CFD Analysis of the Effect of gas flow in Ytterbium: fiber laser cutting process – A review

Hardik J Patel[1], Prof. D.M. Patel[2], Dr. Kedar Pathak[3]
1 P.G Student, U.V Patel College of Engineering, Kherva, Mehsana
2 Associate Prof., U.V Patel College of Engineering, Kherva, Mehsana
3 Associate Prof., U.V Patel College of Engineering, Kherva, Mehsana

ABSTRACT
There are many non-linear interaction factors responsible for the performance of the laser cutting process. Identification of the dominant factors that significantly affect the cut quality is important. In recent years the researchers have explored the number of ways to improve the quality of cutting in the different lasers. This paper reviews the research work carried out so far in the area of Laser cutting process and computational fluid dynamics. Several modeling and optimization techniques used for the determination of optimum laser cutting condition have been critically examined. CFD is a new branch of design engineering which integrates the discipline of Fluid mechanics/Dynamics with mathematics and also with computer science.

Keywords – Computational fluid dynamics, gas-flow, laser cutting process

1. Introduction

Laser

Laser is the acronym of Light Amplification by Stimulated Emission of Radiation. Laser is a special properties of light, light is electromagnetic (EM) wave in visible range. It is essentially a coherent, convergent, and monochromatic beam of electromagnetic radiation with wavelength ranging from ultraviolet to infrared. Lasers have now found applications in almost every field of engineering, medicine, commercially etc [6].

Laser Cutting Process

Laser cutting is a common manufacturing process employed to cut many types of materials. Materials which may be cut included ferrous metal, non ferrous metal, stone, plastic, rubber and ceramic. Laser cutting works by directing a high power pulsed laser at a specific location on the material to be cut. The energy beam is absorbed into the surface of the material and the energy of the laser is converted into the heat, which melt or vaporize the material. Additionally gas is focused or blown into the cutting region to expel or blow away the molten melt and vapor from cutting path.
There are several advantage of laser cutting over mechanical cutting, since the cut is performed by the laser beam, there is no physical contact with the material therefore contaminates cannot enter or embed into the material. Laser cutting can produce high quality cut, complex cut, cut several part simultaneously, produce clean cutting edge which require minimal finishing as well as low edge load during cutting which will reduce distortion [7].

2. Computational Fluid Dynamics

Computational fluid dynamics (CFD) is the analysis of systems involving heat transfer, fluid flow and associated phenomenon like chemical reaction by means of computer based simulation. CFD enables a computational model representing a physical system to be built and studied. When fluid flow physics is applied to this virtual prototype, the CFD application outputs a prediction of the fluid dynamics. The software predicts not only the fluid flow behavior, but also the transfer of heat, mass, phase change, chemical reaction, mechanical movement, and stress or deformation of related solid structures. It covers a wide range of industrial and non industrial application areas like; Aerodynamics of aircraft and vehicles, Combustion mechanism in IC engines and power plants, Turbomachinary flows inside rotating passages and diffusers [8].

There are several advantages of CFD include:

- Substantial reduction in lead times and costs of new designs.
- CFD enables us to study systems where controlled experiments are difficult or impossible to perform (large systems).

- CFD provides the environment to study systems under hazardous conditions and beyond their normal performance limits.
- CFD facilitates practically unlimited level of details of results.

Steps for CFD analysis process:

- Formulate the Flow Problem
- Model the Geometry and Flow Domain (Figure 2).
- Generate the Grid.
- Specify the Boundary and Initial Conditions.
- Specify the Input Parameters.
- Perform and Monitor the Simulation for Completion.
- Post-process the Simulation to get the Results.

3. Literature Survey

Prof D. M. Patel, Dipesh Patel. Parametric Analysis of ytterbium: fiber laser cutting process. In this report they mainly focus on cut quality and the cut quality mainly decided by surface roughness, kerf width, and perpendicularity. The experiment was carried out on 5mm thickness M.S. plate by varying the parameter like; laser power, gas-pressure, and cutting speed. The factorial design was used for design of experiment and for find out the percentage contribution of process parameter used Minitab 15 software. Surface roughness was measured by Surface roughness tester SJ-201 and kerf width was measured by equipment including digital camera and the UTHSCSA image tool version 3.0 program [1].

Shang-Liang Chen. The effects of high-pressure assistant-gas flow on high-power CO2 laser cutting. In this research they investigated CO_2 laser cutting performance on 3 mm thick mild steel plate with assistant-gas pressures of up to 10 bar. A co-axial cutting nozzle able to withstand pressures of up to 12 bar was designed and set up. Experiments were performed with this high-pressure coaxial nozzle. The cutting edges were examined to provide information on cutting quality. The results show that an acceptable-quality cutting region does not exist for pure oxygen cutting, but that good cutting cannot be obtained at an assistant-gas pressure of over 4 bar with 3 mm thick mild-steel plate as shown in figure 1 and figure 2. For inert-gas cutting, dross under the cut kerf was formed with most of the cutting parameters. An almost clean cut was found with an argon gas pressure of 10 bar at a cutting speed of 25 mm/s. For the laser cutting of 3 mm thick mild steel plate it is advised that oxygen cutting is still the best, although argon and nitrogen may be used instead. Air is inferior to these gases as an assistant gas [2].

Jun Hu, J. Luo. Simulation and experiment on standoff distance affecting gas flow in laser cutting A three-dimensional axial symmetrical model of laser cutting is established by adopting N– S equation and RNG k–e onflow model in the paper, and numerical simulation is put up to analyze the flow field of shield gas in cutting slot. The investigation reveals the law about how standoff distance affects the dynamic characteristic of gas jet in cutting process, and the distribution of pressure and velocity of gas jet with different standoff distances. Two typical subsonic nozzles: convergence nozzle and taper nozzle are designed for the laser cutting experiment. In this experiment the power is 2.5 kW the cutting slot width is 0.35 mm and cutting speed is 4.0 m/min. The work piece is normal carbon steel plate with thickness of 2 mm, and shield gas is nitrogen with pressure of 3.0 atm [3].

I. Dohnke, D. Peter, Modeling of supersonic gas flow of nozzles for laser cutting systems. In this paper the gas density gradient was observed by the “Schlieren”-technique and the velocity distribution was measured with laser doppler anemometer. The supersonic gas flow of nozzles for laser cutting systems has been modeled with CFD simulations. After the comparison of these methods, shown that CFD simulation in conjunction with ‘Schlieren’ technique are suitable and efficient tools for designing high performance nozzles for laser cutting systems. The influence of the laser parameters such as focal position and cutting speed has been included in these experiments [4].

Results are presented for a conic, a ring and a convergent-divergent nozzle. Identical process parameters were used for all methods (nozzle distance = 0.5 mm, nitrogen gas pressure p = 1.6 MPa, material = stainless steel = 10 mm, cutting speed = 1’400 mm/min, laser power = 5.2 kW. The best results have been achieved with the nozzle with the smallest flow separation at the lowest reflection point, steepest angle of the gas flow and shock wave formation below the metal sheet. After that, the case for the ring nozzle which shows the best cutting performance over a wide range [5].

J. Carlos, Lin Li. The effect of moisture content in fiber laser cutting of pine wood. This paper reported a statistical analysis of the multiple-pass laser cutting of wet and dry pine wood with an Ytterbium fiber laser. Design of experiments (DOE) and statistical modeling were used in this study to investigate the significant process parameters and the interactions. A high brightness, 1 kW IPG single mode, continuous wave Ytterbium doped fiber laser was employed to cut wet and dry pine wood samples. The parameters investigated are laser power, traverse speed, focal plane position(f.p.p.), gas pressure, number of passes, direction of cut (normal or parallel to wood's tracheids) and the moisture content. The experimental results were compared against process responses defining the efficiency (i.e.kerf depth and energy consumption) and quality of the cut section (i.e. kerf width, heat affected zone—HAZ, edge surface roughness and perpendicularity).It has been found that the laser cutting process was mainly affected by the moisture content and the cut direction with respect to the wood's tracheids, followed by traverse speed, laser power and the number of passes. The effect of moisture content on energy consumption in the laser cutting process of both wet and dry wood is analyzed. The wood cutting results with fiber laser are compared with those from a CO_2 laser [5].

4. Conclusion and Discussion

Gas-flow plays an important role in laser cutting. Despite extensive research efforts directed to address this phenomenon, the effect of gas-flow is still not completely understood with experiments as well as fluid modeling. The effect of gas-flow reduces the quality of the cutting and creates inappropriate geometrical shape. Minimization of gas-flow effects improves the cut quality and reduces post machining process. It is important to compare analytical CFD data with experimental data of gas pressure effects on cut quality which gives optimum condition.

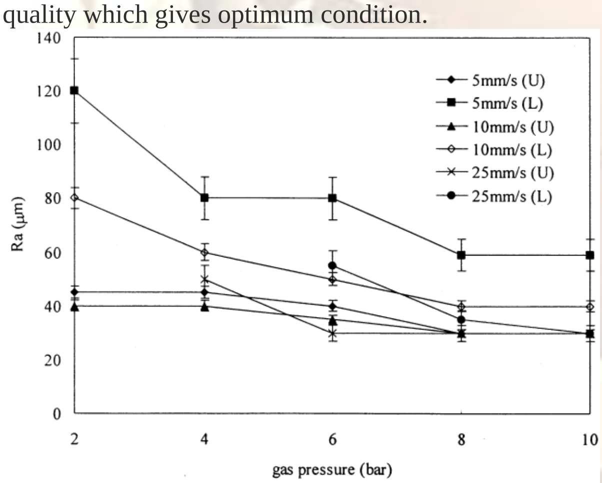

Figure 1: Variation of the surface roughness with pressure [2]

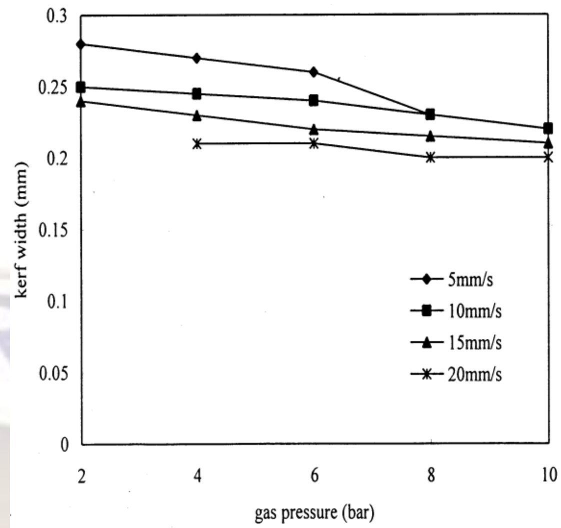

Figure 2: Variation of the kerf width with pressure [2]

Figure 3: Basic geometry of nozzle

6. References

[1] Dipesh Patel, Prof. D.M.Patel. "Parametric Analysis of Ytterbium: fiber laser cutting process" Ganpat university, kherva, Mehsana, Gujarat, India August-2010.

[2] Shang-Liang Chen. "The effects of high-pressure assistant-gas flow on high-power CO_2 laser cutting" Proceeding by journal of

Materials Processing Technology in May-1999 Volume 88 Page no. 57-66.

[3] Jun Hu, Zhuoxian Zhang, Jingwen Luo, Xiaojun Sheng. "Simulation and experiment on standoff distance affecting gas flow in laser cutting" Proceeding by journal of Applied Mathematical Modeling in August-2011 Volume 35 Page no. 895–902.

[4] I. Dohnke, D. Peter, J. Comps, T. Sprunk, K.C. Heiniger. "Modeling of supersonic gas flow of Nozzles for laser cutting systems" proceeded by the Bystronic Laser AG and the Institute of Thermo- and Fluid Engineering of the FACHHOCHSCHULE Aargau, Switzerland.

[5] Juan Carlos Hernandez-Castaneda , Huseyin Kursad Sezer, Lin Li "The effect of moisture content in fiber laser cutting of pine wood" Proceeding by journal of Optics and Lasers in Engineering in May-2011 Volume 49 Page no. 1139-1152.

[6] Introduction to Laser Material Processing by Columbia University.

[7] http://www.ipgphotonics.com/apps_mat_lab_cutting.htm.

[8] http://en.wikipedia.org/wiki/CFD