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MELT FLOW AND ENERGY LIMITATION OF LASER CUTTING

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Abstract

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Laser technology is a convertible technology for plenty of parts in most materials. Laser material processing for industrial manufacturing applications is today a widespread procedure for welding, cutting, marking and micro machining of metal and plastic parts and components. Involvement and support this huge mass-production industry of laser cutting, new technology and dry-process using lasers were and are being actively developed. Fundamentally, industrial laser cutting or other applications on industry should satisfy the four key practical application issues including “Quality or Performance”, “Throughput or Speed”, “Cost or Total Ownership Cost”, and “Reliability”. Laser requires for examples several complicated physical factors to be resolved including die strength to be enable good wire-bonding and survival of severe cycling test, clean cutting wall surface, good cutting of direct attach film, and proper speed of cutting for achieving economy of throughput. Some example of maximum cutting rate, wherewith is normally limited laser energy, cutting speed is depend on type laser, different of cutting with one laser beam and beam pattern and applied laser power / material thickness will be introduced in this paper.

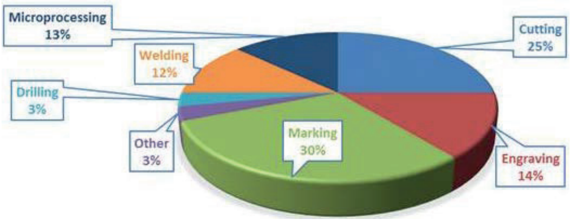
Keywords: laser cutting, energy limitation of fibre and CO_2 laser, energy input and melt flow limitation

INTRODUCTION

Since the first laser demonstration by Theodore Maiman in 1960 researchers and engineers have eagerly looked for practical applications of this coherent radiation source in new material processing and manufacturing procedures that couldn’t be performed with the existing technologies. In 1989 the worldwide sales of laser systems for material processing exceeded the 1 billion Euro level for the first time with up and downs in the following decades. In 2006 the value toped to 6.1 billion Euro with an ongoing upward trend. Although the ‘old’ CO_2 laser [Fig. 2] still is the workhorse in the material processing area – especially in the power range over 500 W – new solid-state laser systems, either flash lamp or diode-pumped rod and slab systems or diode-pumped disk and fibre laser configurations are gaining ground in the low, medium and high power regime. In the course of this development and with the invent of new and alternative solid-state laser sources discussions have emerged which of the laser configuration – rod, slab, disk or fibre – is best suited for all laser material procedures outlined in Fig. 1. After a review of the most important laser, material processing parameters in view of these solid-state laser configurations two major application areas will be shown in detail: laser marking and laser cutting (Steiger, 2007).

Industrial laser applications units

The graft shows a market of lasers use. However, in terms of revenues, laser cutting is counting for almost 40 %! (more than 2 Billion $ per year system sales). Today around 30,000 laser-cutting systems are producing goods throughout the world. The laser processing market is segmented into four categories namely: gas lasers, solid state lasers, fiber lasers, and other types of lasers (excimer and semiconductor). These types specifically include CO_2 lasers, fiber lasers, Nd: YAG laser, and Er: YAG laser. The industrial laser market 2005 up to 2007 in units. Still CO_2 laser is the workhorse in the material processing area. However, in terms of revenues, laser cutting is counting for almost 40 %! (more than 2 Billion $ per year system sales). Today around 30,000 laser-cutting systems are producing goods throughout the world.



1: *Industrial laser applications units.*

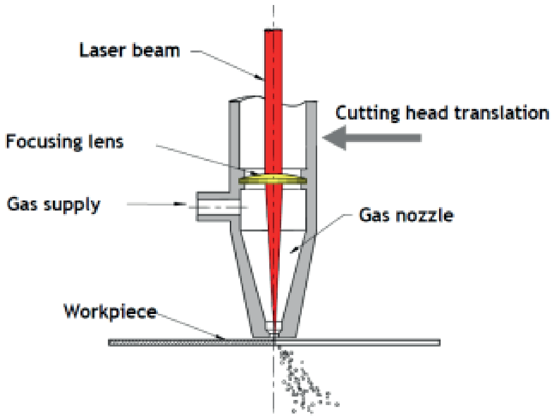
Industrial laser market

The graphs shows (years 2005–2007) where the lasers are produced units, where the laser systems are produced revenues and last one is laser cutting systems distribution. Those years has laser biggest potential in Europe and North America. The global market of laser processing is expected to grow to $17.36 billion by 2020 from its 2013 market size of $11.24 billion, at an estimated CAGR of 6.18 % between 2014 and 2020. Fig. 2 Laser cutting systems distribution.The report entails the market analysis and forecasts related to the laser processing market. This report deals with the driving factors, restraints, and opportunities for the global laser processing market, which are helpful in identifying industry trends and key success factors in this industry. Moreover, it also profiles the major companies that are active inthe field of laser processing along with their product offerings, strategy, financial details, developments, and competitive landscape. Some of the key players are Coherent, Inc. (U.S.), Epilog Laser (U.S.), Rofin-Sinar technologies (U.S.), Newport Corporation (U.S.), Laserstar technologies corporation (U.S.), and IPG Photonics Corporation (U.S.). The analysis of the global laser processing market is done with a special focus on the high growth applications in each vertical and the fast growing application market segment, along with, highlighting the winning imperatives and burning issues pertaining to this market (CUTLASERCUT, 2015). Different laser technologies such as CO_2 laser, solid-state lasers, fiber lasers, and excimer lasers are useful for processes such as cutting and marking in small dimensions. Thus, different laser technologies play an important role in the marking process for small electronic components. The industrial growth in the Asia Pacific region is another factor driving the growth of this market. Countries such as China, Japan and South Korea are expected to witness a strong growth in the laser processing market, during the forecast period. This is majorly due to the growing number of automobile and original equipment manufacturing (OEM) industries in these countries (CUTLASERCUT, 2015).

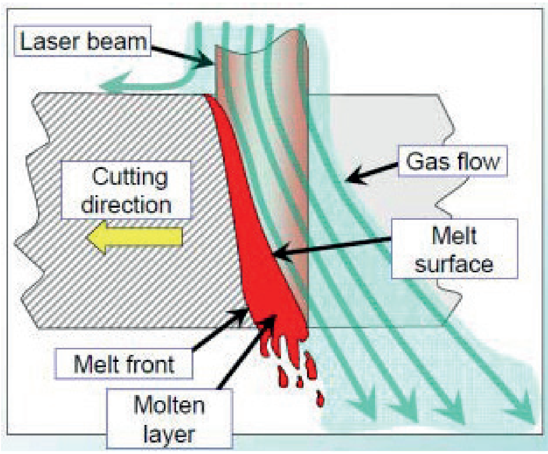
2: *Laser cutting systems distribution.*

Laser cutting

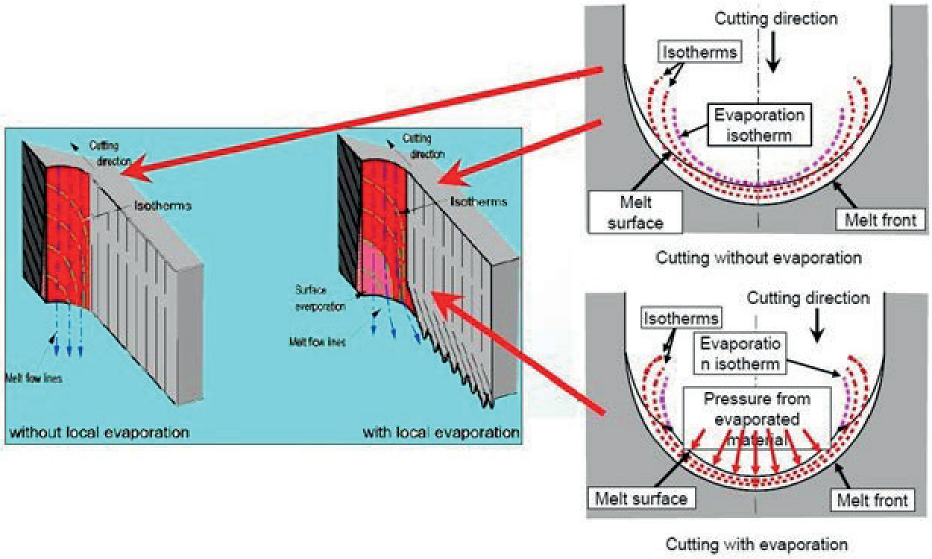
Laser cutting is a precise method of cutting a design from a given material using a CAD file to guide it. There are three main types of lasers used in the industry: CO_2 lasers Nd and Nd-YAG. We use CO_2 machines. This involves firing a laser, which cuts by melting, burning or vaporizing your material. You can achieve a fine level of cutting detail on with a wide variety of materials. Bare in mind that CO_2 lasers cannot cut metals and hard materials, they can however engrave them (CUTLASERCUT, 2015).



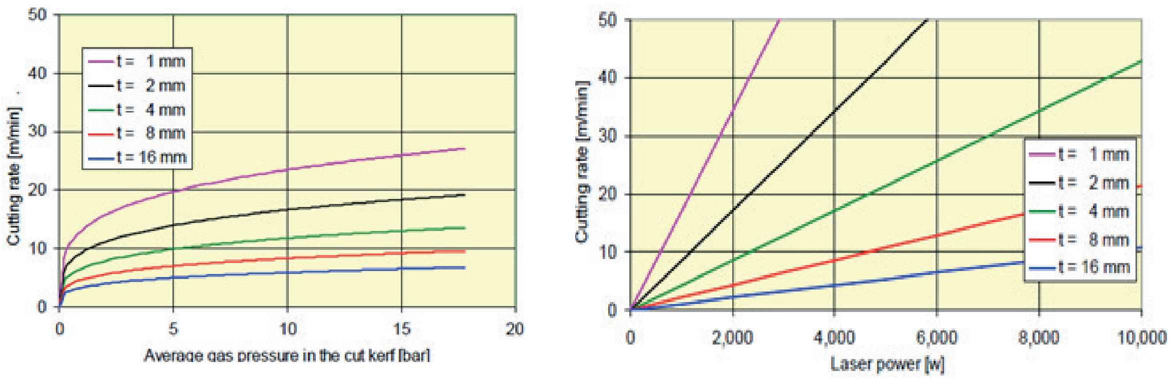
3: *Laser cutting. (Hoult, 2006).*



4: *Detail laser cutting. (Hoult, 2006)*



5: *Melt flow patterns. (Hoult, 2006)*



6: *Laser melt flow limitation and laser power limitation (maximum cutting rate-melt cutting). (DTU, 2016)*

Cut front formation of laser cutting

The behavior of the liquid film is largely dependent on the gas velocity, liquid flow rate (or Reynolds number), and film thickness. Ripples are generated on the surface when a high-velocity gas flows above a thick liquid layer because the VISCOUS dissipation is less than the energy transferred by the wave-induced pressure perturbation. The wave behavior depends on the gas velocity and liquid flow rate. As the film thickness is reduced, the surface smooths out because the fiction in the liquid phase can overcome the pressure perturbation. As the film thickness is further reduced to a very small value, it is found that the liquid film becomes unstable because the wave-induced shear stress perturbation is sufficient to overcome the restoring forces, and so-called slow waves are generated on the surface (Stergios *et al.*, 1991). It is perceivable that, if the liquid film gets even thinner and has a lower liquid flow rate, the film will rupture. In addition to the aforementioned destabilizing forces, the intermolecular dispersion forces may become important m film rupture (Stergios *et al.*, 1991). The laser beam shall has melt the material and partly evaporate the material.

Energy and melt flow limitation

Energy limitation is by maximum cutting rate and melt flow. The cutting gas shall has blown the molten material out of the kerf, ensure a good energy transfer from melt surface to melt front, requires high temperature gradient within the melt film, requires a thin melt film.

The local variation in cut front velocity will result in (across the cut front):

- Varying melt – film thickness.
- Varying – temperature and gradients.

Theoretical conclusion: Classical laser cutting as a result of cutting is normally limited by melt flow and not by energy!

MATERIALS AND METHODS

The goal of testing was to compare two examples. The first experimental compare roughness of fiber laser and CO_2 laser. The second example was cutting with one laser beam and cutting with beam pattern. Material, which was used – 2 and 6 mm AISI 304 stainless steel material.

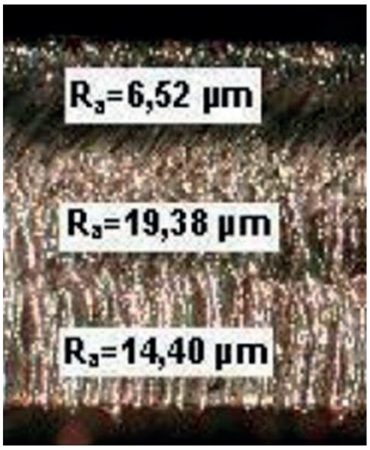
Workpiece material

The first experimental

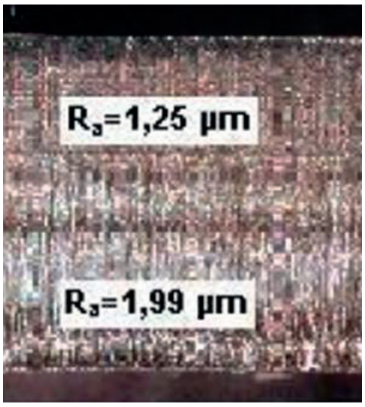
Examples on cutting of 6 mm stainless steel by fiber laser and CO_2 laser.

Laser input:

- 4-kilowatt laser power.
- Fiber laser (4.5 m/min).
- CO_2-laser (1.9 m/min).



7: *Cutting plate by fiber laser and by CO_2 laser. (Hoult, 2006)*



8: *Cutting plate by CO2 laser. (Hoult, 2006)*

The second experimental

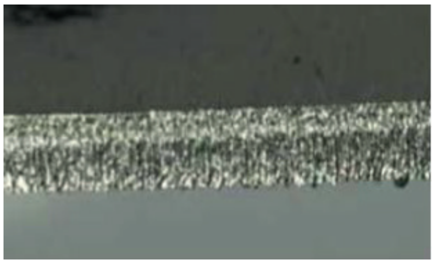
Lasers, which can form beam patterns based upon up to 17 diffraction limited laser beams in the kerf, 1 main beam plus up to 9 melt guiding beams, each with a beam radius around 25 µm, have been established (all beams concentrated within a radius of around 75 µm).

Examples of cutting of 2 mm stainless steel by one laser beam and beam pattern.

Laser input

- Primary power: 450 w.
- Secondary power: 100 w.
- Kerf width: around 100 µm.
- Laser beam (2.1 m/min).
- Beam pattern (2.4 m/min).

9: *Cutting with one laser beam (2.1 m/min). (Hoult, 2006)*



10: *Cutting with beam pattern (2.4 m/min). (Hoult, 2006)*

RESULTS AND DISCUSSION

Comparison of two kinds of lasers and the setting that was given has a different surface roughness. Of course, It depends on the feed rate and cutting power for a given type of laser. Fibre laser cutting has as figure shows different roughness, but more than twice cutting speed. However, cutting by CO_2-laser has more stable roughness, but cutting speed is slower. Both examples have been done at same laser power. If we compare second examples, which are cutting by one laser beam and cutting with beam pattern, the result is obvious from figures. The cutting rates are almost same. However, roughness is different and melt flow too. Because as was shown before, classical laser cutting is normally limited by melt flow and not by power!

CONCLUSION

Types of lasers, cutting input data (cutting speed, laser power etc.) exists many choices and combination. Very important laser material processing parameter is the material property itself. Transmission, reflection and scattering of the laser radiation, heat conduction, melting and transition points and numerous other material properties can even play a much more pronounced influence on the process result than a specific laser configuration. What is now the best choice for laser material processing? In view of the discussion about the influence of all the laser material processing parameters that must be considered in a laser machining process and the examples shown for cutting depends: The application will decide what the best laser configuration really is. Finally yet importantly, the customer will decide in view of system and running costs what his personally best choice will be.

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