# The laser cutting process.

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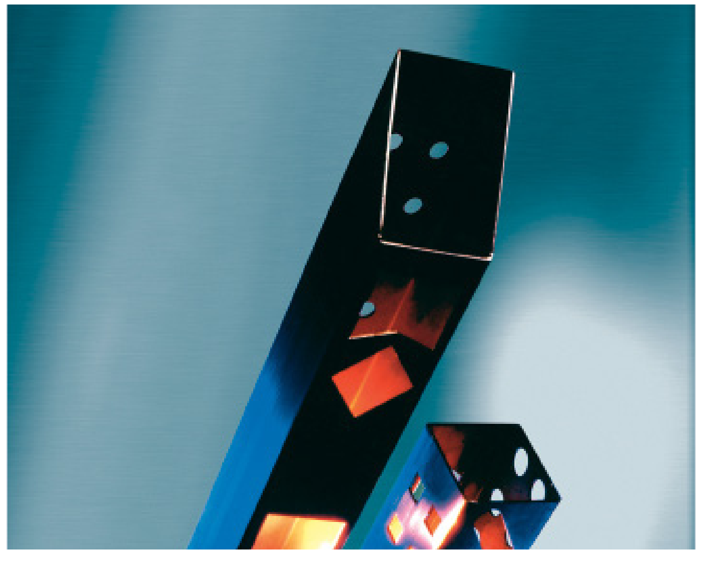
# Contents.







# Introduction.



Over the past decade, laser cutting has developed into state-of-the-art technology. It is estimated that more than 40,000 cutting systems are used for the high-power cutting of metals and non-metals worldwide. When including low-power applications, such as plastics cutting and paper cutting, the numbers are even higher.

Impressive examples of modern laser cutting applications are:

- → Cutting of hydro-formed parts and tubes
- → High-speed cutting of thin sheet metal
- → Cutting of thick-section material

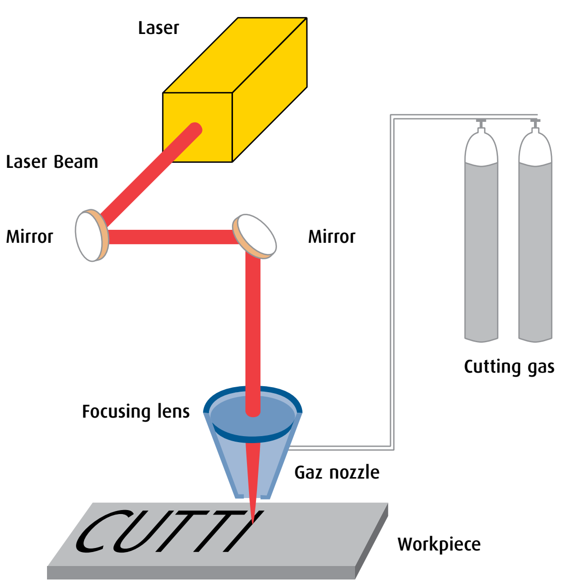
Developing lasers with higher output powers without sacrificing beam quality has been one important goal in the past. Other efforts focused on improving the drive technology of the motion system and enhancing material handling around the cutting table.

Predictions are that laser cutting based on improved cutting speeds, little tool wear and unlimited flexibility will further replace competing technologies. There are market surveys suggesting that the number of flatbed laser cutter installations will double over the next ten years. In addition, laser manufacturers will address new markets, such as cutting tubes and pipes.

The gases used to generate the laser beam and expel the molten metal out of the cut kerf are important consumables during laser operations. They can prolong the lifetime of the optical component, increase the cutting speed and improve the cutting quality. All of the above contribute to more profitable laser operation. It is therefore the objective of this technical information to familiarise potential users of laser cutting systems with the technology and to provide guidelines for proper use of the cutting gases. Many of the results presented in this technical information were obtained in projects carried out in the application lab of Linde or in projects that were initiated and sponsored by Linde.

# The laser cutting process.

Fig. 1: Principles of a laser cutting system (schematic)




## Types of cutting processes

An almost parallel laser beam, which is usually invisible, is generated in the laser source and directed to the cutting head by mirrors, where it is concentrated (focused) by a lens on a small spot (fig. 1). Depending on the process, the spot is placed on the surface of the workpiece or on the material to be cut (fig. 1, see also the technical information: "Lasers for industrial applications").

The intense light beam quickly heats up the workpiece and melts the material. The assist gas (also called cutting gas) is applied to protect and cool the focusing lens and to remove the molten metal from the cut kerf at the same time. There are two cutting processes, depending on the type of assist gas used:

- When cutting with oxygen, the material is burned and vaporised after being heated up to ignition temperature by the laser beam. The reaction between the oxygen and the metal actually creates additional energy in the form of heat, which supports the cutting process. These exothermic reactions are the reason why oxygen enables penetration of thick and reflective materials when it is used as a cutting gas.

- When cutting with non-reactive (inert) gases such as nitrogen or argon, the material is melted solely by the laser power and blown out of the cut kerf by the kinetic energy of the gas jet. As non-reactive gases do not react with the molten metal, and no additional heat is generated, the laser power required is usually much higher than in oxygen cutting of the same thickness. Cutting with non-reactive gases is often referred to as clean cutting or high-pressure cutting.

Vaporisation cutting is another cutting process. In vaporisation cutting, the solid material is converted into vapour without passing through a liquid phase. Gases can be used to support the process, remove vapour and shield the cutting optics.

In "cold" cutting, the energy of the laser beam breaks the chemical bonds of the material to be cut, thereby producing powdery residues. Laser beam energy and chemical bond energy must match, and cutting gas is often not needed.

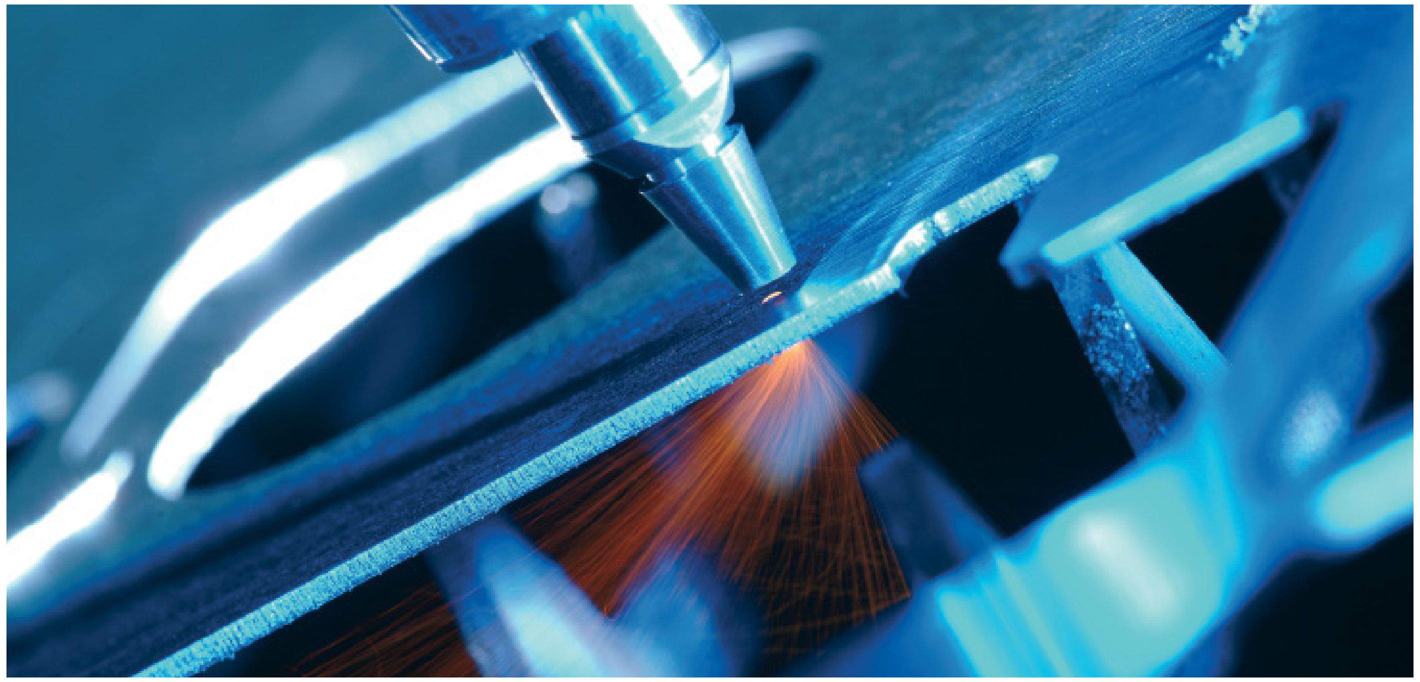
## Lasers for laser cutting

Many lasers can be used for laser cutting, provided their beam can be focused on a small spot with sufficient intensity to melt the material and their specific wavelength is absorbed by the material. $CO_2$ and excimer gas lasers as well as solid-state lasers, such as Nd:YAG and Yt:YAG lasers, are the most commonly used in the field of materials processing.

Diode lasers, as another example of solid-state lasers, do not provide similar beam quality and intensity and may be used for the cutting of non-metallic materials.Types of cutting processes.



# Parameters in laser cutting.



## Continuous wave (cw) or pulsed laser operations

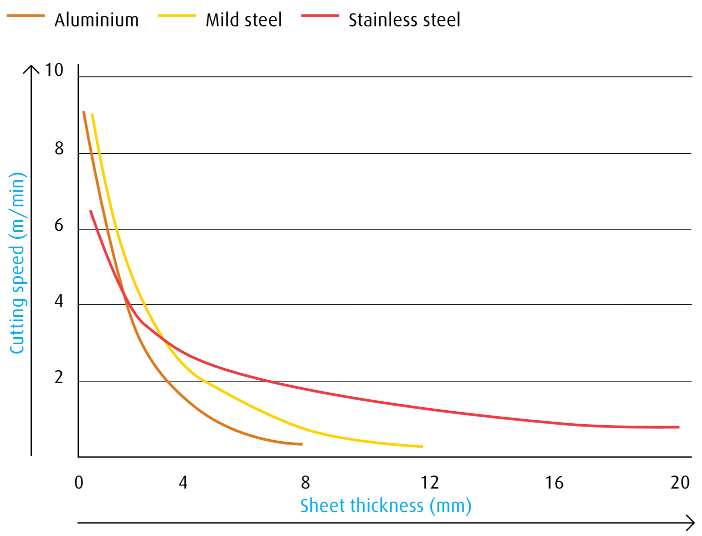
The highest cutting speeds can be obtained at high power levels in cw-mode operation. Continuous wave (cw) means that the laser power output is constant, without interruption over time.

At high speeds, the laser power is used almost entirely to melt or vaporise the material on the cut front and there is relatively little heat conduction into the base material. However, some of the heat is conducted into the base metal when the cutting direction is reversed or when cutting around a sharp corner. This reduces the feed rate and causes the workpiece to heat up, with the effect that cutting quality deteriorates.

When cutting filigree structures or piercing holes into thicker materials, it can be especially difficult to achieve acceptable cutting qualities with a high-power cw laser. Pulsed processing can produce better cuts under such circumstances. High peak power in the short pulses ensures efficient heating with an effective removal of hot material from the kerf while low average power keeps the workpiece cool.

The cutting speeds obtainable in pulsed cutting are much lower than with continuous wave (cw) laser beams. Average power normally has to be reduced to some hundred watts in order to achieve a significant increase in cutting quality by pulsing. This often results in cutting speeds that are only 10 % of those obtainable in the cw mode. When cutting metallic materials, the peak power generally must be within a range of 1 to 10 kilowatts, and each pulse must be long enough to melt a layer of the cutting front, which is typically 1–3 milliseconds.

Fig. 2: Typical cutting rates with approximately 3 kW of laser power




## Laser power and intensity

Lasers are usually described in terms of power, e. g. 1,000 watts or 6 kW. Laser power is the total energy emitted in the form of laser light per second. The intensity of a laser beam is equal to its power divided by the area over which the power is concentrated.

For example, focusing a 1-kW laser beam over a diameter of 0.1 mm (0.004 in) will result in a power density of approx. 125 kW per mm$^2$.

The high intensity causes the material to heat up rapidly, so that little time is available for heat to dissipate into the surrounding material. This produces high cutting rates and an excellent quality of cut.

$$\text{Intensity} = \frac{\text{Laser power}}{\text{Irradiated area}}$$

A laser's intensity also determines the thickness that can be cut. The thicker the material to be cut, the higher the intensity needed. Higher intensities can be reached by increasing laser power or by using a focusing lens with a shorter focal length. However, focusing the beam onto a smaller spot also reduces the depth of focus and is therefore unsuitable for cutting thick materials.

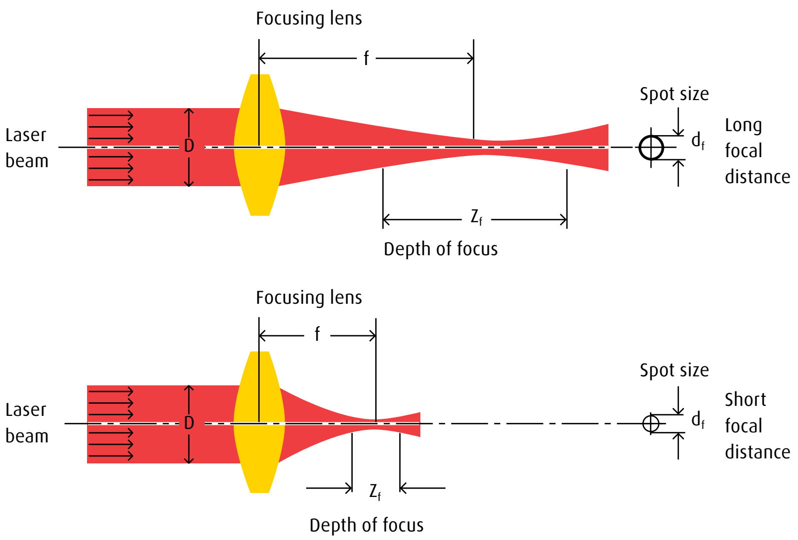
High intensity can be achieved both in pulsed and continuous beams. Accordingly, either the peak pulse power in pulsed cutting or the average power in continuous cutting determines the penetration.

Cutting speed, however, is determined by the average power level. The higher the average power, the higher the cutting speed (fig. 2). The intensity of $CO_2$ and fibre lasers can be very high, allowing continuous vaporisation cutting of thin materials. Metals with a thickness of 1–1.5 mm are cut at speeds in excess of 10 m/min. Cutting gas is used to remove metal vapour and to protect the focusing optics. As the reaction time is very short, the kind of gas is not important and therefore compressed air is sufficient.

Fibre lasers provide excellent focus ability even over long distances. This is used in cutting-on-the-fly where scanner optics are used to quickly move the laser beam across the material to be cut. Cutting gas is not used as it cannot be applied over long distances and the material is evaporating spontaneously.



Fig. 3: Focusing a laser beam




## Focal length of the lens

The focal length of the lens defines the shape of the focused laser beam. The minimum spot size ($d_f$) is a function of wavelength (λ), beam mode (K), the diameter of the unfocused beam (D) at the lens and the focal length of the lens (f) according to:

$$d_f = \frac{4\lambda}{\pi} \times \frac{f}{D} \times \frac{1}{K}$$

A small spot diameter is favoured by:

→ Short focal length (f)

→ Good mode = even intensity distribution (close to Gaussian, K = 1/M$^2$ = 1)

→ Short wavelength of the laser beam (λ)

→ A large beam diameter at the lens (D)

The depth of focus $Z_f$, which defines the level of tolerance for variation of the distance from the lens to the workpiece as well as the thickness that can be cut, depends on the same parameters. In general, a small spot size goes along with a short depth of focus.

This means that a lens with a short focal length produces a small spot size and a short depth of focus, generally resulting in high speed and good cutting quality of thin sheet metal. However, careful control of the distance between the lens and the workpiece (lens working distance) is necessary. When thicker materials are cut, the depth of focus must be adapted to the material's thickness by selecting a longer focal length (fig. 3). As the longer focal length also results in greater focal spot power, it must be increased in order to maintain intensity and cutting speed.

**Fig. 4: Intensity distribution across the laser beam**

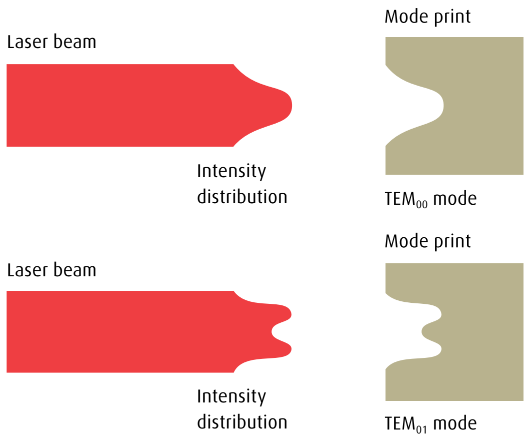



**Fig. 5: Absorption as a function of wavelength for different materials**

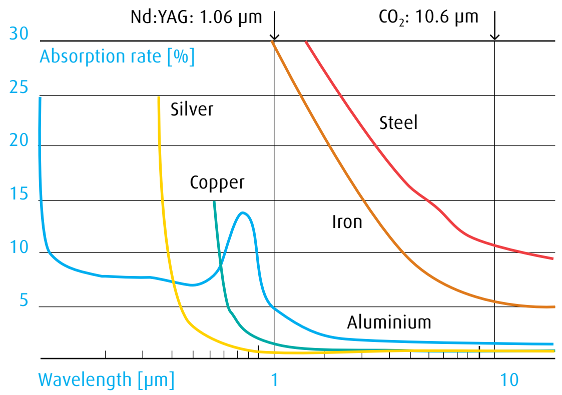
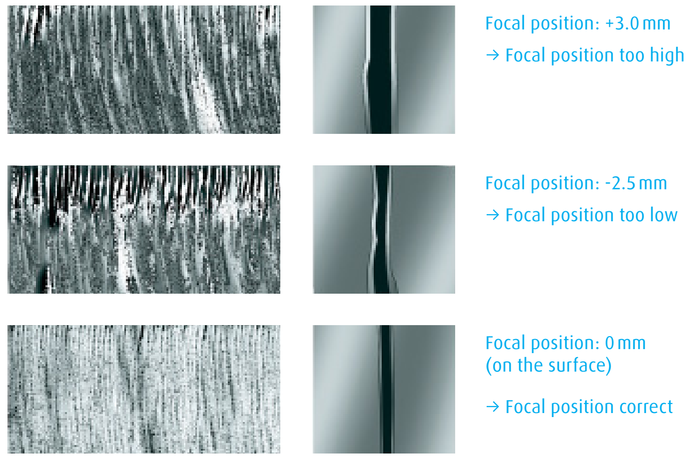



**Fig. 6: Effect of focal position on cutting performance**




## Laser beam mode

A laser beam's mode refers to the distribution of energy through its cross section (fig. 4, see also the technical information: "Lasers for industrial applications"). The mode affects the cutting process, because:

- It affects the size of the focused spot and the intensity of the focused beam.
- It affects the intensity distribution in the beam and focus and, as a result, the cut quality.

A good mode is therefore essential in laser cutting. The best mode is Gaussian intensity distribution, which is required for optimum focusing properties. The Gaussian mode is often termed TEM$_{00}$ (Transverse Electromagnetic Mode of the zero order).

## Wavelength of the laser beam

The absorption by the material being cut depends on the wavelength of the laser beam (fig. 5). The absorption rate of $CO_2$ laser radiation in cold steel, for example, is approx. 11 %, with the effect that 89 % of the radiation is reflected. The absorption rate of Nd:YAG radiation, on the other hand, is approximately 30 %. The high initial reflectivity of many metals can be overcome by both Nd:YAG and $CO_2$ lasers, provided the intensity of the focused beam is sufficiently high. The absorption rate increases remarkably as the temperature of the material rises. To give another example, glass cannot be cut with laser light of visible or near-infrared (Nd:YAG laser) wavelength, as it is transmitted through the glass without any energy absorption.

While some highly reflective materials (e. g. aluminium or copper) might absorb some wavelengths better than others, a specific type of laser is generally more suitable for a specific application than others. Suitability usually depends on other laser parameters, such as peak power, pulse length and focus ability, rather than wavelength characteristics. Therefore, if for example Nd:YAG lasers are claimed to cut with better quality or more precision than $CO_2$ lasers, this is true only when comparing pulsed Nd:YAG lasers with cw $CO_2$ lasers.

## Focal position relative to the workpiece

The small spot size obtained by focusing the laser beam provides high intensities for material treatment. Above and below the focus, the intensity in the beam drops. The depth of focus expresses how quickly the beam becomes wider and the intensity drops. A shorter focal length results in a smaller spot size and a smaller depth of focus.

Generally, the focal point must be positioned accurately with reference to the surface of the workpiece, and the position must be kept constant during processing.

The beam waist or focus (the point where the beam diameter is smallest) should either be located on the surface of the workpiece (when using oxygen as a cutting gas, see fig. 6) or up to 75 % of the material thickness of the workpiece. The sensitivity of focusing is less in high-power lasers than in lower-power ones. The sensitivity to focal positioning is also greater in some materials than in others.

However, the focal position is a parameter that must be controlled in order to ensure optimum cutting performance. Also:

- Variations in material and thickness may require alterations of focus.
- Variations in the laser beam shape or the mode and changes in the temperature of the cooling water and contamination on the lens may change the focal position.

**Fig. 7: Nozzle geometry definitions and stand-off distance**

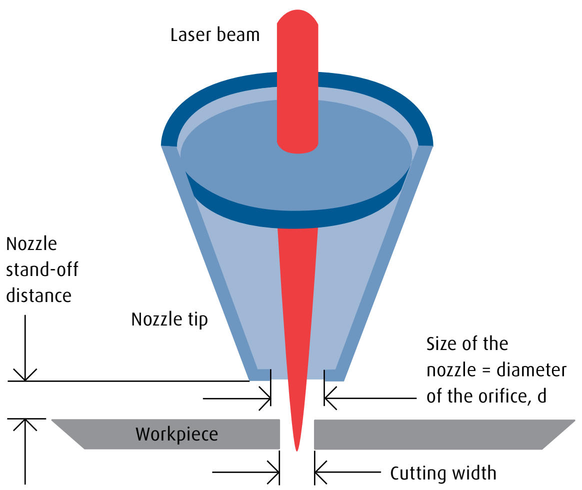
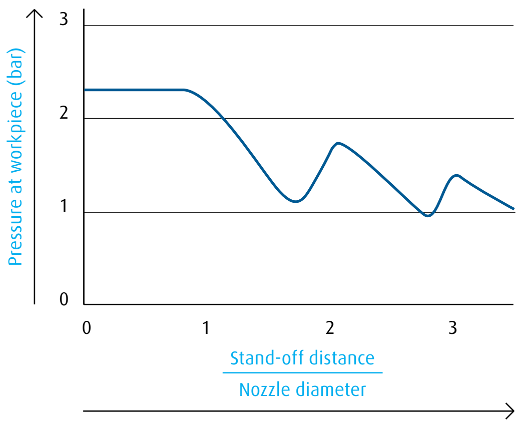



**Fig. 8: Effect of nozzle parameters on effective cutting gas pressure**




## Nozzle size and stand-off distance

Gas assistance is essential in laser cutting. Therefore, nozzle geometry and stand-off distance are important. Nozzle design and flow dynamics through the nozzle differ substantially from other thermal cutting processes (fig. 7). This is mainly due to the compactness and diameter of the nozzle, which is always larger than the kerf produced below it. As a result, only a portion of the gas jet formed by the nozzle penetrates the kerf.

Nozzle stand-off distances depend on the design of the nozzle. The stand-off distance for standard nozzles used in laser cutting applications should be smaller than the diameter of the nozzle, as turbulence and pressure variations may appear in the cutting gas jet with larger distances (fig. 8). At short nozzle stand-off distances, the kerf itself acts as a nozzle and the geometry of the nozzle tip is not so critical. If large nozzle stand-off distances are required, great care must be taken in designing the nozzle tip, especially when the nozzle pressure exceeds 2–3 bar (30–45 psi).

Typical nozzle diameters are in the range of 0.8–3 mm (0.03–0.12 in), so that the nozzle stand-off distance should be in the range of 0.5–1.5 mm (0.02–0.06 in) for the best cutting results.



## Gas type and gas pressure

The cutting gas used is crucial to the cutting result. Oxygen generally yields good cutting performance in carbon steels and low-alloyed steels. However, oxygen reacts with the base metal, and the cut edge is covered with an oxide layer. These are the reasons why high-alloy steels are being cut with nitrogen more and more often whenever sufficient laser power is available.

Nitrogen is also being used increasingly for parts that are subsequently powder-coated. Any oxides on the cut edge decrease the bond between the coating and the material, and may therefore result in corrosion problems (see reference 1, page 19).

The change from oxygen to nitrogen as a cutting gas requires additional changes in the set-up of the machine. The following rules of thumb apply to the cutting pressure:

Recent developments in the laser industry have led to cutting lasers with output powers of up to 8 kW. As a result, more and more businesses are changing over to nitrogen for cutting stainless steels and other high-alloy materials. As there are no exothermic reactions supporting the laser process, cutting gas pressure increases with increasing material thickness.

As the focusing lens is an integral part of the gas chamber, its strength limits the gas pressure, which may not exceed 12 bar (175 psi) in older machines, depending on lens material and dimensions. Modern cutting machines, however, are equipped with thicker cutting lenses, allowing considerably higher cutting gas pressures of 20 bar and higher, which are required for cutting thick-section stainless steel.

The following section deals with common materials and their specific cutting parameters.

### General rule for cutting mild steel with oxygen:

→ The thicker the material, the lower the pressure
→ Maximum pressure at approx. 6 bar (90 psi)

### General rule for cutting stainless steel with nitrogen:

→ The thicker the material, the higher the pressure
→ Minimum pressure at approx. 8 bar (120 psi)

# Pressure and volume requirements for different materials.

**Table 1: Parameters for laser cutting of mild steels with laser-cutting oxygen including pressure and volume requirements**

| Material thickness mm (in) | Laser power W | Nozzle stand-off mm (in) | Nozzle diameter mm (in) | Oxygen pressure bar (psi) | Gas volume $m^3/h$ (scf/h) | Cutting speed m/min (in/min) |
|---|---|---|---|---|---|---|
| 0.5 (0.02) | 500 | 0.3–0.6 (0.01–0.02) | 0.6–0.8 (0.03–0.04) | 3.5–6.0 (50–90) | 2.0 (70) | 15.0 (600) |
| 1.0 (0.04) | 800 | 0.3–0.6 (0.01–0.02) | 0.6–0.8 (0.03–0.04) | 3.5–6.0 (50–75) | 1.8 (64) | 11.0 (440) |
| 2.0 (0.08) | 1,000 | 0.3–0.8 (0.01–0.03) | 0.6–1.2 (0.03–0.05) | 2.5–4.0 (35–60) | 3.0 (105) | 7.0 (280) |
| 4.0 (0.16) | 1,000 | 0.3–0.8 (0.01–0.03) | 0.6–1.2 (0.03–0.05) | 2.0–4.0 (30–60) | 2.7 (95) | 4.0 (160) |
| 6.0 (¼) | 1,000 | 0.5–1.0 (0.02–0.04) | 1.0–1.5 (0.04–0.06) | 1.5–3.0 (20–45) | 3.2 (115) | 2.5 (100) |
| 8.0 (0.32) | 1,500 | 0.5–1.0 (0.02–0.04) | 1.2–1.5 (0.05–0.06) | 1.5–2.5 (20–35) | 3.0 (105) | 2.0 (80) |
| 12.0 (½) | 1,500 | 0.5–1.0 (0.02–0.04) | 1.2–1.5 (0.05–0.06) | 1.0–2.0 (15–30) | 2.4 (85) | 1.0 (40) |
| 18.0 (¾) | 2,000 | 0.5–1.0 (0.02–0.04) | 1.2–1.5 (0.05–0.06) | 0.5–1.0 (7–15) | 1.4 (50) | 0.5 (20) |
| 25.0 (1.0) | 4,000 | 0.5–1.0 (0.02–0.04) | 1.5–2.0 (0.06–0.08) | 0.5–0.7 (7–10) | 1.3 (46) | 0.5 (20) |
| 25.0 (1.0) | 6,000 | 0.5–1.0 (0.02–0.04) | 2.0–2.3 (0.08–0.09) | 0.5–0.7 (7–10) | 1.5 (52) | 0.9 (36) |
| Note | Oxygen pressure and volume are higher compared to cutting of mild steel. The listed values are indicative and may vary depending on the cutting system. | | | | | |

## Mild steel and low-alloy steel

Oxygen cutting with $CO_2$ lasers is the most common method for cutting flat-stock mild steels and low-alloy steels. Hollow profiles and tubular structures, such as those used in the car industry, are often cut with Nd:YAG lasers manipulated by robots.

Today, plates with a thickness of up to 25 mm (1 in) can be cut easily with laser powers of up to 6 kW. The focal point is positioned close to the upper surface of the workpiece. Table 1 contains a guideline for the most important parameters. Fig. 10 surveys the gas consumption. The cutting tables in this technical information should only be regarded as guidelines. Deviations may occur, depending on type of laser, beam delivery system, nozzle arrangements and focus conditions. This applies particularly to the cutting of profiles. Here, cutting speed is often much lower than indicated in the cutting tables, because the motion system (i. e. robot) cannot follow the contours quickly enough.

A lens with a focal length of 127 mm (5 in) may be used when cutting sheets of plate material of up to 6 mm (¼ in). A 190-mm (7.5 in) lens should be used for material thicknesses of over 6 mm (¼ in).

Laser power of at least 3 kW or higher is required when cutting plates with thicknesses of 12–25 mm (0.5–1.0 in). Cutting oxygen pressure is generally under 1 bar (14.7 psi), and the nozzle diameter is larger, 2–3 mm (0.08–0.12 in). The focus point may be situated 1–3 mm (0.04–0.12 in) above the upper surface of the workpiece.

Purity of oxygen is an important parameter when cutting mild steels and low-alloy steels (see reference 2, page 19). The cutting speed can be increased by using higher-purity oxygen (99.9 %–99.95 %) rather than standard oxygen purity (99.5 %, see fig. 9).

Cutting speed can be increased by 10–30 %, depending on material thickness and types of steel, although the productivity gain depends largely on the nature of the parts being produced. The positive effect is greater when cutting larger parts with simple geometry than when cutting complicated shapes, where cutting speed is limited by the capacity of the mechanical steering system rather than the cutting process itself.



**Fig. 9: Effect of oxygen purity on the cutting speed for 1-mm mild steel using 800 W laser power and cutting oxygen pressure of 3 bar**

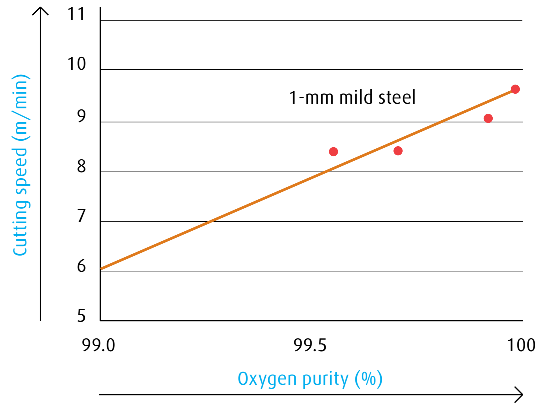
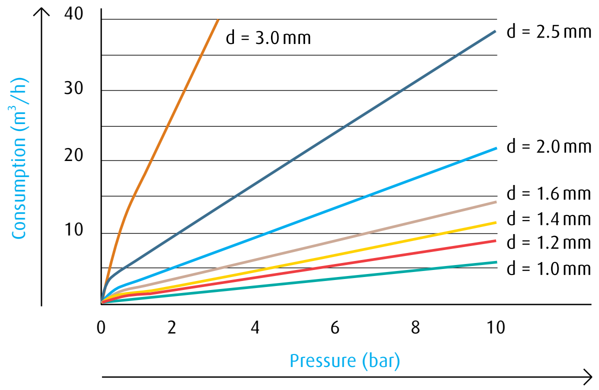



**Fig. 10: Consumption of oxygen depending on the gas pressure in the nozzle and the size of the nozzle, d**




During oxygen cutting of mild and low-alloy steels, a thin oxide layer is formed on the cut surface. In most cases, this does not cause any problems. However, it may lead to difficulties if the cut parts are to be painted or powder-coated, in which case paint adhesion and, consequently, corrosion protection may be insufficient. Here, high-pressure nitrogen cutting can be used as an alternative to obtain oxide-free cuts. When cutting thick materials, however, the cutting speed is reduced. Modern high-power lasers allow for the same cutting speeds and sometimes even higher cutting speeds when cutting thin material (thickness less than 0.08 in).

The surface condition of mild and low-alloy steels is important in laser cutting. Oxygen cutting of sheets with rust, for example, may cause dross and notches. Likewise, painted surfaces can also cause problems. This applies particularly to sheets coated with zinc primers and iron oxide shop primers. During oxygen cutting, problems only occur when the paint layer faces the gas nozzle. The cuts then often exhibit dross and notches.

These problems do not occur when the paint layer is on the lower side of the sheet. The problems with painted sheets can be avoided by using high-pressure nitrogen cutting, although the cutting speed will, of course, be lower.

Zinc-coated mild steels, galvanised or hot-dipped, cause considerable problems when cutting with oxygen. There is always dross formation and the cut surfaces may be quite rough. High-pressure nitrogen cutting is therefore used in industry to cut zinc-coated steels. The cutting quality is acceptable and free of adhering dross.

**Table 2: Parameters for laser cutting of stainless steel with laser-cutting oxygen including pressure and volume requirements**

| Material thickness mm (in) | Laser power W | Nozzle stand-off mm (in) | Nozzle diameter mm (in) | Oxygen pressure bar (psi) | Gas volume $m^3/h$ (scf/h) | Cutting speed m/min (in/min) |
|---|---|---|---|---|---|---|
| 0.5 (0.02) | 1,000 | 0.3–0.6 (0.01–0.02) | 0.3–0.6 (0.01–0.02) | 4.0–6.0 (60–90) | 5.0 (175) | 15.0 (600) |
| 1.0 (0.04) | 1,000 | 0.3–0.6 (0.01–0.02) | 0.3–0.6 (0.01–0.02) | 4.0–6.0 (60–90) | 5.0 (175) | 11.0 (440) |
| 2.0 (0.08) | 1,000 | 0.3–0.8 (0.01–0.03) | 0.3–0.6 (0.01–0.02) | 4.0–6.0 (60–90) | 5.0 (175) | 7.0 (280) |
| 4.0 (0.16) | 1,500 | 0.3–0.8 (0.01–0.03) | 0.3–0.6 (0.01–0.02) | 4.0–5.0 (60–90) | 7.0 (250) | 3.0 (120) |
| 6.0 (¼) | 1,500 | 0.3–0.8 (0.01–0.03) | 0.5–0.8 (0.02–0.03) | 3.5–5.0 (50–75) | 7.0 (250) | 0.6 (24) |
| 9.0 (3/8) | 1,500 | 0.5–1.0 (0.02–0.04) | 0.5–0.8 (0.02–0.03) | 3.5–4.0 (50–60) | 5.5 (195) | 0.3 (12) |
| Note | Oxygen pressure and volume are higher compared to cutting of mild steel. The listed values are indicative and may vary depending on the cutting system. | | | | | |

## Stainless steels and other high-alloy steels

In industry, both oxygen and nitrogen are used as cutting gases for stainless steel and other high-alloy steels.

High cutting speeds are possible when using oxygen, due to the exothermic energy contribution. The maximum thickness today is 16–18 mm (¾ in). The optimal focal position is situated at or just below the upper surface of the sheet. By contrast, with mild steels, relatively high oxygen pressure – approx. 5 bar (75 psi) – is also advantageous when cutting thicker sheets. Greater oxygen purity (99.90–99.95 %) than standard oxygen purity (approx. 99.5 %) can be used to increase the cutting speed. A cutting table for laser cutting of stainless steel with oxygen is shown in table 2.

The disadvantage of oxygen cutting is that the cuts always exhibit burrs and that the cut surfaces are discoloured due to chromium and iron oxide (see reference 3, page 19). These oxides obstruct the subsequent welding procedure. TIG welds, for example, have black oxide spots on the root side, which sometimes cause incomplete penetration. Beyond that, the oxidised cut surface facilitates corrosion of the cut edges. These drawbacks in oxygen cutting are serious, as they often require expensive finishing operations.

Oxide-free and burr-free cuts can be obtained by high-pressure nitrogen cutting, although the cutting speed must be reduced considerably compared to oxygen cutting. Higher cutting speeds can be used with higher-power lasers. $CO_2$ lasers with a power of at least 2.5 kW are commonly used for this application. Today, the maximum sheet thickness range where burr-free cuts are possible is about 12–16 mm (0.50–0.64 in).

During high-pressure nitrogen cutting, the focal point should be close to the back surface of the sheet in order to assure burr-free cuts. The kerf then becomes wider, so that a larger part of the nitrogen flow can penetrate into the kerf and flush out the molten material. The lower focal position results in a larger cross-section of the laser beam inside the gas nozzle than in oxygen cutting (see fig. 11). The diameter of the nozzle must also be enlarged in order to allow the laser beam to pass through the nozzle without being clipped. A nozzle diameter of at least 1.5 mm (0.05 in) is usually required for high-pressure nitrogen cutting.

Table 3 contains a cutting table for high-pressure nitrogen cutting of stainless steel. Fig. 12 examines the gas consumption.

The purity of the cutting nitrogen has little effect on the cutting speed, at least as long as the nitrogen purity is better than 99.5 %. Even small amounts of oxygen impurity, however, have an oxidising effect. In stainless steel, this means a discolouration of the cut surface. Corrosion resistance of the workpiece may also be impaired. The oxygen impurity level would have to be below 20 ppm (0.002 %) in order to avoid all traces of oxidation. This specification, however, is desirable during laser cutting of stainless steel, but is normally not required in other industrial applications.

The oxygen impurity level is important when using gaseous nitrogen in cylinders or bundles as there are various purity grades available. On the other hand, the use of liquid nitrogen in tanks, which generally has a very low impurity level, does not lead to discolouration of cut surfaces.



**Table 3: Parameters for laser cutting of stainless steel with laser-cutting nitrogen including pressure and volume requirements**

| Material thickness mm (in) | Laser power W | Nozzle stand-off mm (in) | Nozzle diameter mm (in) | Nitrogen pressure bar (psi) | Gas volume $m^3/h$ (scf/h) | Cutting speed m/min (in/min) |
|---|---|---|---|---|---|---|
| 1.0 (0.04) | 1,500 | 0.3–0.6 (0.01–0.02) | 1.2–1.5 (0.05–0.06) | 6.0 (90) | 8.0 (280) | 7.0 (280) |
| 2.0 (0.08) | 1,500 | 0.3–0.6 (0.01–0.02) | 1.2–1.5 (0.05–0.06) | 9.0 (135) | 12.0 (420) | 4.0 (160) |
| 4.0 (0.16) | 3,000 | 0.3–0.8 (0.01–0.03) | 2.0–2.5 (0.08–0.10) | 13.0 (195) | 28.0 (990) | 3.0 (120) |
| 6.0 (¼) | 3,000 | 0.5–1.0 (0.02–0.04) | 2.5–3.0 (0.10–0.12) | 14.0 (210) | 52.0 (1,840) | 1.5 (60) |
| 9.0 (3/8) | 4,000 | 0.5–1.0 (0.02–0.04) | 2.5–3.0 (0.10–0.12) | 16.0 (240) | 60.0 (2,120) | 1.0 (40) |
| 12.0 (½) | 4,000 | 0.5–1.0 (0.02–0.04) | 2.5–3.0 (0.10–0.12) | 18.0 (260) | 68.0 (2,400) | 0.5 (20) |
| 20 | 5,000 | 0.5–1.0 (0.02–0.04) | 2.5–3.0 (0.10–0.12) | 22 (320) | 89.1 (3,120) | 0.4 (16) |
| 25 | 6,000 | 0.5–1.0 (0.02–0.04) | 2.5–3.0 (0.10–0.12) | 22 (320) | 89.1 (3,120) | 0.25 (10) |
| Note | The thicker the material, the higher the nitrogen pressure. The listed values are indicative and may vary depending on th cutting system. | | | | | |

**Fig. 11: Focus position for oxygen cutting compared to high-pressure nitrogen cutting**

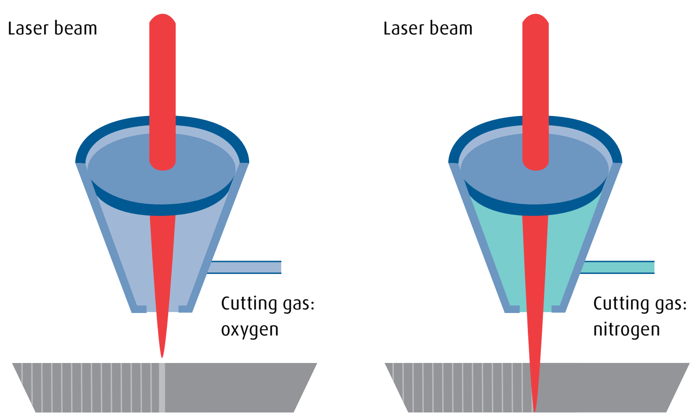



**Fig. 12: Consumption of nitrogen depends on the gas pressure in the nozzle and the size of the nozzle, d**

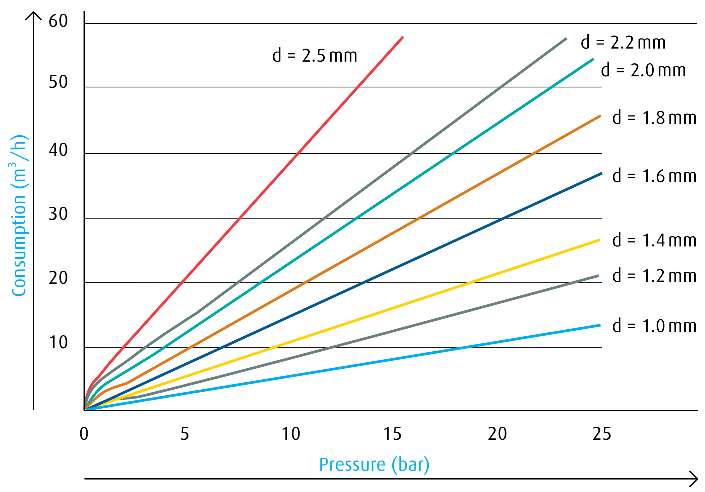
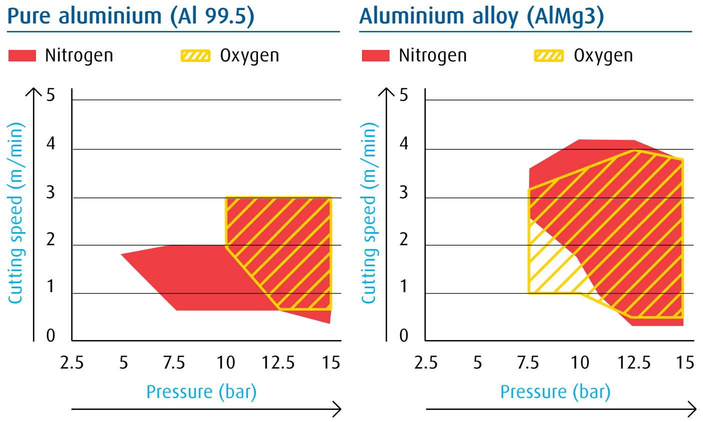


**Fig. 13: Dross-free parameter ranges when using nitrogen and oxygen of up to 15 bar for cutting 2-mm pure aluminium and 2-mm aluminium alloy, laser power: 1,500 W**




## Aluminium and aluminium alloys

“Aluminium” is a term used for both pure aluminium and aluminium alloys. Pure aluminium is soft, and it is often alloyed with small amounts of magnesium, copper, manganese, silicon or zinc to improve its mechanical strength.

Cutting of aluminium with $CO_2$ lasers is considered difficult on account of its high reflectivity and thermal conductivity. Aluminium alloys, however, are usually somewhat easier to cut than pure aluminium and the cutting speed is higher.

Anodised aluminium is also easier to cut, due to enhanced laser light absorption in the thick surface layer of aluminium oxide. High laser power – over 2 kW – and a good laser mode help improve the cutting suitability of aluminium.

A small focal length of about 63 mm (2.5 in) is advantageous for thinner sheets due to the higher power density in the focal spot. The maximum sheet thickness that can be cut is about 6–8 mm (0.24–0.32 in).

Aluminium can be cut with both oxygen and nitrogen as cutting gases, but cutting speed with oxygen is not significantly higher than with nitrogen. This can be attributed to aluminium oxide’s extremely high melting point, which is 2,072 °C (3,762 °F). Solid or viscous aluminium oxide forms a seal on the cut front, which prevents oxygen from penetrating into the metal itself. The oxide seal frequently bursts as a result of turbulent melt flow, and the oxidation reaction may still proceed, although at a lower rate.



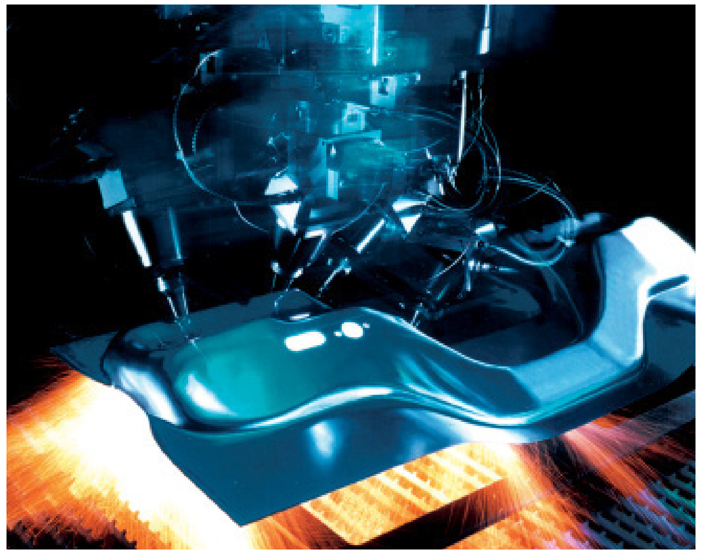
**Table 4: Parameters for laser cutting of aluminium alloy (AlMg3); the table refers to dross-free cuts, cutting gas: laser-cutting nitrogen**

| Material thickness mm (in) | Laser power W | Nozzle stand-off mm (in) | Nozzle diameter mm (in) | Nitrogen pressure bar (psi) | Gas volume $m^3$/h (scf/h) | Cutting speed m/min (in/min) |
|---|---|---|---|---|---|---|
| 1.0 (0.04) | 1,800 | 0.3–0.6 (0.01–0.02) | 1.2–1.5 (0.05–0.060) | 12.0 (180) | 11.0 (390) | 8.2 (320) |
| 2.0 (0.08) | 1,800 | 0.3–0.6 (0.01–0.02) | 1.2–1.5 (0.05–0.060) | 14.0 (210) | 15.0 (530) | 3.6 (140) |
| 3.0 (0.12) | 3,000 | 0.3–0.8 (0.01–0.03) | 1.2–1.5 (0.05–0.060) | 14.0 (210) | 15.0 (530) | 2.5 (100) |
| 4.0 (0.16) | 3,000 | 0.3–0.8 (0.01–0.03) | 1.8–2.2 (0.07–0.085) | 14.0 (210) | 35.0 (1,240) | 1.8 (70) |
| 6.0 (¼) | 4,000 | 0.5–1.0 (0.02–0.04) | 2.0–2.4 (0.08–0.090) | 16.0 (240) | 40.0 (1,410) | 1.8 (70) |
| 8.0 (3/8) | 4,000 | 0.5–1.0 (0.02–0.04) | 2.0–2.5 (0.08–0.100) | 16.0 (240) | 45.0 (1,590) | 0.8 (30) |
| 12 (½) | 5,000 | 0.5–1.0 (0.02–0.04) | 2.0–2.5 (0.08–0.100) | 18 (260) | 53.0 (1,880) | 0.5 (19) |
| 15 (3/8) | 6,000 | 0.5–1.0 (0.02–0.04) | 2.0–2.5 (0.08–0.100) | 16 (230) | 47.0 (1,670) | 0.4 (16) |
| Note: | The listed values are indicative and may vary depending on the cutting system. | | | | | |

Low-pressure oxygen cutting – less than 6 bar (85 psi) – is frequently used for cutting aluminium nevertheless. The laser beam should be focused on the upper surface of the sheet. Standard oxygen purity (99.5 %) is sufficient, as higher oxygen purity does not improve cutting speed. The drawbacks of low-pressure oxygen cutting are cut edges with dross and a rather rough cut surface.

Dross-free cuts can be obtained by using high-pressure cutting with nitrogen or oxygen. It appears that nitrogen is the better alternative when cutting aluminium alloys, whereas oxygen is better for pure aluminium (see reference 4, page 19). This is demonstrated in principle in the diagrams in fig. 13, which show the parameter ranges where dross-free cuts are obtained for 2 mm (0.08 in) sheets of pure aluminium (Al 99.5) and an aluminium alloy (AlMg3). When aluminium is cut with high pressure, the laser beam should be focused close to the lower surface of the sheet. Typical parameters for the cutting of AlMg3 are summarised in table 4.

# Bibliography.



## Titanium

Oxygen and nitrogen are not suitable as cutting gases for titanium and titanium alloys because these gases, like hydrogen, are absorbed into the surface, where a hard and brittle layer is formed. This layer may crack, and propagation of the crack can cause component failure.

High-pressure cutting with a completely inert gas is therefore the preferred method for laser cutting of titanium. In addition, the workpiece is often fixed in a vessel at inert atmosphere during the cutting process. High-purity argon and argon-helium mixtures with a very low oxygen content (99.996–99.999 %) are most frequently used. Helium content in the cutting gas is advantageous as high intensities in the focus cause process-disturbing plasma formation. The cuts exhibit no significant dross adhesion. A deep focal point position beneath the upper surface of the sheet is advantageous.

## Nickel alloys

Nickel is the base metal in a number of industrially important alloys: Inconel (Ni-Cr), Nimonic (Ni-Cr-Co), Hastelloy (Ni-Mo-Cr) and Monel (Ni-Cu).

Low-pressure oxygen cutting – lower than 6 bar (85 psi) – can be used to obtain high cutting speeds, but the cut edges exhibit dross and the cut surfaces are oxidised.

Although burr-free and oxide-free cuts may be achieved with high-pressure nitrogen, the cutting speed is reduced significantly compared to oxygen cutting. The focal point should be positioned deep within the material, below the upper surface of the sheet.

## Copper alloys

The high reflectivity and thermal conductivity of copper make cutting of this material quite a challenge. Precautions must be taken to avoid re-reflections of the laser beam and subsequent damage to the resonator. Brass is one of the important copper alloys (copper-zinc alloy) and has lower reflectivity and thermal conductivity than copper. It is therefore easier to cut with $CO_2$ lasers. Very high laser power and a short focal length of the lens – about 63 mm (2.5 in) – are beneficial.

Oxygen cutting is preferable when cutting brass and other copper alloys with $CO_2$ lasers. Oxygen is better suited as a cutting gas, as the oxide layer at the cut front improves absorption of the laser beam. Both low oxygen pressures of up to 6 bar (85 psi) and high oxygen pressures of up to 20 bar (300 psi) are used. When cutting brass at high oxygen pressures of up to 20 bar (300 psi), proper ventilation of the working area must be provided to avoid dangerous enrichment of the atmosphere with oxygen. The maximum sheet thickness that can be cut is 4–5 mm (0.16–0.20 in). Sometimes, high-pressure nitrogen is also used to cut copper alloys.

## Non-metals

Laser application is widespread in the cutting of non-metals.

$CO_2$ lasers are used for cutting plastics, rubber, textiles, wood, ceramics and quartz. When using a 1-kW $CO_2$ laser, the maximum thickness of plastics and plywood is about 25 mm (1 in). Nd:YAG lasers are sometimes used in industry for cutting certain types of ceramics, such as silicon carbide and silicon nitride.

Compressed air free from oil/grease and moisture is the cutting gas predominantly used for practically all of the above-mentioned materials. Inert cutting gases such as nitrogen are only used in a few cases when a plastic material or a fabric is highly flammable. Oxygen can be used to avoid discolouration of the cut surface of ceramics, such as aluminium oxide and zirconium oxide.

During laser cutting of certain non-metals, such as plastics, synthetic textiles and ceramics, toxic fumes or dust are formed, thereby making good fume/dust extraction systems necessary.

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3. M. Faerber and W. Schmidt: Laser cutting gases, DVS-Berichte, Band 185, DVS-Verlag (1997), pp. 72–74
4. T. Kristensen and F.O. Olsen: Cutting of Aluminium Alloys, Proc. of the 4th NOLAMP Conf., Sonderborg (1993), pp. 121–129

## Further reading

- → "Lasers for industrial applications"
- → "Laser gases and gas supply systems"
- → "The laser welding process"
- → "Evaluation of costs in laser processing"

For a selection of other technical information documents, please contact your local Linde representative.

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