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Laser or Plasma Cutting – Is there a choice?

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Abstract

There are various methods that can be used for cutting metals. Depending on the type of material as well as economic and quality-related aspects, each technology has its own strengths and thus its justification.

On the one hand, there is the versatile laser cutting; on the other hand there is the constantly improved plasma cutting technology. Thus, new areas of application for cutting metallic work-pieces with plasma could be opened up over the past years and process variants have been developed which cover even non-conductive or interrupted materials in a wide performance range and a wide range of material thicknesses.

Today, some plasma cutting systems achieve in many areas cut qualities which are equal or almost equal to laser cutting. Due to the significantly lower investment costs compared to laser, the costs per cutting metre for plasma cutting are considerably lower. The achieved performance increase of the plasma cutting units with regard to thick mild steel sheets is also increasingly competing with gas cutting methods.

But which cutting method is the right one? This contribution shows the strengths and weaknesses, which every user should consider. It does not always have to be a laser, because laser cutting also has its limits, or there are areas of application where other methods, like plasma cutting, can be more economic and/or achieve high quality.

"Keywords: Cutting; Plasma; Laser; Fiber"

1. Introduction

Today, there is a number of productive separation processes integrated in automated systems available which are used to cut metallic materials. Although the different thermal cutting processes autogenous oxy-fuel cutting, plasma cutting and laser cutting all have their advantages within their specific areas of application, new technological developments have led to the extension and some overlapping of these areas of application. Which process the user will choose in the end, depends not only on the material and the cutting task at hand, but of course also on the investment and operating costs.

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2. Thermal Cutting Processes

Autogenous oxy-fuel cutting, plasma cutting and laser cutting are thermal separation processes. Because autogenous oxy-fuel cutting can only be used for unalloyed steels and is therefore not considered further in this investigation, plasma cutting was developed for high-alloyed steels. Today in the metal-working industry, it is an established and effective cutting process for unalloyed and low-alloyed as well as high-alloyed steels. Laser cutting is mainly used for high-precision cutting and cutting of small contours, especially concerning thin sheets.

2.1. Plasma Cutting

In physics, there are three aggregate states which describe the different temperature and pressure-dependent states of materials. In addition to the three classic aggregate states „solid“, „liquid“ and „gaseous“, plasma is often described as the fourth aggregate state. If a material is in the gaseous state and is supplied with energy, plasma is created because neutral atoms decompose into ions and electrons. The required ionisation energy is supplied for example in the form of heat or by strong electrical fields.

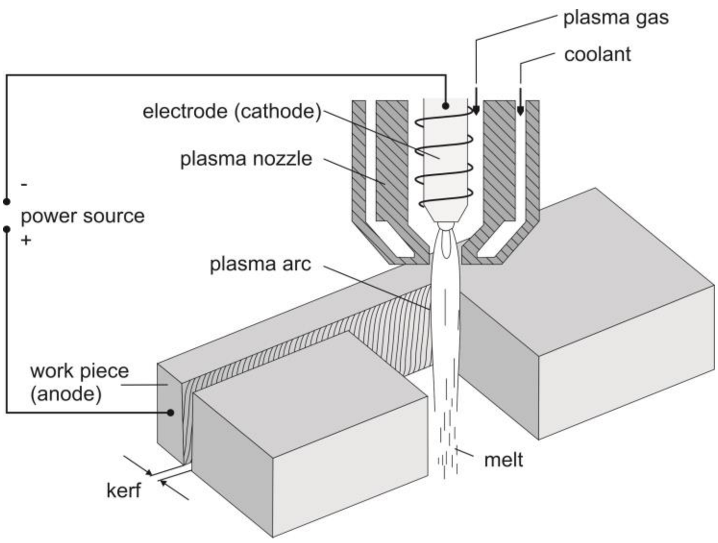


Fig. 1. Diagram of process principle

The arc is the cutting tool of the plasma cutting process. The plasma created by the arc is additionally constricted by a liquid-cooled nozzle. Thus, energy densities of up to 2 x 10^6 W/cm² within the plasma beam are achieved. Due to the high temperature connected therewith, up to approx. 30.000 Kelvin, the plasma expands and flows with supersonic speed in the direction of the work-piece. Due to the high thermal energy of the arc and the kinetic energy of the plasma beam the material melts and is driven out.

The plasma cutting process can be used for cutting all electrically conductive materials. Thanks to the high power and the high energy density, very high cutting speeds can be realised.

2.2. Variants of Plasma Cutting

In the course of the development of plasma cutting, several variants have emerged. A distinction is made between conventional (standard) plasma cutting and plasma cutting with focused arc. The latter is the latest available plasma cutting technology. In contrast to conventional plasma cutting, it is characterised by a considerably higher quality of the cut result which is shown by low rectangularity and inclination tolerances, low dross formation, smoother cut surfaces and a smaller heat-affected zone (Fig. 2.).

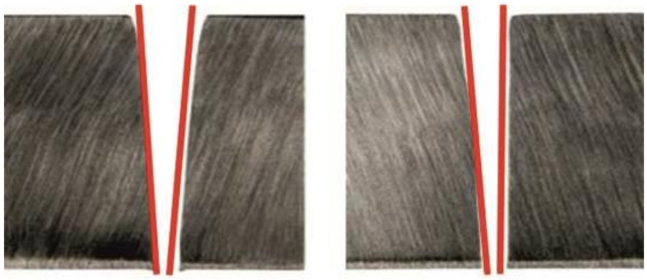


Fig. 2. Comparison of cut results in 10 mm mild steel, hole diameter = 12 mm: left conventional plasma cutting, right plasma cutting with increased constriction (HiFocus Contour Cut)

Fig. 3. Comparison of the kerf form in unalloyed steel, thickness 15 mm; left: conventional plasma cutting, right: plasma cutting with focused arc

This is made possible; inter alia, by using plasma torches which work with a secondary gas in addition to the plasma gas. The nozzle which causes further constriction of the plasma beam has a bore with a smaller diameter than nozzles for conventional plasma torches. Thus, the plasma arc becomes narrower and significantly more stable. This leads to higher current densities which result in higher energy densities.

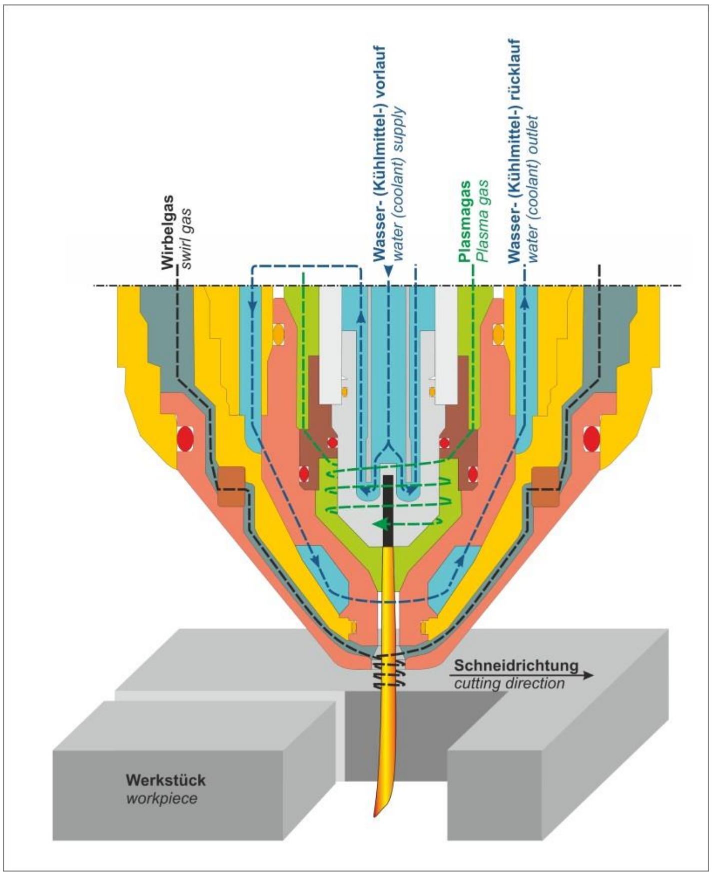


Fig. 4. Plasma cutting with focused arc (with secondary gas)

The secondary gas improves the piercing process because it protects the nozzle from spatter. In addition, the plasma beam is influenced by the composition of the secondary gas and its rotation. This leads to a considerable extension of the possible parameter field for plasma cutting. The gas rotation of the secondary gas and its effect is shown in Fig. 3 and Fig. 4. Thus it was possible to reduce the plasma-typical angular deviation at the „good side“ (work-piece side) to a minimum and to realise nearly rectangular cuts.

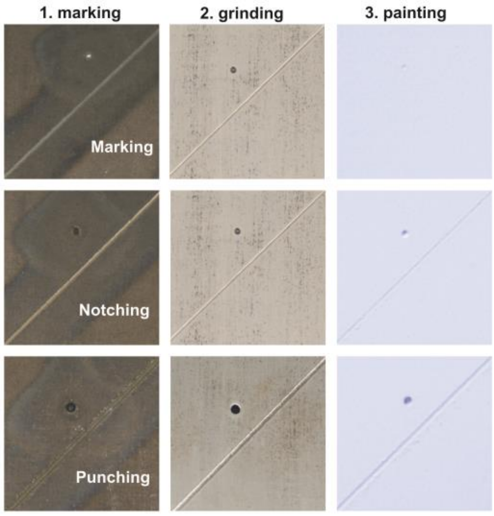


Fig. 5. Comparison of marking, notching and punching with plasma without surface treatment (left), grinded (centre) and painted (right)

Conventional plasma cutting is used for manual plasma cutting applications with mobile inverters as well as for mechanised applications. It is mainly characterised as a cost-efficient process at low investment costs and uses air as plasma gas. However, in contrast to the economic advantages there are limitations with regard to the cut quality and the cutting range.

High-end plasma cutting with focused arc is used for automated applications on guiding systems. This process covers not only a wide range of material thicknesses from 0.5 mm to 160 mm, but it is also possible to produce markings on the work-piece surface. Though the investment costs are higher than for conventional plasma cutting, they are much lower than for laser cutting.

2.3. Laser Cutting

For laser cutting of metallic materials mostly CO_2 or solid state lasers (fibre or disk lasers) are used. The energy required for cutting is converted into heat by absorption of the laser in the material. In contrast to plasma cutting, a „cold“ gas is used here which flows through a nozzle and is constricted. Its main purpose is to blow out the melted material and to supply additional energy by oxidation when cutting with oxygen.

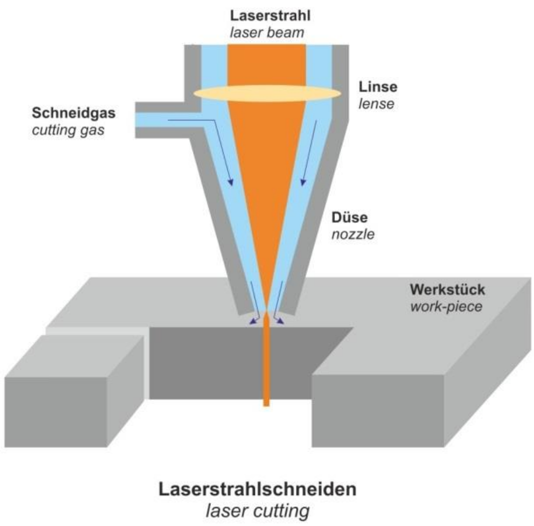


Fig. 6. Laser cutting principle

The following three laser cutting variants can be distinguished: laser oxy-fuel flame cutting, laser fusion cutting and laser sublimation cutting.

The mild steel samples were cut by using laser *oxy-fuel flame* cutting with oxygen.

The stainless steel samples were cut by using laser *fusion* cutting with nitrogen.

3. Comparison of the Cutting Processes

The demands on processes for cutting metallic materials have increased constantly. The cut quality as well as the total production time per component plays an important role. In summary, these criteria can be divided into two categories: parameters for the evaluation of the *cut quality* and *economic factors*.

In order to be able to compare directly the quality of the cut surface, the rectangularity, the quality of the holes, the roughness, the kerf width, the gas consumption, the cutting speed and the total costs per cutting metre, the same samples have been cut (Fig. 7) with a conventional plasma cutting unit (CutFire 100i), a high-end plasma cutting system (HiFocus 161i) and a solid-state laser (TruLaser 7025 - TruDisk5001 of the Fraunhofer Institute IWS Dresden).

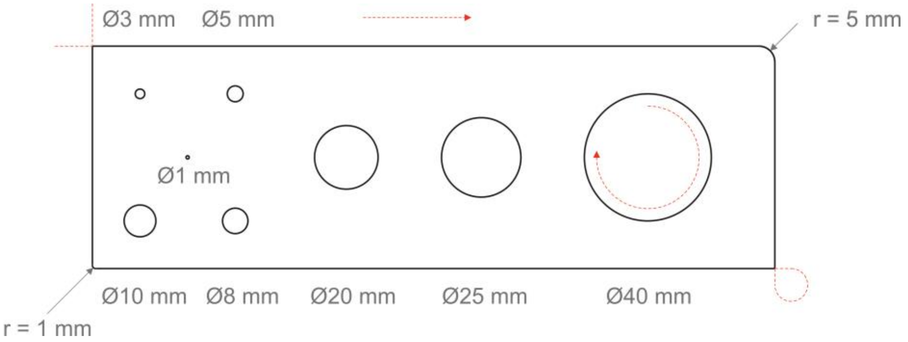


Fig. 7. Reference Sample

In total, 30 samples of different material thicknesses (1 mm/ 3 mm/ 10 mm/ 20 mm/ 25 mm) and material types (mild steel/ stainless steel) were compared with each other.

3.1. Comparison Regarding Cut Quality

Cutting range: When comparing the cutting range it is evident that plasma covers a larger range of material thicknesses than laser. For process-related reasons the limits of laser cutting are at approx. 40 mm material thickness. The maximum sheet thickness that can be cut with the TruDisk 5001 is around 25 mm (mild steel) and 20 mm (stainless steel). In contrast, plasma cutting can be used for materials with up to 160 mm thickness.

Fig. 8. Cutting samples stainless steel; left: 150 mm, centre: 100 mm, right: 80 mm

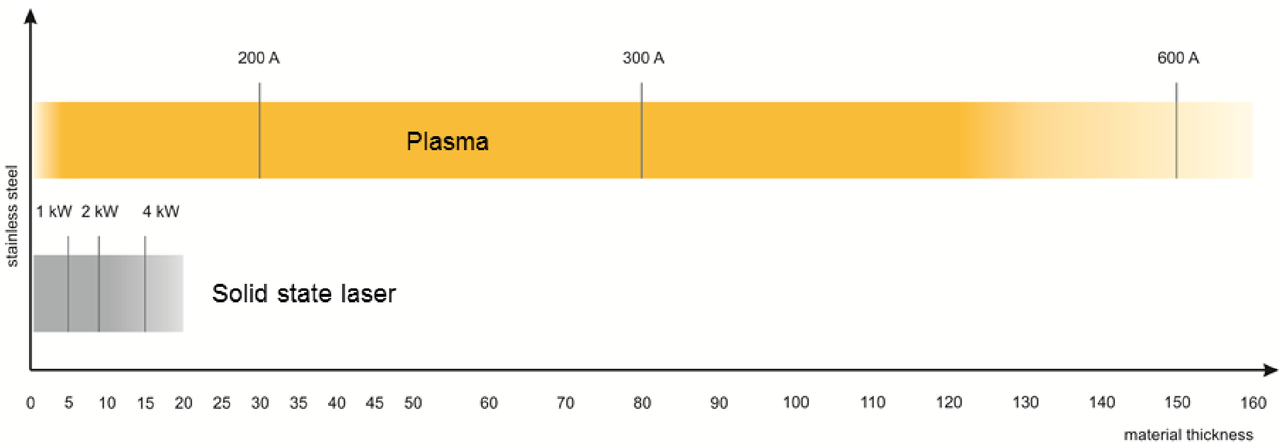
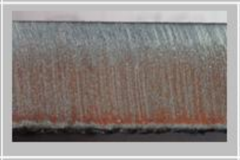


Fig. 9. Cutting range for stainless steel, above: plasma, below: laser

Cut surface: The tests within the mentioned cutting range demonstrated that especially the laser-cut samples with material thicknesses of 10 mm and more show a much higher roughness than the plasma-cut samples with the same material thicknesses. The samples cut with HiFocus plasma technique showed the lowest average surface roughness. The following tables in Fig. 10 and Fig. 11 show the comparison of the three cutting systems using 10 mm mild steel and 10 mm stainless steel as examples.

Cutting Parameters:				
Cutting system	**CutFire**	**HiFocus**	**Solid state laser**	
Material thickness	10 mm			
Cut surface				
Cutting current / Cutting power	70 A	90 A	2 kW	4 kW
Cutting Speed	800 mm/min	1600 mm/min	1000 mm/min	2100 mm/min
Roughness Rz*	40 µm	9 µm	66 µm	35 µm

* Measuring range: 2.5 mm x 5, sample centre (cut surface),
For process-related reasons the samples cut as examples in the laboratory may show some variations (influence of the guiding system, variations in the material etc.).

Fig. 10. Comparison of cutting processes – cut surface mild steel, 10 mm

Cutting Parameters:				
Cutting system	**CutFire**	**HiFocus**	**Solid state laser**	
Material thickness	10 mm			
Cut surface				
Cutting current / Cutting power	70 A	130 A	2 kW	4 kW
Cutting Speed	800 mm/min	1400 mm/min	300 mm/min	600 mm/min
Roughness Rz*	78 µm	10 µm	105 µm	90 µm

* Measuring range: 2.5 mm x 5, sample centre (cut surface),
For process-related reasons the samples cut as examples in the laboratory may show some variations (influence of the guiding system, variations in the material etc.).

Fig. 11. Comparison of cutting processes – cut surface stainless steel, 10 mm

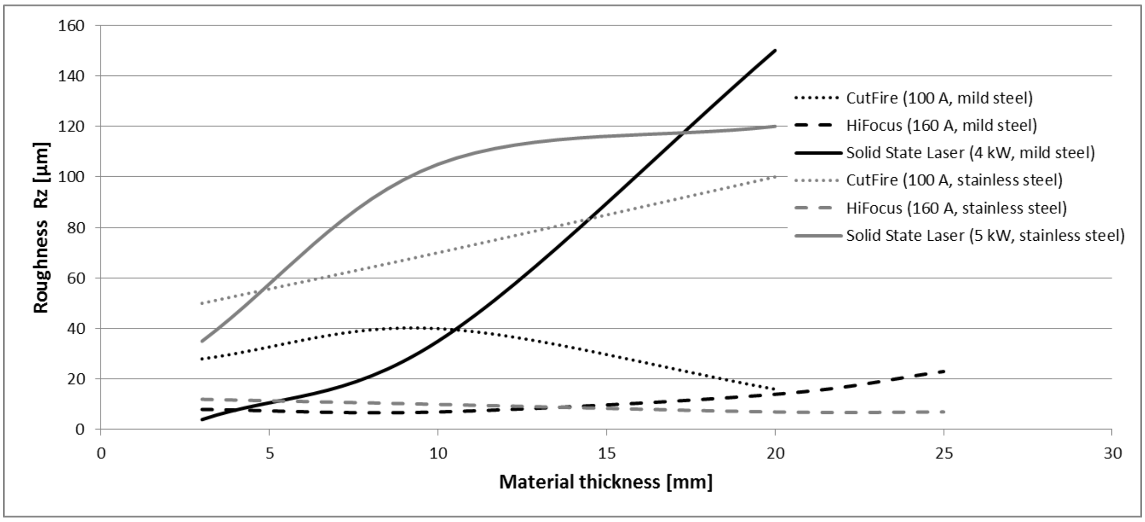


Fig. 12. Comparison of cutting processes – roughness Rz

Quality of holes: Whereas HiFocus and solid-state laser allow very precise hole cutting, the cost-efficient plasma cutting process showed a low preciseness and contour accuracy. Often the holes were non-circular and showed a slightly conical shape.

Up to a material thickness of 10 mm the solid-state laser could cut holes with a hole diameter to material thickness ratio of 0.5: 1. Then the ratio changed to 1: 1. Where plasma was concerned, there were differences between the materials. Whereas the holes in mild steel of all material thicknesses could be cut with a hole diameter to material thickness ratio of 1 : 1 (minimum hole diameter = 5 mm), the ratio concerning all stainless steel samples was 2 : 1 (minimum hole diameter = 10 mm).

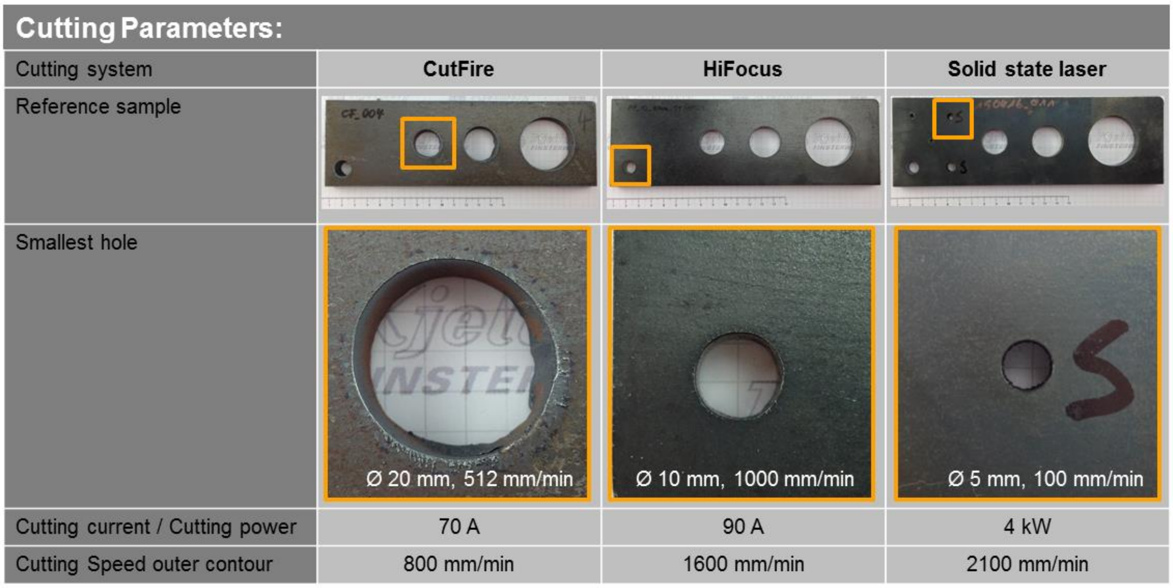


Fig. 13. Comparison of cutting processes – holes mild steel, 10 mm

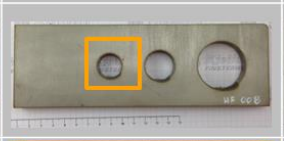
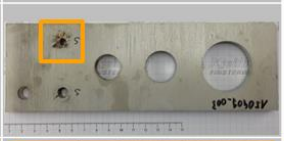
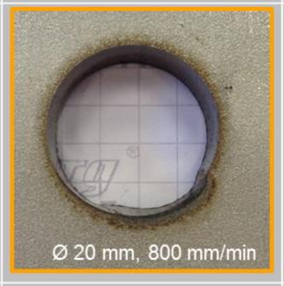
Cutting Parameters:			
Cutting system	**CutFire**	**HiFocus**	**Solid state laser**
Reference sample			
Smallest hole			
Cutting current / Cutting power	70 A	130 A	4 kW
Cutting Speed outer contour	800 mm/min	1400 mm/min	600 mm/min

Fig. 14. Comparison of cutting processes – holes stainless steel, 10 mm

In order to achieve the highest possible cut quality, the inner contours were cut at lower speeds than the outer contours during all cutting processes.

One target of the developments in the area of plasma technique during the last years has been to improve the contour quality in order to reduce after-treatment of the cut components. One of the results of these development activities is the „Contour Cut“ technology. It allows the cutting of holes with minimum diameters corresponding to the material thickness in unalloyed and low-alloyed steels and with sheet thicknesses between 3 mm and 30 mm. The improvement of the hole quality is shown in Fig. 2.

Kerf width: As expected, the kerf width of the tested solid-state laser cuts was smaller than the plasma-cut samples, so that also smaller and filigree contours can be cut with laser. With laser, kerf widths between 0.2 mm and 0.7 mm were achieved with sheet thicknesses ranging between 3 mm and 20 mm. With plasma, the kerf widths were between 1.7 mm and 3.9 mm with sheet thicknesses ranging between 3 mm and 25 mm. However, it turned out that such a narrow kerf achieved with laser can also have an adverse effect as the inner contours often did not fall out without problems because the molten metal could not completely be driven out of the narrow kerf.

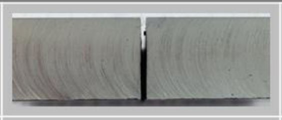
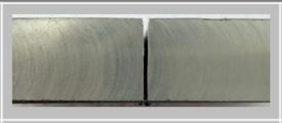
Cutting Parameters:			
Cutting system	**HiFocus**	**Solid state laser**	
Material	**Mild Steel – 1.0037**		
Kerf width			--
Cutting current / Cutting power	90 A	4 kW	--
Cutting Speed	1600 mm/min	2100 mm/min	--
Material	**Stainless Steel**		
Kerf width			--
Cutting current / Cutting power	130 A	4 kW	--
Cutting Speed	1400 mm/min	600 mm/min	--

Fig. 15. Comparison of cutting processes – kerfs, 10 mm

Rectangularity of the cut surfaces: Concerning this criterion, clear differences were visible. Whereas it was possible to achieve nearly rectangular cut surfaces on both sides with the solid-state laser, the work-pieces cut with the simple plasma cutting process showed a slight inclination on both sides. During plasma cutting with the HiFocus process the „good side“ of the work-piece was also nearly rectangular, whereas the „waste side“ showed a slight inclination. Therefore, during plasma cutting it is important to take the cutting direction into consideration in order to have the “good side” on the component side. For this reason, outer contours are cut in clockwise direction and inner contours in anticlockwise direction. For laser cutting the cutting direction does not matter.

3.2. Comparison Regarding Economic Factors

Gas consumption: The gas consumption for laser fusion cutting, in particular where material thicknesses of more than 3 mm are concerned is many times higher compared to plasma cutting and has therefore a decisive influence on the costs per cutting metre. Whereas the simple CutFire plasma cutting process uses the cheap air as plasma gas, HiFocus plasma cutting works with oxygen for cutting mild steel and nitrogen or a Ar/H_2 mixture for cutting stainless steel. Regarding laser cutting, mild steel was also cut with oxygen and stainless steel with nitrogen.

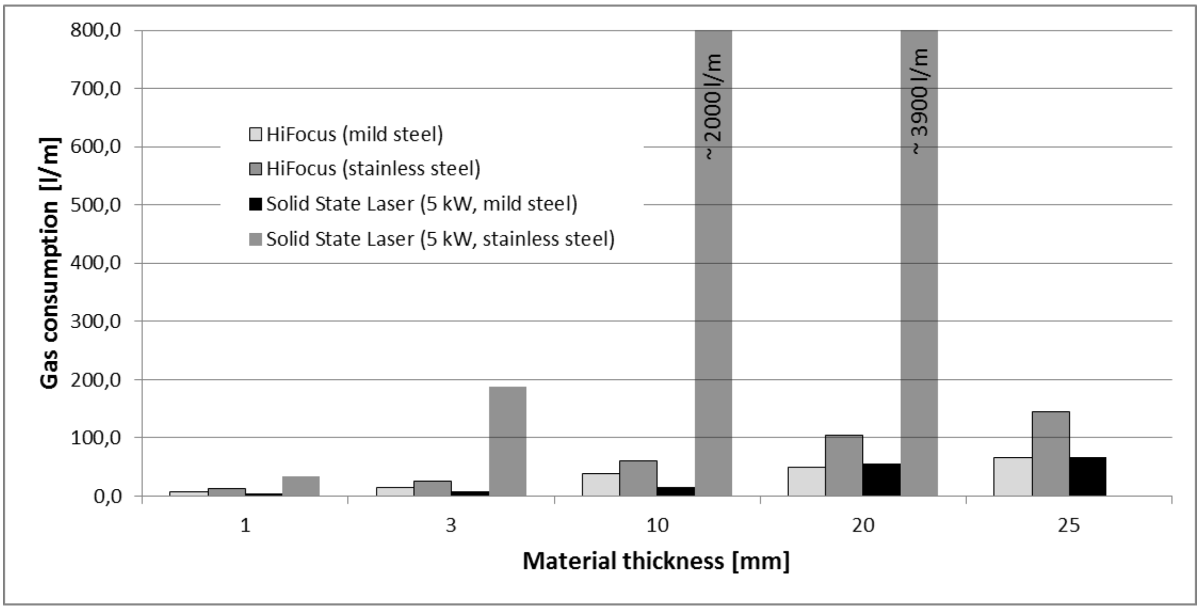


Fig. 16. Comparison of cutting processes - gas consumption (cutting)

Cutting speed: The comparison of the cutting speeds shows that laser can make the most of its advantages especially where thin materials are concerned. Plasma cutting convinces with cutting thicker sheets at higher speeds which has a favourable effect on the costs per cutting metre.

During the investigation we attached great importance to high cut quality. In particular plasma cutting allows even higher cutting speeds with only minor losses in the cut quality.

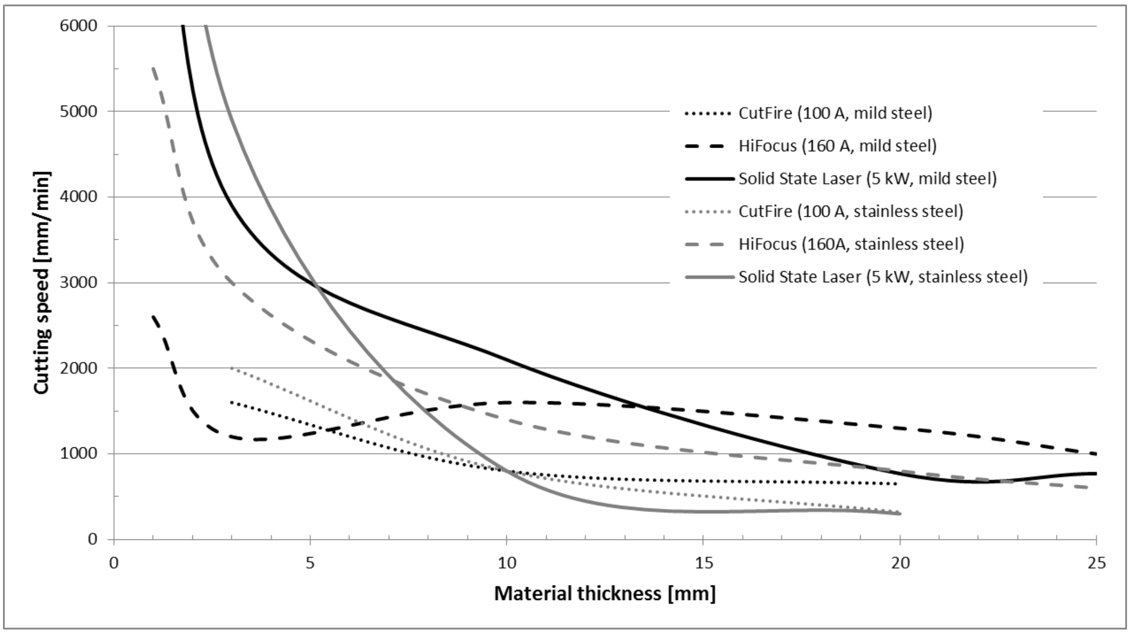


Fig. 17. Comparison of cutting processes – cutting speeds

Costs per cutting metre: The costs per cutting metre for the simple plasma system with air are relatively low. The main advantage of this system compared to the other two variants are the very low investment costs, thus making this process economic even at low utilization. The costs for cutting with the solid-state laser are the highest for the materials and material thicknesses in question. For material thicknesses of approx. 10 mm and more the laser cutting costs increase significantly. While the conventional plasma cutting system cannot achieve the high cut quality, HiFocus plasma cutting is characterized by a wide range of material thicknesses and a high cut quality at moderate costs. There are only limits regarding the forms of contours that can be cut: if fine or very small contours have to be produced, then laser cutting offers the highest quality at present. The costs per cutting metre mentioned below are approximate values which have been determined under similar conditions for each cutting process. Of course, they depend on the actual investment amount, the technical equipment of the plant and the prices for expendable materials, e. g. gas and consumables.

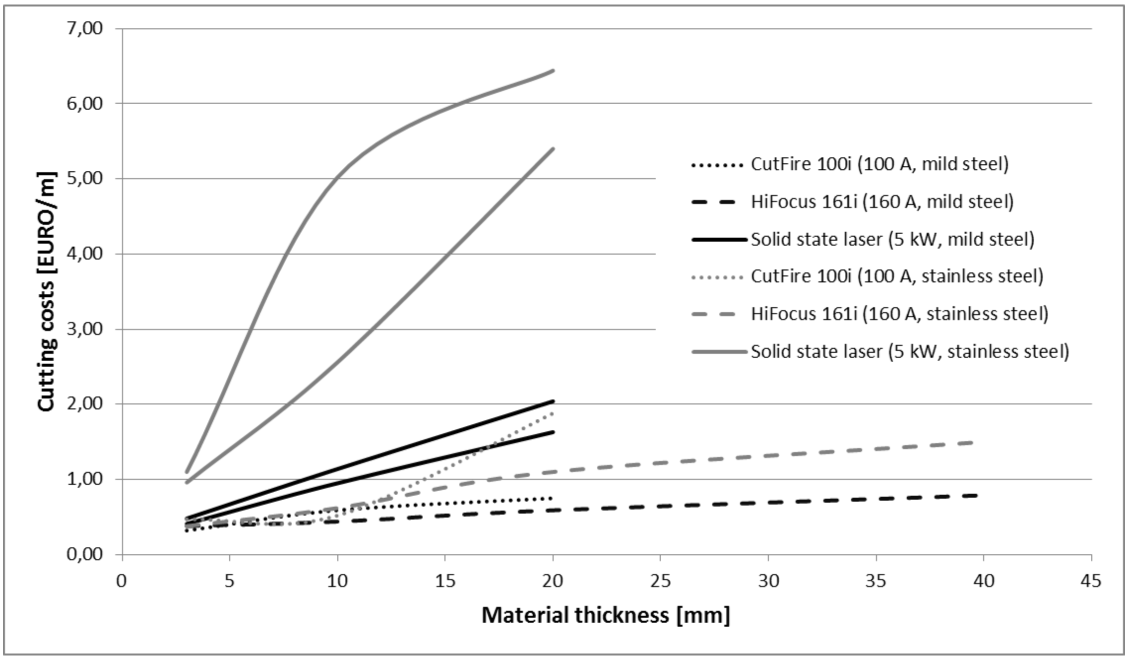


Fig. 18. Comparison of cutting processes – cutting costs Plasma/ Laser (2 shifts) - Approximate values, can differ depending on cutting speed and quality.

In addition to the high cut quality with no rework required, if possible, the time needed for cutting the component is a decisive cost factor. The cutting time is nearly proportionally reflected in the component costs. Auxiliary process times are also essential, for example times for loading and unloading the cutting table, the operating time between the cuts and not least the cutting speed itself.

It is of the utmost importance that a higher cutting speed does not compromise the cut quality, if possible. The „Contour Cut Speed" plasma cutting technology allows higher cutting speeds than mentioned in the investigations and achieves a similar cut quality. The cutting speeds are up to 50% higher than the indicated values depending on the material thickness. A further increase can be achieved by choosing a higher cutting current. For this purpose, the cutting databases offer several cutting current values in most cases. This is a further potential for cost reduction. However, the results may differ in quality especially where small contours or corners are concerned.

3.3. Summary

The investigations show that all processes have their areas of application and their special advantages. While the conventional plasma cutting system CutFire 100i achieves the lowest costs per cutting metre, a lower cut quality in the form of rougher cut surfaces, imprecise contours and limitations regarding the cutting range have to be accepted. The high-end plasma cutting system HiFocus 161i convinced in the tests with a good cut quality and reasonable costs, especially for material thicknesses from 3 mm and 5 mm. Where thinner sheets with a thickness of up to 10 mm were concerned, the laser cutting system could cut small contours and achieved a good cut quality. Thick materials can be cut with laser only at relatively low speeds. Depending on the material, the costs per cutting metre increase considerably for laser oxy-fuel cutting from 20 mm and for laser fusion cutting from 15 mm because the cutting speeds decrease and the gas consumption increases significantly especially during laser fusion cutting.

A combination of plasma and laser cutting makes it possible to use the special advantages of each process: laser works quickly and precisely where thin sheets and small contours are concerned, whereas plasma cutting is suitable for cutting thicker materials with high quality and at low costs. From an economic point of view, when combining the two systems and depending on the cutting task at hand, it is recommendable to use laser cutting for sheets with a thickness of up to 5 mm and plasma cutting for sheets with a thickness from 3 mm.

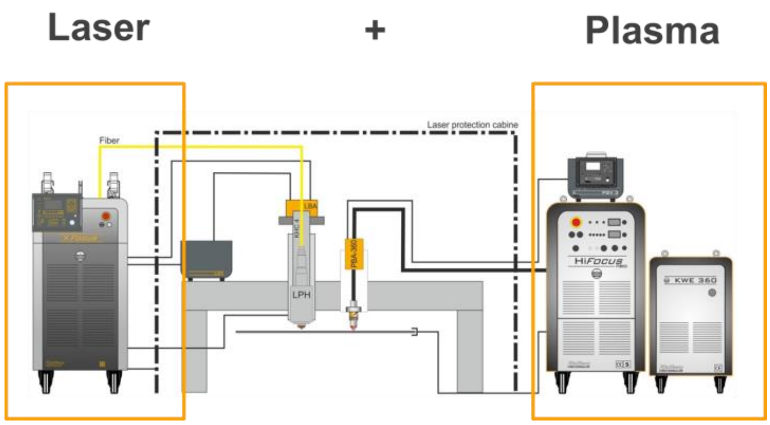


Fig. 19. Combination of plasma and laser on guiding system

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