Proceedings of the 2nd International Conference on Industrial and Mechanical Engineering and Operations Management (IMEOM), Dhaka, Bangladesh. December 12-13, 2019

Characteristics Analysis of Laser Beam Machining Process

Md. Ashrafuzzaman Miah and Farzad Hossain
Department of Mechanical and Production Engineering (MPE)
Islamic University of Technology (IUT)
Boardbazar, Gazipur-1704, Bangladesh
ashrafuzzaman@iut-dhaka.edu, farzadhossain@iut-dhaka.edu

Abstract

Machining is one type of process in which metal removing, surface making, and surface finishing etc. are done. Two types of machining processes are used: nonconventional and conventional machining process. Machining of harder materials and of complicated shapes is difficult, wasteful and, time-consuming by conventional methods of machining. Nonconventional machining process is very popular for machining at the moment. Laser beam machining is one type of mechanical nonconventional machining process. Since the laser is the source of energy in laser beam machining, it is possible to focus optical energy on the surface of the work piece. A portion of the work piece is melted and evaporated in a manner by the highly focused high-density energy. Some aspects of laser beam machining process i.e. features of laser beam, manipulation of laser beam, principle and different processes of laser beam machining, process analysis, characteristics of cut front and cut surface etc. have been theoretically studied. Effect of different parameters on the LBM process like cutting speed, polarization of laser beam, wavelength of laser beam, focusing of laser beam, assist gas, gas nozzle, work piece thickness, work piece material etc. have been analyzed. The efficiency of material withdrawal mechanisms has a pivotal influence on the quality and performance of the laser cutting process. However, they are not so easy to understand since the physical processes and parameters, which govern them, are very complicated to observe and measure experimentally. The development of theoretical models for analyzing the material withdrawal mechanisms is very necessary to understand the characteristics and influence of these processes. For this reason, a mathematical model for the material withdrawal rate of laser beam machining process has been developed.

Keywords
Machining, Material withdrawal, Theoretical model, Mathematical model, Characteristics

1. Introduction
As the world is advancing forth technically in the field of space research, missile and nuclear industry; very complicated and precise component having some special requirements are demanded by these industries; the challenge is taken. After world war many new materials and non-conventional methods of forming difficult to machine metals have evolved which are being put to commercial use with time. The processing of the parts of complicated appearance has been time consuming, uneconomical and difficult by the conventional methods of machining. For this inventions have been created to meet increasingly complex needs of modem society and new tools have been devised.

Originally the nontraditional machining designation was applied to emerging processes or to process that have not even been used extensively. Nontraditional machining has a classification of manufacturing operations. In general traditional machining processes are characterized by lower power consumption as a function of material withdrawal rate as compared with nontraditional machining process. Although notable exceptions exeunt the stock removal rate of nontraditional machining process is usually less than that attainable with conventional machining techniques.

Laser (the acronym derived from Light Amplification by Stimulated Emission of Radiation) is a spectacular manifestation of this process. It is a source, which emits a kind of light of unrivalled purity and intensity not found in any of the previously known sources of electromagnetic radiation. This discovery made a huge impact on the scientific world and exhibited that optics is very much alive. By being able to generate highly coherent signals, lasers made it possible to enrich optics.

A light of dual wave-particle nature is emitted when electrons change the atomic energy levels. Light travel across medium as an electromagnetic wave, but when it encounters matter it behaves as energy quantum photon. This phenomenon is an underneath concept of photons used as an effective engineering tool, However, before laser (Light Amplification by the stimulated Emission of Radiation) was discovered in the middle of twentieth century, the light feature had not been fully utilized. Spontaneous photons have different energy, therefore different wavelengths. The spectrum of visible light ranges from violet 400nm to red 750nm; it consists of many wavelengths and is not polarized. The light generated by laser becomes is able to break chemical bonds of because it is amplified, hence intense, of monochromatic wavelength, direct polarized and coherent. It is estimated that energy required to break chemical bonds of plastics varies between 3-7 eV; for metals it is around 20 eV.

Laser cutting of metals has been successfully applied in industry in order to cut two dimensional shapes on work pieces with thickness up to 10 mm. Laser has also been applied for cutting intricate contours on curved work pieces in three dimensions. Two types of laser cutting can be used for processing metals: reactive gas cutting and laser fusion cutting. For reactive cutting of metals, an O_2 gas jet is used, and material removal is achieved through high-temperature oxidation reactions. In fusion cutting of metals, an inert gas jet is used while the laser beam serves as a heating source to melt material. In general, higher material removal rates can be archived through reactive gas cutting; however, fusion cutting achieves better surface quality and dimensional accuracy.

Electrons are arranged in different cells in an atom and each has a set number of electrons. If any atom is excited, i.e. we pump some amount of external energy, then the atomic cell will be in excited condition and some electrons will jump up to next energy level, i.e. electrons jump from one orbit to next one. Normally atom is not excited. Then it will absorb external energy and shoot up to higher energy level. An assembly of atoms of some kind that have metastable states of excitation energy hv, somehow raises a majority of the atoms to the metastable level. There will be more induced emission from the metastable level than induced absorption by the lower level. The result will be amplification of the original light. This is the concept that underlines the operations of the laser.

2. Mathematical Modeling and Analysis

The validation of the model was done with experimental and analytical approach. Most important aspect of the model is the adoption of certain phenomenological approaches to incorporate various phenomena such as multidimensional heat diffusion, absorption by vapor, etc. which does not alter the simplicity of model. In processes using high-power density laser beams, laser drilling, laser cutting and penetration welding, evaporative removal of material is an important phenomenon. An understanding of the laser-material interaction and the evaporation phenomenon is important for study and optimization of such processes. In the present paper, evaporative material removal during such processes is analyzed by constructing a mathematical model which is one-dimensional. The rate of evaporation is modeled using an Arrhenius-type reaction equation. The variation of material absorptive is also an important issue in laser-material interaction and is modeled as a function of temperature using an approach discussed in the paper.

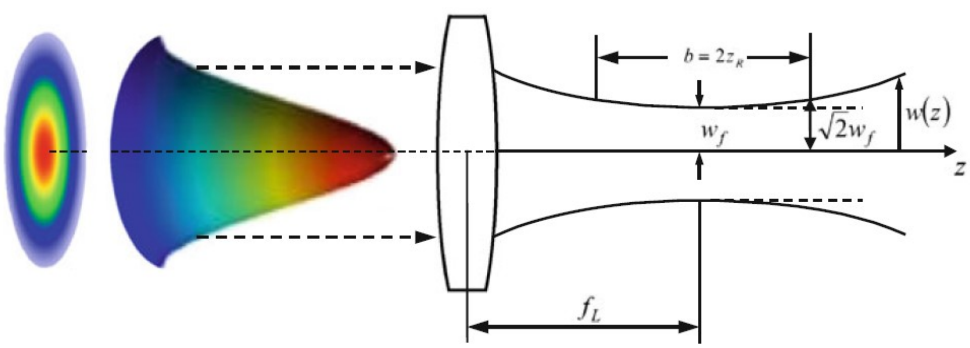

Figure 1. Distribution of power and focusing of TEM00 Gaussian-mode laser beam

For better monochromaticity, single mode can be achieved by forcing laser to oscillate on a single transverse (usually, the fundamental TEM00 Gaussian mode as shown in Fig. 1) and longitudinal mode.

The intensity distribution in the Gaussian beam is expressed as:

$$I(r) = Io\ exp(-2r^2/\omega^2)$$

The divergence angle (θ) for TEM00 beam is expressed as:

$$\theta = \frac{\lambda}{\pi\omega_0}$$

The beam quality is expressed as:

$$M^2 = \frac{\pi}{\lambda}\omega_0\theta$$

The beam parameter product BPP is expressed as:

$$BPP = \omega_0\theta$$

Table 1. Characteristics of lasers for the purpose of material processing

	CO_2	Excimer	Nd:YAG	High-power diode	Fiber laser
Wavelength	10.6	0.125-0.351	1.06	0.65-0.94	1.07
BPP (mm×mrad)	12	12[a]	25-45[b]	100-1000	0.3-4
Overall efficiency (%)	5-10	1-4	1-3	30-50	10-30
Output power in CW mode	Up to 20 kW	300 W	Up to 16 kW	Up to 4 kW	Up to 10 kW
Focused power density (W/cm^2)	10^{6-8}	10^{5-7}[a]	10^{6-9}[b]	10^{3-5}	-
Pulse duration (sec)	10^{-4}	10^{-9}	10^{-8}-10^{-3}	10^{-12}	10^{-13}
Fiber coupling	No	Yes	Yes	Yes	Yes

Electric field vector in (a) linearly and (b) circularly polarized beams is shown in Fig. 2

3. Result and Discussion

An accurate analysis of the whole process is difficult. For this reason, only the increase in temperature of the work material up to the melting point is considered. Vaporization will not be taken in to account our analysis. It is necessary to ensure that the work surface must not reflect back so much energy of the incident beam. When the beam is falling on the work surface, maximum part of the energy is absorbed in a very thin layer at the surface (thickness around 0.01 μm). Since absorbed heat energy is transformed into the heat surface, the laser beam can act like a heat flux. Radiation from the surface at a temperature of 3000 K is of the order of only 600 W/cm^2 and it is negligible as compared with the input flux 10^5–10^7 *W/cm*^{2}.

To make our analysis one dimensional, the diameter of the beam spot is assumed to be larger than the depth of penetration. However, thermal properties, i.e. specific heat and conductivity remain constant with the temperature change. A more realistic approach is to consider the heat to be on a circular spot with a diameter equal to that of the focused beam. If the power intensity of the beam is such that heat flux is below its critical value, the melting temperature will never be reached. Such information, however, cannot be obtained from the simper one-dimensional model. However, if the molten pit is deep and narrow, the major portion of heat conduction from the molten hole takes place through the sidewalls.

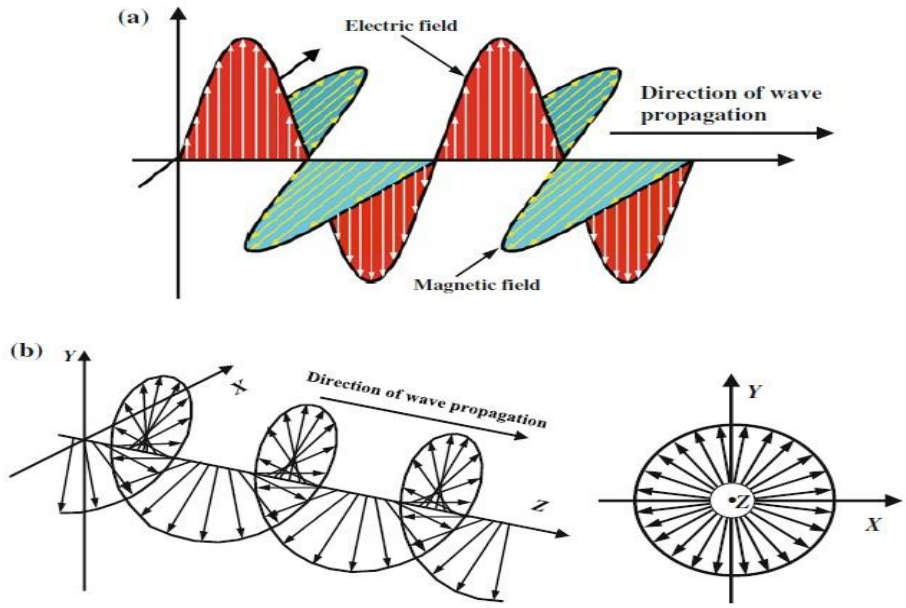

Figure 2. Electric field vector in (a) linearly and (b) circularly polarized beams

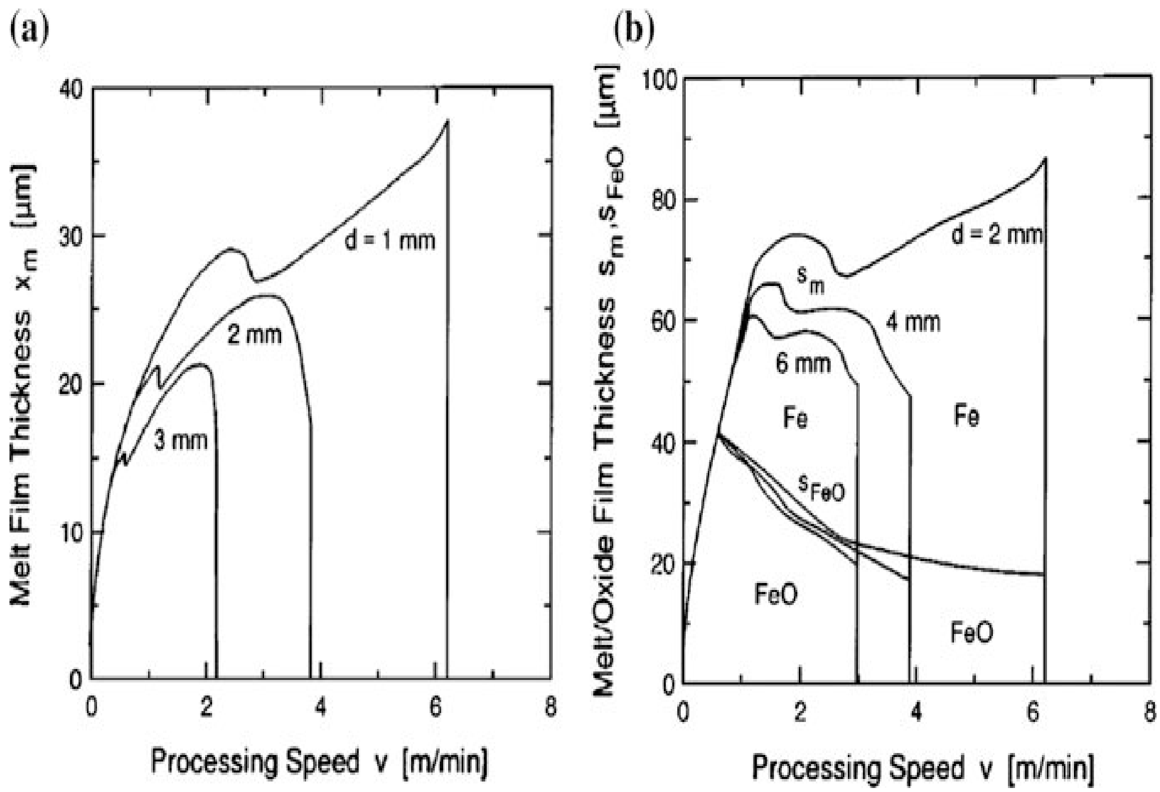

Figure 3. Melt film thickness as function of cutting speed and workpiece thickness in (a) laser fusion cutting and (b) reactive laser cutting

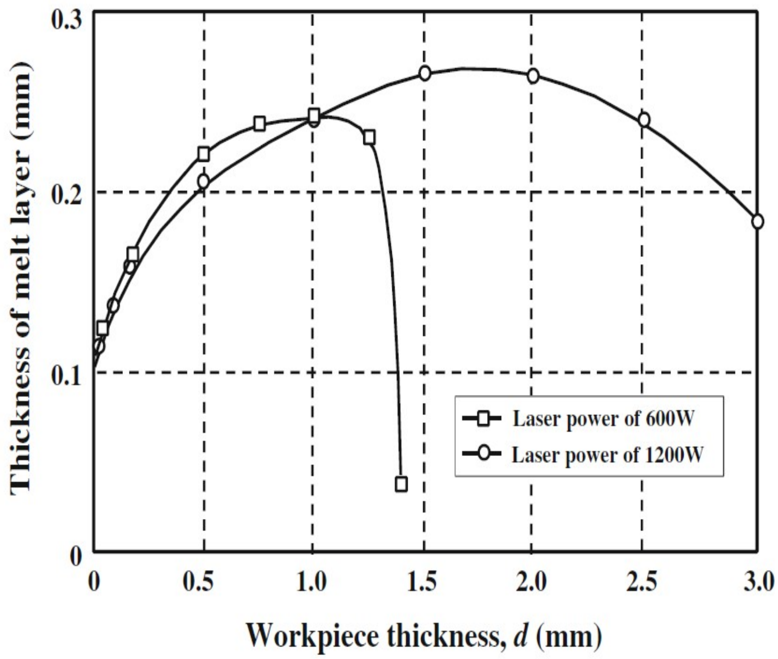

Figure 4. Effect of laser power and workpiece thickness on melt layer thickness

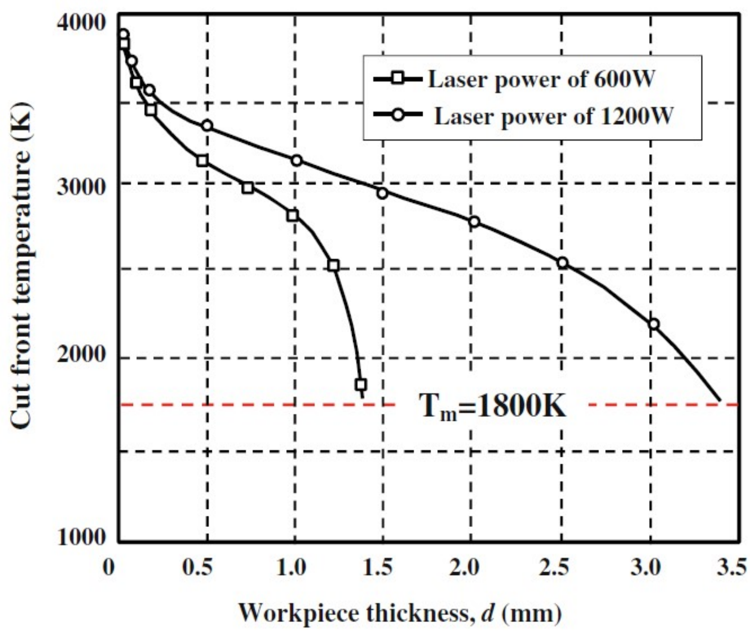

Figure 5. Effect of work piece thickness on the cut front temperature

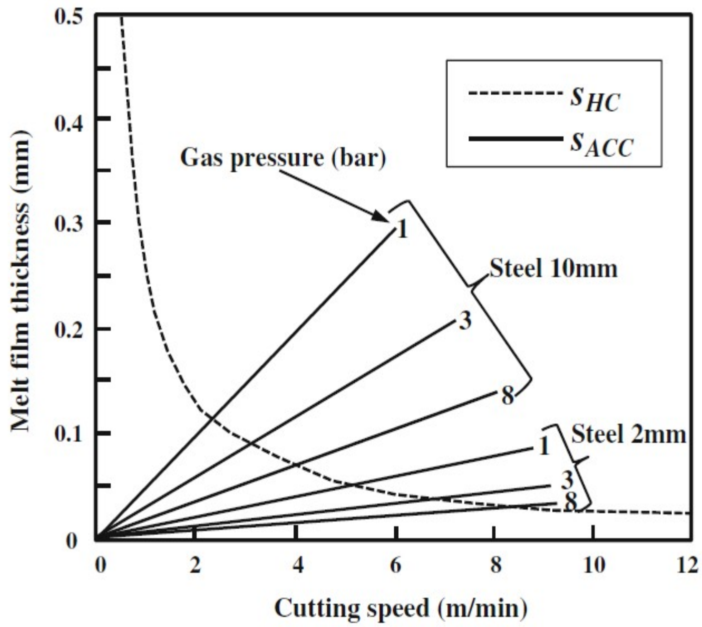

Figure 6. Melt film thicknesses of s_{HC} and s_{ACC} as function of cutting speed, gas pressure, and workpiece thickness

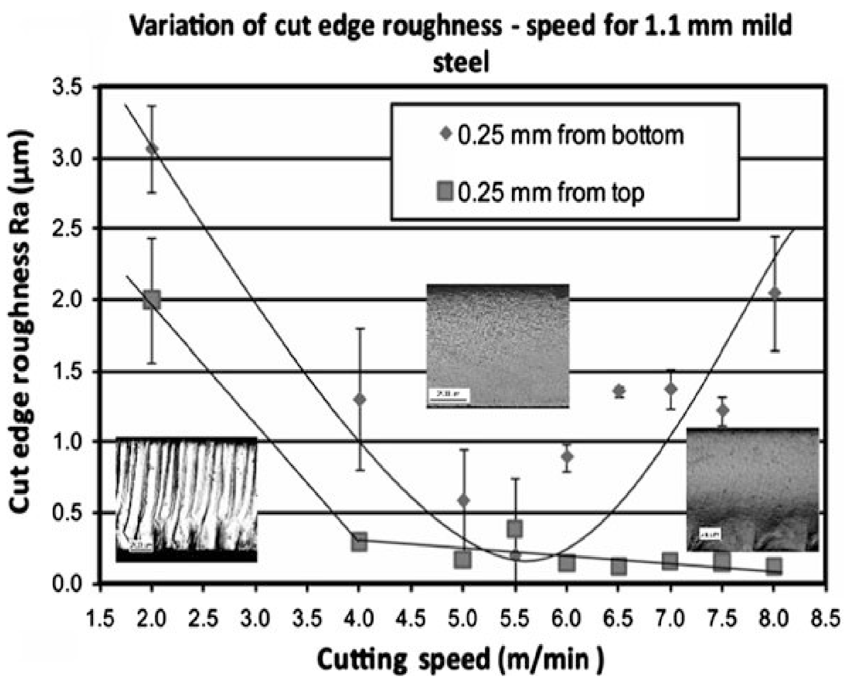

Figure 7. Variation of surface roughness at 0.25 mm from top and bottom surfaces with cutting speed during fiber laser cutting mild steel with oxygen jet

4. Conclusion

Laser beam is an identical machining source which can detruncate materials by photo thermal processes, in which materials are segregated by controlled fracture or locally withdrawn by vaporization, melt ejection or ablation mechanisms. For achieving the superior quality results, it is necessary to reduce the degree of melting involved and lasers with short pulse can show specific advantages in this regard. The quality of cutting and the highest speed of cutting are highly influenced by the laser beam characteristics. The technology of laser cutting will continue to grow into the future as more powerful, flexible, efficient and compact.

References

Jam, R. K., *Production Technology*, 4th edition, Khanna publishers, Delhi, India, 1999.

Thompson, T. D., *1989 TRW Space Log*, TRW Space and Technology Group, Redondo Beach, CA, USA, 1990.

Laud, B. B., *Laser and Nonlinear Optics*, 2nd edition, New Age International Publishers, New Delhi, India, 1997.

Tavis, M. T., Levinson, S. W., and Parker, K. M., *Implications of Cloud Obscuration on Ground-Based Laser Systems for Strategic Defense*, Technical report, The Aerospace Corporation, El Segundo, CA, USA, 1990.

Motalab, M., Shakil, A. S., Rahman, T., and Suhling, J. C., Variation of Thermal Cycling Life Prediction of PBGA Microprocessor Components with Substrate Properties, *Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS)*, vol. 6, no. 5, pp. 371-376, 2015.

Johnson .V .Harold, *Manufacturing Processes*, Revised Edition, Canton Illinois Glencoe Publishing Company, USA, 1999.

Chitale, A. K., and Gupta, R. C., *Product Design and Manufacturing*, 3rd edition, Prentice-Hall of India Pvt. Ltd, New Delhi, India, 2005.

Ghosh, A., and Malik, A. K., *Manufacturing Science*, 2nd edition, East-West Press Pvt. Ltd, New Delhi, India, 2010.

Biographies

Md. Ashrafuzzaman Miah is from Khulna, Bangladesh. He is pursuing his Master's Degree in Mechanical Engineering at Islamic University of Technology (IUT). He has completed his Bachelor's Degree in Mechanical Engineering from Khulna University of Engineering and Technology (KUET). He has experience of working in a Power Plant. His research interests are Computational Fluid Mechanics (CFD), Heat and Mass Transfer, Thermo-Fluids, Nuclear Energy, and Power Plant. He is also looking for further research opportunities.

Farzad Hossain is from Dhaka, Bangladesh. He is pursuing his Master's Degree in Mechanical Engineering at Islamic University of Technology (IUT). He has completed his Bachelor's Degree in Mechanical Engineering from Military Institute of Science & Technology (MIST). He has experience of working as a Teaching Assistant at the Department of Mechanical Engineering, MIST. His research interests are Computational Fluid Mechanics (CFD), Heat and Mass Transfer, Thermo-Fluids, Nanofluids, Biomedical, and Renewable Energy. He is also looking for further research opportunities.