Laser Cutting Parameters Effect on 316L Stainless Steel Surface

B S Wardhana, K Anam, R M Ogana and A Kurniawan
Mechanical Engineering Department, Brawijaya University

Email : wardhanabayu@ub.ac.id

Abstract. Laser cutting is a cutting technology that enables fast processing in high precision. This technology utilizes high temperatures generated by engine to perform the cutting process. Selection of cutting parameters becomes the main factor to determine the cutting surface quality. Cutting parameters in the form of cutting speed and gas pressure are varied between 60 mm/minute - 100 mm/minute and 17 bar - 21 bar to examine the effect on surface character. The character of the laser-cutting surface on 316L series stainless steel material was observed related to the roughness, hardness and microstructure. The results showed that the parameters of cutting speed and gas pressure had an effect on the cutting surface. Changes in cutting speed has more effect on surface roughness while gas pressure has more effect on cutting surface hardness. Observations on the surface also illustrated that there were differences in cutting quality along with the deeper penetration performed by the laser.

Keywords: cutting speed, gas pressure, surface roughness, hardness

1. Introduction
Manufacturing is a process of converting raw materials into finished or semi-finished materials. In the practice, the conversion process can contain the cutting/reducing dimensions process, connecting processes, as well as finishing processes. In the future, the keys of manufacturing processes are speed, accuracy, result uniformity, and product quality. Departing from those, technology in manufacturing continues to evolve to adapt to the era demands.

The development of the manufacturing process is inseparable from automation process. In this case, the numerical controls existence is a considerable leap in the manufacturing industry. The manufacturing process that was very dependent on the operator capabilities/skills has become structured and controlled by numerical control concepts existence. The products diversity that was previously high has been decreasing so that the products quality is maintained more. The application of numerical controls also allows the process to be faster because the settings are only set up once, while the next processes simply need to use the previously stored data.

In addition to developments in the control field, the cutting methods that are used in the manufacturing industry also experienced significant developments. Conventional cutting generally uses tools and utilizes shear force principle in performing the process. Non-conventional cutting uses a variety of media such as water, electric wire, and even laser light in the process. The cutting principles that are used are also various; starting from using pressure, temperature, and even chemical reactions. Laser cutting is one of the non-conventional cutting methods that utilize heat energy in the cutting process. Laser cutting works by directing the output of a high-power laser; most often through optical
media. Optical laser and CNC (computer numerical control) that are used to direct the material or laser light produced. Industrial laser cutting is designed to concentrate a high amount of energy into small areas [1]. Usually laser-cutting rays are around 0.003-0.006 inches in diameter. The heat energy produced by the laser will melt or evaporate the material in the work area. Gases such as oxygen, CO₂, nitrogen, or helium are used to dispose of the evaporating material that comes out/arises from a laser beam collision with the work piece [2].

Laser stands for light amplification by stimulated emission of radiation. Laser can be formed due to quantum energy absorption by a laser material/medium from a light source that causes electrons to jump to a higher energy level (an orbit farther from the nucleus). These electrons will then fall into their original orbit spontaneously while emitting previously absorbed energy. The energy in the form of radiation has the same wavelength as the stimulating energy and same phase with it.

The cutting process with a CO₂ laser uses a gases mixture of CO₂, N₂ and He that are energized with high frequencies that cause the electric field occurrence in the laser medium. When the amount of energy needed for laser beam generating (excitation) is sufficient, then the molecules of CO₂ will release energy in the form of photons. The photons will experience strengthening so that a laser beam starts to form which will be reflected through the lens. Through high power, the material is heated, later melting, and some evaporating. In the material cutting, O₂ or N₂ gas is used to eliminate melted material. O₂ gas or N₂ gas is emitted together with a laser beam coming out of the nozzle. O₂ cutting gas has characteristic of burning work pieces during the cutting process, cutting with O₂ gas results from an exothermic reaction between oxygen and material. Cutting with O₂ gas is also called flame cutting. In this case, the O₂ purity influences the cutting surface quality [3]. N₂ cutting gas has characteristic of fusing work piece during the cutting process, cutting with N₂ gas occurs because of the energy of the laser beam itself. Cutting with N₂ gas is also called fusion cutting [4].

1.1 Laser cutting classifications
1. Laser sublimation cutting
   The principle is fusing material with heat produced by a laser beam. Laser sublimation cutting is used in cutting wood, paper and plastic. High enough laser intensity is needed to maintain heat conductivity loss.
2. Laser fusion cutting
   Using a laser beam to melt the material in the cutting process, and the noble gas used is N₂, Ar is blown and it can remove the melted material. This fusion-cutting laser is usually used in cutting glass, plastic and metal.
3. High pressure cutting
   It is part of laser fusion cutting where high-pressure nitrogen is depend on the thickness used. This high-pressure gas causes the melt to separate quickly from the kerf. This cutting type is able to eliminate vibration formation and prevent the melting from sticking to the cutting side. When nitrogen is used as a cutting gas, there is no oxidation that affects the edge pieces. This cutting is specifically used for cutting stainless steel material.
4. Laser flame cutting
   In this type of gas cutting laser, it has a working principle that is almost the same as the two types above. But what distinguishes it is the use of gas cutters; in this cutting type, it is performed with O₂, that the gas is sprayed from the beginning of the cutting to accelerate the exothermic reaction on the work piece.

1.2 Machinery process parameters on laser cutting
Some parameters in the cutting process with a laser cutting which is estimated to have an effect on the cuttings surface quality are as follows;
1. The gas type used in the laser cutting machines.
   The gases used in the laser cutting process are usually CO₂, N₂ and He. In the laser cutting process, the use of O₂ or N₂ gas is to eliminate melted material. O₂ gas or N₂ gas is emitted together with a
laser beam coming out of the nozzle during the cutting process. O<sub>2</sub> cutting gas has the characteristic of burning work pieces during the cutting. Cutting with O<sub>2</sub> gas results from an exothermic reaction between oxygen and material. Cutting with O<sub>2</sub> gas is also called flame cutting. Cutting gas N<sub>2</sub> has the characteristic of fusing work piece during the cutting, cutting with N<sub>2</sub> gas occurs because of the energy of the laser beam itself. Cutting with N<sub>2</sub> gas is also called fusion cutting.

2. The gas pressure used

The gas pressure used by a laser-cutting machine has an effect on the temperature level that can be achieved during the cutting process, thus also contributing to the surface quality of the work piece [5].

3. Cutting speed

Cutting speed is how long a machine perform cutting at a certain time. The greater the value of cutting speed, the cutting area will be greater in the unit of time [5].

2. Method

The research was performed by directly cutting AISI316L stainless steel sheets of 1,000 mm x 1,000 mm with a thickness of 3 mm (see table 1 for material composition) to be 30 mm x 30 mm using a laser cutting machine. The laser cutting machine was EAGLE 3015 type with a maximum power of 1000W, and a maximum cutting area of 3000 mm x 15000 mm. Gas pressure was varied at 17 Bars; 19 Bars; 21 Bars; 23 Bars; 25 Bars; meanwhile the cutting speed was varied at 60 mm / minute; 70 mm / minute; 80 mm/minute; 90 mm/minute; 100 mm/minute. The nozzle diameter was 2.0 mm; the nozzle angle was 90°; and the gas type was nitrogen. In variations in the gas pressure, the cutting speed was kept at 80 mm/minute, whereas at the cutting speed variation, the gas pressure was kept constant at 21 bar.

Cutting results from the laser cutting were observed for hardness and surface roughness. Hardness was observed by using the Vickers method with a load of 300gf for 30s. Surface roughness was observed by using Mitutoyo SJ-10 surface roughness tester with a sample length of ± 8 mm each; by taking 3 points in the thickness direction (see figure 1). Micro photos were taken on the cutting surface to obtain an overview of the microstructure of 316L stainless steel specimens after undergoing a cutting process.

| Table 1. Composition of 316L Stainless Steel [6] |
|-----------------|-----------------|-----------------|-----------------|
| C, %           | Mn, %           | P, %            | Si, %           |
| ≤0.03          | ≤2.00           | ≤0.045          | ≤0.03           |
| Cr, %          | Ni, %           | Mo, %           | N, %            |
| 16-18          | 10-14           | 2-3             | ≤0.10           |

3. Results & Discussions

3.1 Gas pressure effect

In the laser cutting process, the gas pressure functions as the gas thrust force, so that it flows towards the cutting point and there is a reaction with the material that has been cut off. Higher pressure allows gas supply when cutting is better so that the material evaporation process is better. In this study, more pressure has an effect on surface hardness than surface roughness (figure 2.a). The effect of gas
pressure on hardness is due to the phase transformation at the cutting surface due to high temperatures and the relatively fast cooling process that allows a martensitic structure formation. In some materials cut by the laser cutting method, the increase in hardness was 10%-20%. In this study, microstructure observations showed composition differences between pearlite and ferrite represented by the dark and light colors percentage (figure 3). The martensitic structure in cutting is not visible because the cooling after the cutting process is in the air medium that is included in the intermediate speed cooling. This causes the carbon atom (C) to have time to diffuse into the atom (Fe) so that pearlite is formed. In addition, from microphoto it also appears that the higher the gas pressure used, the smaller the grain formed. Small grain size indicates that the hardness of the surface increases.

The cutting surface roughness value in the cutting laser increased (figure 2.b) [7] as well as increased in gas pressure, although not very significant [8]. The phenomenon is a little contrary to the existing theory that it should be with the sufficient gas availability during the cutting process, the evaporation reaction of the residual melting material takes place better and results in the roughness value decrease. This is probably due to the high temperature achieved in the cutting process and the wider heat affected zone (HAZ). The extent of this HAZ area leaves more residual melt material on the cutting surface; and not comparable to the evaporation reaction that occurs.

![Figure 2](image)

**Figure 2.** (a) Gas pressure effect on hardness; (b) Gas pressure effect on surface roughness

![Figure 3](image)

**Figure 3.** Cutting surface microstructure with a constant speed of 80 mm/minute, 400x magnification, (a) Pressure of 17 bars; (b) Pressure of 19 bars; (c) Pressure of 21 bars

### 3.2 Cutting speed effect

Cutting speed resulted in a decrease in the roughness value and an increase in surface roughness (figure 4.a). The higher cutting speed in the laser cutting causes the inclination angle on the cutting surface to increase (figure 5). Increasing the inclination angle resulted in the cutting surface shape
produced. The intersection line that had previously approached the normal line turned and formed a curve / bending. The shape of this bending curve occurs because the laser beam focus on the top is better than on the bottom. This indicates that the material melting process at the bottom is slightly slower when compared to the top/surface. The curve shape on the cutting surface causes the roughness value to increase. Figure 4.a also shows that the material thickness affects the surface quality produced. The highest temperature occurs on the surface, while getting to the bottom then the temperature will decrease [9].

Cutting speed also affects the HAZ area produced. Increasing cutting speed will reduce the HAZ area because laser contact with the work piece is getting shorter [10]. The reduced area affected by temperature causes the phase transformation opportunity to decrease so that hardness tends to decrease (figure 4.b) or remains like its material base properties.

**Figure 4.** (a) Cutting speed effect on surface roughness; (b) Cutting speed effect on surface hardness

**Figure 5.** Changes in the inclination angle on the cutting surface with increasing cutting speed [9]

## 4. Conclusions

The conclusions that can be drawn from laser cutting on 316L stainless steel types with variations in cutting parameters are as follows:

- Gas pressure has a considerable influence on the material hardness properties changing.
- Cutting speed affects more the surface quality produced. (In this study surface quality was represented by roughness values)
The work piece thickness has an effect on the surface quality produced; the thicker the work piece, the cutting surface quality decreases.

5. References

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