerf Width

The laser melts away a portion of material when it cuts through; this is known as kerf which is a groove or a slit or a notch. The width of the portion after the cut is called the kerf width. The kerf width refers to the width of the slot that is formed during through-thickness cutting and is normally narrower at the bottom surface of the workpiece than at the top surface. The kerf width represents the amount of material removed during the cutting process, which is essentially wasted material; therefore, a smaller kerf width is always desirable especially when small details are to be cut. The width of the cut kerf corresponds to the circular beam waist size which is determined mainly by the laser beam quality and focusing optics. The power at the focused spot, cuttingspeed and the assist gas jet also has influence on the size of the cut kerf. Figure shows the variation of kerf width with cutting speed, assist gas pressure and laser output power. Increases in laser power, assist gas pressure and reduction in cutting speed were found to result in increased kerf width.

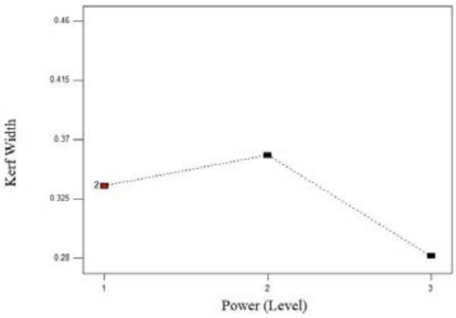

Figure 4. Kerf Width vs Power [02]

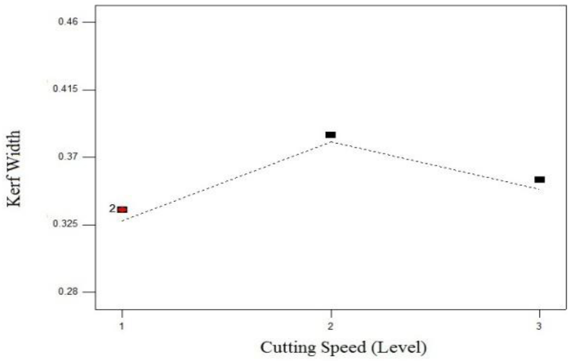

Figure 5. Kerf Width vs Cutting Speed[02]

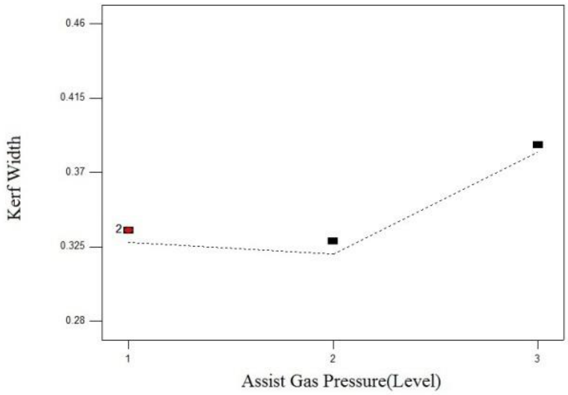

Figure 6. Kerf Width vs Assist Gas Pressure [02]

C] Nozzle Alignment

Nozzle misalignment may cause poor cutting quality, as the process is extremely susceptible to any discrepancy in the alignment of the cutting gas jet with the laser beam. The gas flow from the nozzle generates a pressure gradient on the material surface, which is coaxial with the nozzle itself. If the nozzle and the focused laser beam are coaxial, the cutting zone established by the beam will lie directly under the central core of the gas jet and there will be uniform lateral gas flow. Illustrates the equilibrium set up if the gas jet and laser beam are coaxial. However, nozzle-laser beam misalignment leads to an overall directional gas flow across the top of the cut zone which can lead to unwanted cut edge burning and dross adhes

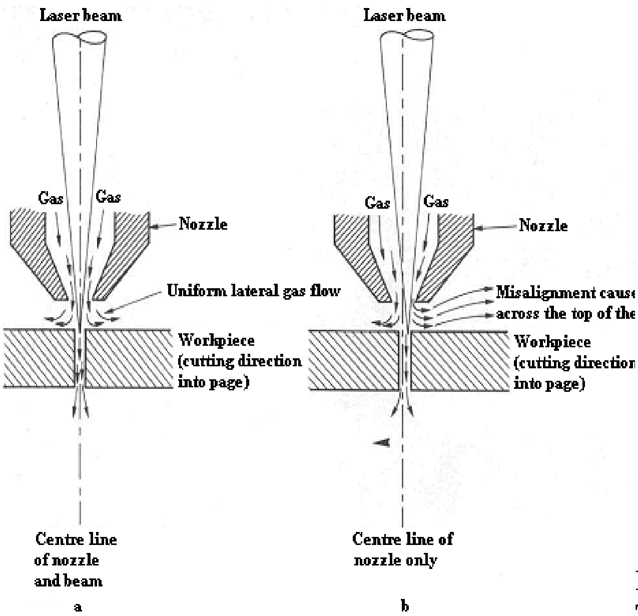

Figure 7. Nozzle Alignment [05]

D] Cutting speed

The energy balance for the laser cutting process is such that the energy supplied to the cutting zone is divided into two parts namely; energy used in generating a cut and the energy losses from the cut zone. It is shown that the energy used in cutting is independent of the time taken to carry out the cut but the energy losses from the cut zone are proportion to the time taken. Therefore, the energy lost from the cut zone decreases with increasing cutting speed resulting into an increase in the efficiency of the cutting process. A reduction in cutting speed when cutting thicker materials leads to an increase in the wasted energy and the process becomes less efficient. The levels of conductive loss, which is the most substantial thermal loss from the cut zone for most metals, rise rapidly with increasing material thickness coupled with the reduction in cutting speed. The cutting speed must be balanced with the gas flow rate and the power. As cutting speed increases, striations on the cut edge become more prominent, dross is more likely to remain on the underside and penetration is lost. When oxygen is applied in mild steel cutting, too low cutting speed results in excessive burning of the cut edge, which degrades the edge quality and increases the width of the heat affected zone (HAZ). In general, the cutting speed for a material is inversely proportional to its thickness. The speed must be reduced when cutting sharp corners with a corresponding reduction in beam power to avoid burning.

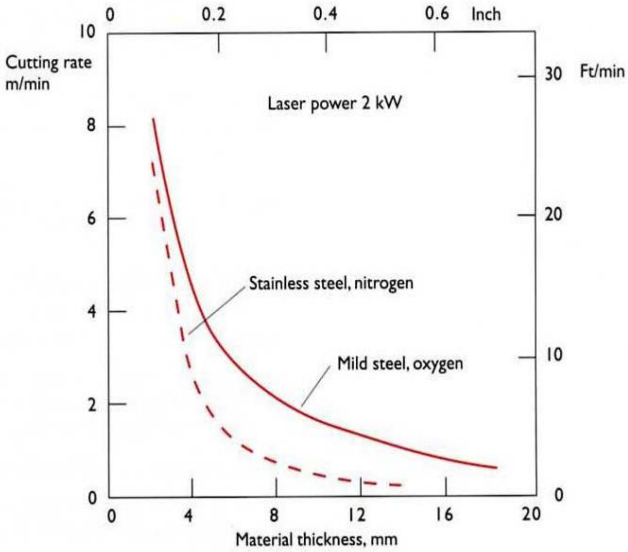

Figure 8. Cutting Speed vs. Material Thickness [01]

E] Nozzle diameter and standoff distance

The nozzle delivers the cutting gas to the cutting front ensuring that the gas is coaxial with the laser beam and stabilizes the pressure on the work piece surface to minimize turbulence in the melt pool. The nozzle design, particularly the design of the orifice, determines the shape of the cutting gas jet and hence the quality of the cut. The diameter of the nozzle, which ranges from 0.8 mm and 3 mm, is selected according to the material and plate thickness. /45/ Due to the small size of the focused laser beam, the cut kerf created during laser cutting is often smaller than the diameter of the nozzle. Consequently, only a portion of the gas jet formed by the nozzle penetrates the kerf, which necessitates the use of a high. The stand-off distance is the distance between the nozzle and the workpiece. This distance influences the flow patterns in the gas, which have a direct bearing on the cutting performance and cut quality. Large variations in pressure can occur if the stand-off distance is greater than about 1mm. A stand-off distance smaller than the nozzle diameter is recommended because larger stand-off distances result in turbulence and large pressure changes in the gap between the nozzle and work piece, with a short standoff distance, the kerf acts as a nozzle and the nozzle geometry is not so critical.

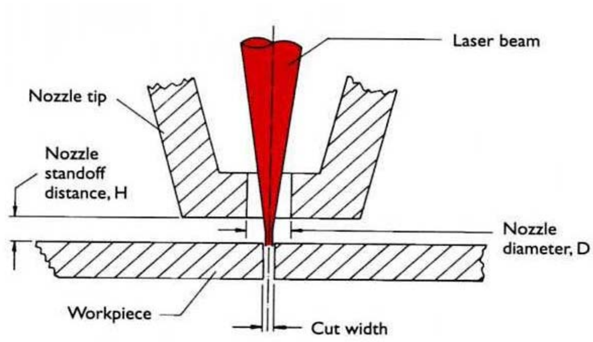

Figure 9. Nozzle Diameter and Standoff Distance [04]

F] Process gas and gas pressure

The process gas has five principle functions during laser cutting. An inert gas such as nitrogen expels molten material without allowing drops to solidify on the underside (dross) while an active gas such as oxygen participates in an exothermic reaction with the material. The gas also acts to suppress the formation of plasma when cutting thick sections with high beam intensities and focusing optics are protected from spatter by the gas flow. The cut edge is cooled by the gas flow thus restricting the width of the HAZ. The choice of process gas has a significant effect on the productivity and quality of the laser cutting process. The commonly used gases are oxygen (active gas) and nitrogen (inert gas) with each having its own advantages and potential disadvantages. Although nitrogen is not purely inert, it is the most commonly used gas for inert gas cutting because it is relatively cheap. Nitrogen gas is the preferred gas for the cutting of stainless steel, high-alloyed steels, aluminum and nickel alloys and it requires higher gas pressures to remove the molten material from the cut kerf. The high gas pressure provides an extra mechanical force to blow out the molten material from the cut kerf. When high-pressure nitrogen cutting is used to cut stainless steel, it produces a bright, oxide free cut edge but the processing speeds are lower than in oxygen assisted cutting.

G] 7. Focal position relative to the material surface

The focal position has to be controlled in order to ensure optimum cutting performance. Differences in material thickness may also require focus alterations and variations in laser beam shape. When cutting with oxygen, the maximum cutting speed is achieved when the focal plane of the beam is positioned at the plate surface for thin sheets or about one third of the plate thickness below the surface for thick plates. However, the optimum position is closer to the lower surface of the plate when using an inert gas because a wider kerf is produced that allows a larger part of the gas flow to penetrate the kerf and eject molten material. Larger nozzle diameters are used in inert gas cutting. If the focal plane is positioned too high relative to the workpiece surface or too far below the surface, the kerf width and recast layer thickness increase to a point at which the power density falls below that required for cutting.

4. Conclusions

Based on the literature review, it has been found that most of the experimental studies on laser cutting are based on the one parameter at a time approach (OPAT). Most of the researchers have investigated the effects of different process parameters on different quality characteristics in laser cutting. The parameters studied in this work are kerf width, surface roughness, nozzle alignment, nozzle diameter standoff distance, focal distance, gas pressure and cutting speed. Consequently, all the parameters are analyzed to get the best result in laser cutting process. Certain parameters are needed to be adjusted to receive a best result for the laser cut on the work piece and enhance the quality of the laser cut.

Laser cutting process is capable of cutting complex profiles in most of the materials with a high degree of precision and accuracy and the performance of laser cutting process depends on the input process parameters like laser power, cutting speed, assist gas pressure and stand-off distance on the important performance characteristics like surface roughness and kerf width.

The parameters such as laser power, cutting speed, stand-off distance have major impact on surface roughness and kerf width. Whereas, the effect of assist gas pressure over surface roughness and kerf width is less significant.

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