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Comprehensive Review on Role of Process Parameters of Laser Beam on Machining Performance of Metal Alloy Based Material

[1]Ratnesh Kumar Sharma, [2]Shiv Ranjan Kumar*, [3]Kumar Gaurav, and [4]Manoj Kumar

Author's Affiliations:

[1]Mechanical Engineering Department, Poornima College of Engineering, Jaipur, Rajasthan, India
E-mail: ratnesher@gmail.com
[2]Mechanical Engineering Department, BCE Bhagalpur, Bhagalpur, Bihar 813210, India
E-mail: ranjan.shiv@gmail.com
[3]Mechanical Engineering Department, BCE Bhagalpur, Bhagalpur, Bihar 813210, India
E-mail: j.k.rkumargaurav@gmail.com
[4]Mechanical Engineering Department, BCE Bhagalpur, Bhagalpur, Bihar 813210, India
E-mail: manojkr100892@gmail.com

***Corresponding author:**

Shiv Ranjan Kumar
Mechanical Engineering Department, BCE Bhagalpur, Bhagalpur, Bihar 813210, India
E-mail: ranjan.shiv@gmail.com

ABSTRACT

As a non-traditional machining process, Laser beam machining can melt/machine/cut/drill any known materials. However, many process variables, including nozzle distance, pulse frequency, power, focal length, and gas pressure, affect the accuracy, precision, and other laser beam machining characteristics. The impact of these parameters on laser beam machining performance has been examined in the current review. The highlights of the numerous current research studies on laser beam machining's varied features that influence process quality are reviewed in this study. For newer and advanced materials such as titanium alloy, laser beam machining is the best suitable to make various profile or drilling holes. The performance of Laser beam machining with other suitable process has been compared. It was revealed that in the LBM process, the power has the most deciding factor in the geometrical precision. Nozzle distance plays a crucial role in achieving precise roundness. Although some recent findings have shown encouraging results, there are still certain obstacles to be addressed.

KEYWORDS

Laser Beam Machining, Process Parameter, Metal Alloy, Nozzle Distance, Pulse Frequency

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1. INTRODUCTION

Due to their efficiency and robustness, unconventional machining technologies have attracted a lot of research interest. These machining techniques make it simple to create intricate and complex part geometries out of materials with exceptional strength and hardness. Due to its extreme strength and hardness, titanium alloy has found extensive use in a various industries. Numerous non-traditional machining methods, such as water jet machining (WJM), abrasive jet machining (AJM), electric discharge machining (EDM), electrochemical machining process (ECM), plasma arc machining (PAM), and laser beam machining (LBM), can be used to machine the titanium alloy materials (Leyens and Peters, 2006; Bodunrin, Chown and Omotoyinbo, 2021; Gupta, Mishra and Singh, 2020; Geethapriyan, Kalaichelvan, Muthuramalingam and, Rajadurai, 2018; Muthuramalingam et al., 2018) .

In the applications where more complicated, delicate, sensitive parts are involved like machining of titanium based dental implant, laser has been proved as the most efficient (Le Guéhennec, Soueidan, Layrolle, Amouriq; 2006). These strong, hard materials may be cut with a laser into the precise forms and sizes that are needed. Better surface finish is one of the benefits of LBM over other conventional methods. The lasers have a 0.002 mm-diameter, collimated, coherent, monochromatic beam of light focused into small areas. In order to cut/ machine a material, the laser beam travels over the work item. Melting and evaporation are combined in laser beam machining to remove material (Kaushik; 2014).

Kumar et al. 2014 describes the way of formation of laser using photon. Within the atomic model, negatively charged electrons follow predetermined orbital routes around the positively charged nucleus. Every electron in an orbit has a certain energy level assigned to it. The temperature at which an atom is at absolute zero is referred to as ground level. Higher energy states of ground state electrons can be induced through external energy absorption, such as generating a chemical reaction, increasing electronic vibration at high temperatures, or absorbing photon energy. Subsequently, the electron transitions from one energy level to another. The electron enters an unstable energy band after reaching the higher energy level. As a result, it quickly returns to its ground state by emitting a photon. The primary energy source used in LBM is photons.

According to Madic and Radovanovic, 2012, LBM is one of the most often used heat-based advanced machining techniques for processing a range of materials. By concentrating the laser beam on the surface of the work piece, LBM melts the material. This high energy method may be applied to nearly any material and works fast on complex and sophisticated design elements. This method offers ecologically friendly technology, decreases waste, removes mechanical stress from the work piece, and may be adjusted to operate in the micro range. However, the accuracy of laser beam machining can be enhanced by controlling its process parameters. The process parameters affecting performance of Laser beam machining are presenting in Figure 1.

2. EFFECT OF NOZZLE DISTANCE ON MACHINING PERFORMANCE

Under high pressure circumstances, the cutting nozzle's geometric structure—including the nozzle distance—has a substantial effect on the laser's flow behavior emanating from the nozzle tip (Man, Duan and Yue, 1998; Man, Duan and Yue, 1999). The pace at which material is removed during laser cutting is intimately correlated with this flow characteristic. Convergent-divergent supersonic nozzles maintain a high gas momentum across longer flow lengths. This is so that, at the nozzle exit, a properly designed supersonic nozzle may accelerate the gas at stationary pressure into a uniform, shock-free gas flow. However, along the flow path of the gas jet at high pressure, traditional subsonic nozzles inherently create a significant normal and oblique shockwave because of their convergent design. The shockwave may cause kinetic energy to be lost and flow behaviour to change. For laser cutting, a small stand-off distance is ideal when utilizing subsonic nozzles. Therefore, when a high operational tolerance of the stand-off distance is needed for laser cutting, the supersonic nozzle cutting method is the best choice. In practical applications, the nozzle diameter needs to be selected based on the trial conditions in order to cut a steel plate successfully. The throat diameter of the supersonic nozzle was increased, increasing the stand-off distance required to complete the cut. However, this led to greater gas consumption (Oh et al., 2019).

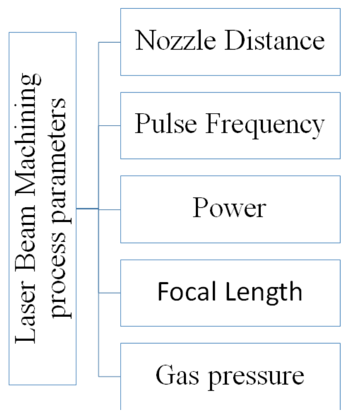

Figure 1: Process parameters of LBM process

3. EFFECT OF PULSE FREQUENCY ON MACHINING PERFORMANCE

Researchers have reported that the pulse frequency has significant role in the machining performance of LBM process. Meijer (2004) claims that light is utilized in everything from phone technology to eye surgery. The fact that photons are charge-less and have no volume is a crucial characteristic. As a result, unlike electrons, they do not reject one another when focused into a beam at a specific location. Photon in contact with matter behaves as the energy particles. It was also concluded that the process's efficiency and material removal rate may both be successfully increased by pulse frequency. In some simulation based studies, laser beam parameters have shown significant effect on machinability (Abidou et al., 2017; Parandoush and Hossain, 2014).

In drilling process, roundness is the important performance parameter which decides machinability of process. The laser plasma energy may eliminate the material exactly. It has been investigated how pulse length affects surface roughness and ablation quality based on the ideas of laser energy and plasma energy (Denkena, Krödel and Grove 2019). Laser beam machining has been demonstrated by Kim et al. to improve the machinability of nickel-based alloys with spherical shapes (Kim and Lee, 2016).

4. EFFECT OF POWER ON MACHINING PERFORMANCE USING LBM

During LBM, huge power is produced that can melt/machine the materials without giving much emphasize on surface finish. Through the use of a densely concentrated laser beam, LBM heats the material to the point of vaporization, melting, or chemical transformation. The materials on the machined surface can be effortlessly eliminated by the high pressure gas jet flow.The LBM technique is an efficient way to mill non-conductive biomaterials, including leather (Vasanth and Muthuramalingam, 2019; Mushtaq et al., 2020). More power heats up the work piece and transmits more energy and develops heat affected zone (HAZ). Since more energy is transmitted to work material as laser power increases, there is an indirect correlation between cutting speed and the heat impacted zone. The most significant component influencing the HAZ is laser power as it has a greater impact on the HAZ than cutting speed does.

Rajaram, Sheikh-Ahmad and Cheraghi, 2003conducted research on laser-cut 4130 steels and concluded that the kerf breadth was mostly influenced by power, and just slightly by feed rate. In most cases, kerf width and HAZ decreased with decreasing power and increased feed rate. Feed rate has a major impact on both the roughness of the surface and striation frequency. As feed rate rose, surface roughness and striation frequency generally increased as well. The optimal feed rate that results in the lowest surface roughness can be found. Power has little impact on striation frequency and very little effect on surface roughness.

5. EFFECT OF LBM FOCAL LENGTH ON MACHINING PERFORMANCE

Focal length in the laser beam machining influences the machining performance. The shortest focal length was found to have no variation. The focal length plots have an oscillating character because of their bigger peak divergence from the mean line and variable nature during the drilling operation (Muthuramalingam et al., 2020). The brass sheets could be cut with high quality at a laser cutting window of 7500 mm/min and 1500 watts with a surface area of 1.491 μm (Magdum, Kittur and Kulkarni, 2022). The cutting speed and surface roughness are impacted by an incorrect focus length.

6. EFFECT OF GAS PRESSURE ON MACHINING PERFORMANCE

Gas pressure used in the LBM has significant effect the machining performance of metallic alloy. Given its limited control over the plasma column, when it comes to input process elements and reaction parameters, gas pressure has the least influence (Meijer, 2004). Gas pressure influences the exit diameter in a wider variety of ways since it can control the plasma column at the exit. Higher pressures have produced a more noticeable effect. However, the system roundness at entrance is least affected by the gas pressure. The gas pressure has the greatest coefficient and contributes significantly to the roundness of the exit hole. Nozzle distance, with less coefficient, is the second most influential parameter on the system. Power has been found to be the primary deciding element in getting the required profile because of its significance for the plasma column. An undesirable profile is produced by the greater power at a larger nozzle distance due to the larger and higher entropy concerning the energy distribution.

7. CONCLUSION

This review highlighted the influence of various parameter of LBM over the performance of machining of hard and high strength metallic alloy material specifically titanium alloy. High material removal rate of LBM can compromise with the quality of machined surface. Due to the inevitable production of burrs and spatters during the LBM process, the surface quality is reduced. It is possible to modify the different input parameters to enhance the quality of surface, reduce HAZ, and achieve other desired output qualities. However, by using LBM and accelerating the cutting speed, the spatter generation and HAZ may be decreased. The HAZ can be significantly reduced by reducing the laser strength. The roundness of the exit hole in the LBM process is mostly determined by the gas pressure. Nozzle distance is the second most influential parameter on the system. The power has the most deciding factor in the geometrical precision. When evaluating machining precision with the least amount of power during the LBM drilling process, power and gas pressure are very important factors. In the LBM process, power and nozzle distance play a crucial role in achieving precise roundness.

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