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Laser Cutting Methods – Review

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Abstract. Nowadays, sheet and profile cutting services, including cutting in 3D systems, are a significant part of laser technologies used in heavy industry. Laser welding is also becoming more common, mainly in the automotive industry [1]. Due to high power fiber lasers, it is possible to robotize the process. Surface treatment such as hardening, padding, alloying, etc. also has a small market share in laser services [2-6]. However, laser cutting is still the main laser treatment technology applied by heavy and machine industry. In this paper, the author described laser cutting methods and showed examples of various materials laser cutting using the discussed methods.

Introduction

Laser cutting was the first laser technology applied in industry. The first described use of the laser beam as a cutting tool was in 1967 [7]. In order for the cutting process to take place, the laser beam must be brought to the workpiece surface and sufficiently high power density must be ensured. Depending on the type and thickness of material being cut, this density is about $10^4 \div 10^6$ W/cm^2 (max ~10^{11}). At the same time, a suitable working gas must be applied, whose type depends on the type of material being treated.

By definition, laser cutting is a thermal process that leads to material continuity loss as a result of the laser beam affecting it with the participation of working gas fed under pressure and coaxial with the laser beam. This gas may be inert or reactive. The choice of gas type depends on the cutting method. Its type and pressure significantly affects the quality and speed of a cutting process.

The laser cutting mechanism is complex and depends on physical properties of the material being cut and the parameters of the laser beam, which acts as a linear heat source forming a stable cutting mesh.

The laser cutting process can be briefly described as follows. A focused laser beam falling on material's surface is partly reflected and partly absorbed (the passing wave is negligible). Laser beam photon energy is absorbed by free electrons of the electron cloud surrounding atomic nuclei of the material being cut. Electrons under the influence of absorbed energy go into the state of forced vibrations, which is expressed in the form of thermal energy. When a sufficient amount of laser radiation energy is delivered, the thermal vibrations of the electrons are so intense that there is a decrease in molecular bonds strength leading to the material transition from solid to liquid state. If the energy of laser radiation increases further, then the energy of electron vibrations increases as well. This leads to a significant decrease in molecular bond strength, which results in material transition from liquid to gaseous state [8]. The stream of working gas blows liquid metal and it vapors out of the gap (inert gas) and/or provides additional energy (reactive gas). A diagram of the cutting process is shown in Fig. 1.

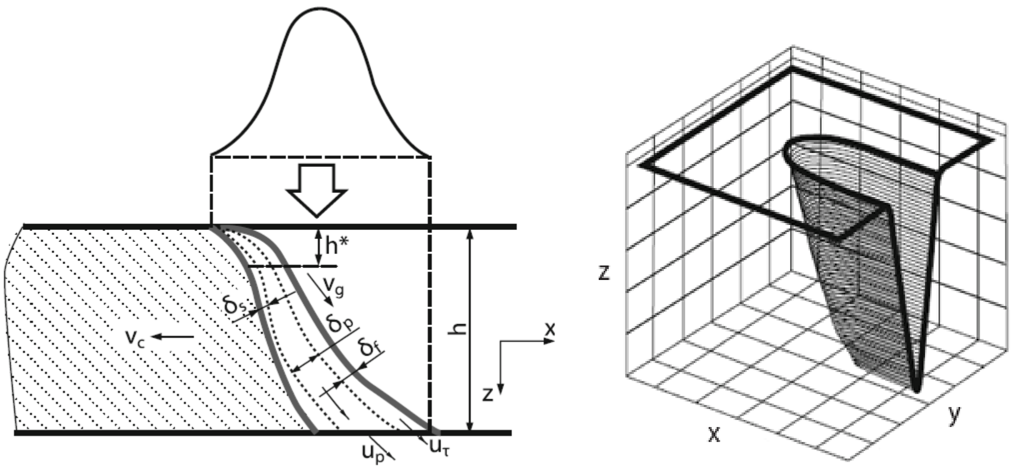

Fig. 1. Diagram of the laser cutting process and the theoretical shape of the cutting gap [5]: v_C - laser beam speed, v_g - flowing gas speed, δ_f, u_τ - respectively thickness and velocity of liquid in the boundary layer caused by gas flow, δ_p, u_p - respectively liquid thickness and velocity due to pressure gradient, δ_s - thickness of boundary layer.

Laser beam can cut anything. From materials of natural origin (wood, leather, stone, etc.), through metal alloys (ferrous and non-ferrous, pure metals) to all kinds of plastics and laminates. The only limitation is a quality restriction that determines the maximum cutting thickness of a given material. In turn, the type of cut material affects the choice of a laser cutting method.

Laser cutting methods

There are five main laser cutting methods separated in the scientific literature [8], [9]. There are methods descriptions below with examples of treated materials.

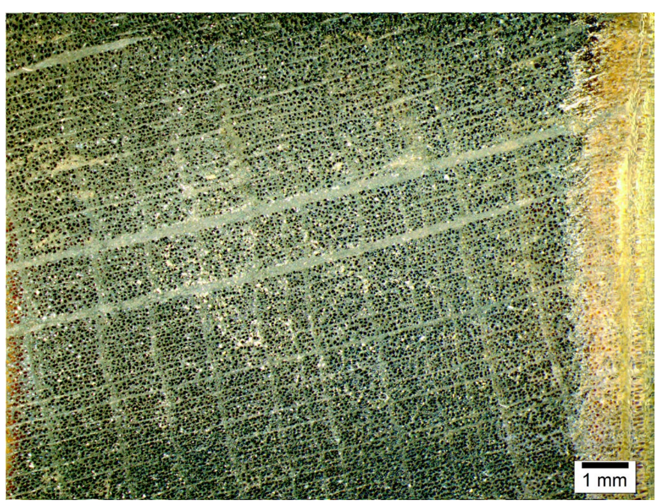

Fig. 2. View of wood cut edge - 13 mm thick. CO_2 laser, working gas: air, working gas pressure: p=2 bar, power: P=1500 W, cutting speed v=2,0 m/min

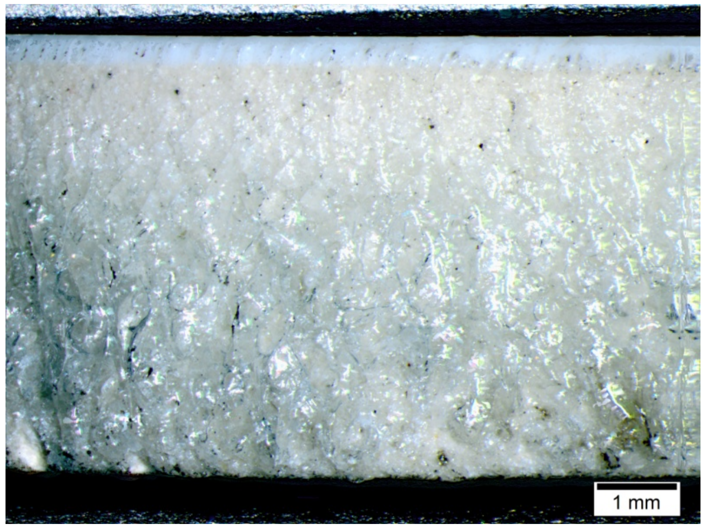

Fig. 3. View of ceramic tile cut edge - 5,0 mm thick. CO_2 laser, working gas: air, working gas pressure: p=1,5 bar, power: P=1200 W, cutting speed v=1,0 m/min

They are as follows:

1. Vaporization cutting - in this method, the material exposed to a focused laser beam is heated to the boiling point, which in consequence leads to its transition from solid to gaseous state. The material evaporates under an inert gas atmosphere. This method is used to cut materials with low thermal conductivity and non-melting materials, such as wood, leather, some plastics and others – Fig.2 and Fig.3.
2. Melt and blow cutting - due to the high power of a laser beam, the material transits from solid to liquid state. Then, due to the high flow pressure of working inert gas, the liquid material is removed from the cutting gap. Due to the fact that this method does not burn the material, the cutting surface is free of oxides. This method is applied for treatment of high-alloy corrosion resistant and stainless steels, aluminum alloys, nickel, titanium, tantalum, and zirconium – Fig.4…Fig.7.

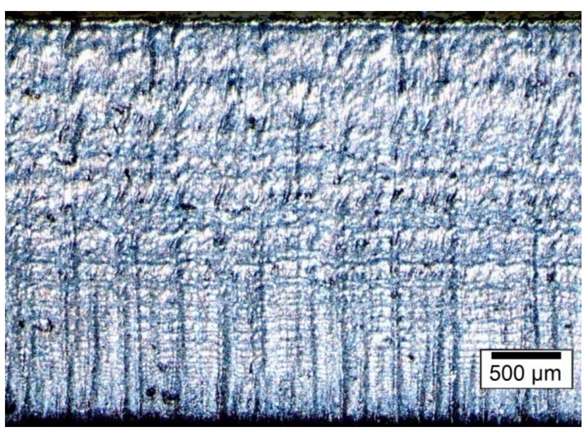

Fig. 4. View of PA6 aluminum alloy cut edge - 3,0 mm thick. CO_2 laser, working gas: N_2, working gas pressure: p=14 bar, power: P=5000 W, cutting speed v=2,5 m/min

3. Reactive cutting - a type of laser cutting in which additional energy is supplied by active gas - oxygen. The material under the action of a focused laser beam is burned out by a stream of oxygen or a mixture of gases containing oxygen in a sufficiently high concentration. The extra

energy from the exothermic reaction allows for cutting materials with less laser radiation power, less working gas volumetric flow and higher process speed. This type of cutting is mainly used for carbon and low alloy steels, some plastics, rubber, quartz, etc. - Fig. 8.

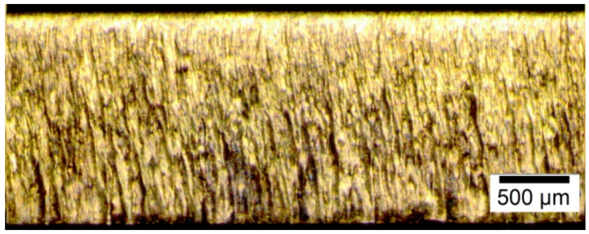

Fig. 5. View of MO58 brass cut edge - 1,5 mm thick. CO_2 laser, working gas: N_2, working gas pressure: p=15 bar, power: P=4000 W, cutting speed v=5,3 m/min

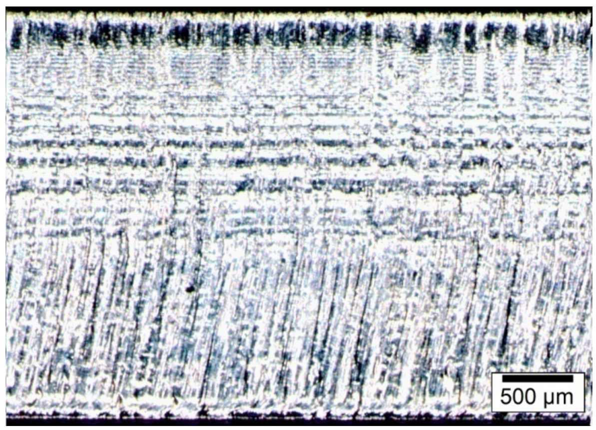

Fig. 6. View of X5CrNi18-10 stainless steel cut edge - 3,0 mm thick. CO_2 laser, working gas: N_2, working gas pressure: p=17 bar, power: P=4000 W, cutting speed v=4,0 m/min

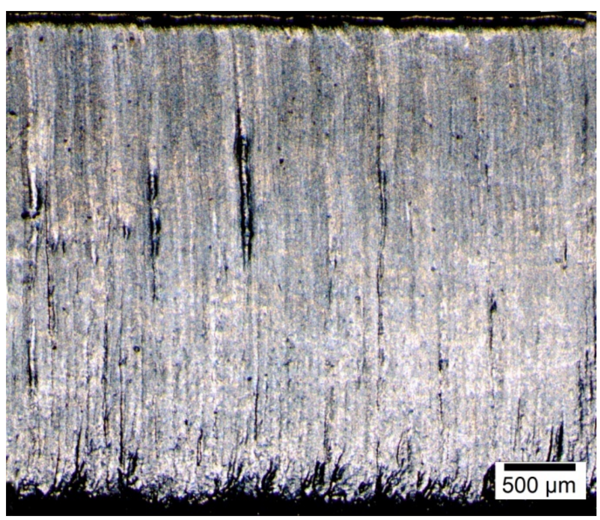

Fig. 7. View of K303 powder steel cut edge - 3,0 mm thick. CO_2 laser, working gas: N_2, working gas pressure: p=8 bar, power: P=3600 W, cutting speed v=3,3 m/min

4. Notching can be considered as a hybrid cutting method. In the first phase, as a result of laser beam action, the material is incised or hollowed out in a series of small holes arranged in a straight line. In the second phase, the material is mechanically broken off. In this case, the

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incise or series of holes act as a notch. This type of cutting is mainly used for brittle materials (e.g. ceramics), laminates (e.g. used for the production of printed circuit boards) and plastics.

5. Cold cutting may occur due to the interaction of laser radiation with matter, resulting in chemical degradation of molecular bonds. As a result, the material loses its integrity here. This process takes place without temperature. This type of cutting is used for special plastics and organic materials. Photochemical ablation (also called cold ablation) is another type of cold cutting. It is a transition of material from solid to gaseous state bypassing the liquid phase. In this process, sufficiently high laser radiation energy leads to the disruption of interatomic bonds of the material, and limited thermal effects appear only on boundary zones of the laser beam impact on the material.

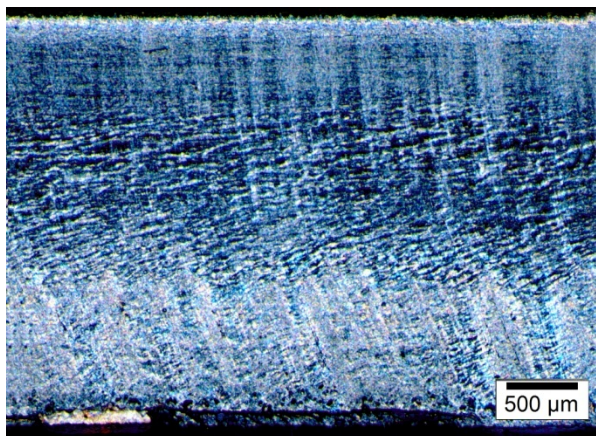

Fig. 8. View of 50HF spring steel cut edge - 3,0 mm thick. CO_2 laser, working gas: O_2, working gas pressure: p=1 bar, power: P=1800 W, cutting speed v=3,6 m/min

Depending on the cutting method, a suitable gas with sufficient pressure is applied. Examples of materials and types of gases used to cutting are shown in Table 1.

Table 1. Commonly used types of working gases applied for cutting typical construction materials and examples of pressure values.

Gas	air (p=0,5÷2 bar)	oxygen (p=0,5÷1 bar)	nitrogen (p=8÷20 bar)	argon (p=8÷20 bar)
Material	plastics, wood, composites, ceramics, rubber, quartz, aluminum	carbon and low-alloyed steels, copper alloys	austenitic steels, high-alloy steels, powder steels, aluminum alloys, nickel alloys	titanium alloys, silicon carbide zirconium alloys (zircaloy), tantalum alloys

Summary

The choice of a laser cutting method depends primarily on the type of material, but has an equally significant impact on the edge quality of the material being cut. Therefore, in this case the ratio of cut quality to process costs is the most reasonable criterion. In this case, the expense is working gas.

The cheapest solution is cutting with air shielding. Due to the high nitrogen content, this gas can be used in the melt and blow method. However, due to the oxygen content, the formation of oxides on the cutting edges of metal alloys cannot be avoided. Therefore, air is generally used in the vaporization cutting method as a shielding gas, and the materials are not sensitive to the negative effects of oxygen.

Cutting in pure oxygen (reactive cutting) allows for applying lower laser power and lower working gas expenditure compared to cutting with nitrogen (melt and blow). Oxygen consumption can be up to ten times lower than nitrogen consumption. This affects the treatment costs – the melt and blow method is about twice as expensive. Unfortunately, due to the fact that oxygen is highly reactive, it is not suitable for cutting some materials, e.g. titanium alloys. An oxide film appears on the cutting edges, which is undesirable in some applications. For example, cutting structural carbon steels intended for direct galvanizing or welding should be carried out in an inert atmosphere. Oxides formed on the edges, if not removed, will cause the zinc layer to fall off and may lead to welding incompatibilities.

Remark

The figures of cut edges of various materials presented in this paper are the result of research and were made by the author of this publication.

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