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Laser Cutting of PE Polymer Films with Adapted Fiber Laser Beam Sources

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Abstract

In the field of plastics technology, films are used for many applications that consist of PE or at least have PE layers. For many applications it is necessary to separate or perforate these films. Conventionally, this is done by using knives or punching tools. The increasing trend towards format flexibility requires new format-independent processes such as the laser cutting of polymers. PE has a wavelength dependent absorption coefficient, which has around 2000 nm areas with higher intrinsic absorption. By using a thulium fiber beam source these areas can be addressed. In comparison to the co2 laser used up to now, the radiation can be flexibly guided via optical fibers. The influence of process parameters such as gas pressure and feed rate on the cutting quality is investigated. The cutting quality is evaluated by thin sections and reflected light microscopy. In addition, the process is monitored by a thermographic recording.

Keywords: Laser cutting; Polymer; Fiber Lasers; Film

1. Introduction and motivation

Up to now for laser-based cutting of visually transparent polymers CO2 gas laser beam sources are used. These are characterized by a good absorption of the emitted laser radiation in the polymer. In contrast to this, the laser beam cannot be guided through a glass fibers due to its wavelength of around 10 µm and the associated good absorption of this wavelength in glass. This property also limits the choice of suitable materials for transmissive beam shaping. For very flexible applications on e.g. robot systems, as they are increasingly required in the sense of industry 4.0, complex hollow axes with mirrors are required for beam guidance. The relatively large design due to the required laser tube also limits the minimum possible size of a laser-based cutting unit. However, polymers also exhibit material-specific absorption peaks or areas of higher absorption in the near infrared range (from 1.5 - 2.0 µm). If these spectral areas are addressed with a suitable beam source, intrinsic volume absorption of the laser radiation in the polymer can be achieved.

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2. Current state of technology

Laser cutting of polymers is based on the principle of energy absorption in polymers. By absorbing the laser radiation, the polymer is heated in the interaction zone until it evaporates. A coaxial gas jet transports the evaporated material out of the cutting gap. Polymers have a wavelength-dependent and material-specific absorption curve. Most polymers have a high absorption in the near and far infrared range. Due to that laser beam sources that emit laser radiation in the infrared range are suitable for cutting processes. The CO2 gas laser, with an emission wavelength of around 10µm, is industrially established and represents the current state of the art in laser cutting of polymers. Studies on laser cutting with CO2 lasers were carried out by various authors [1]; [2]; [3]; [4]. The results of the investigated polymer materials (polyethylene (PE), polypropylene (PP), polycarbonate (PC) and polymathic methacrylate (PMMA)) showed that there are dependencies between the heat affected zone (HAZ), the cutting depth/width, the laser power, the feed rate and the cutting gas pressure. The heat-affected zone becomes larger with higher laser power and smaller with higher feed rate according to [1]; [2]. With higher laser power, the cutting depth/width increases according to [3]; [4]. Due to its wavelength, the laser radiation of CO2 laser cannot be guided thru glass fibers. For a dynamic robot systems beam guidance could be very complex. CO2 gas lasers have often a large footprint due to the resonator. Special designed fiber lasers systems which emit laser radiation in a spectral wavelength range of 1500 to 2000 nm can also address areas of higher absorption of many typical polymers like PE. These absorptions peaks are so-called intrinsic absorption bands. The laser radiation of those thulium fiber laser systems can be easily guided thru glass fibers and thus enables a very flexible beam guidance. Thulium fiber laser systems can also be used for the laser transmission welding of polymers [5]. J. Guerra et al. con-ducted investigations on the suitability of fiber laser systems in the emission range of 1 µm for cutting PLA in the medical field [6]. The author, M. Brosda et al., performed a comparison between CO2 gas laser systems, adapted diode and fiber lasers systems for the cutting process of different Polymers [7]. Furthermore, there are studies to use ultra-short pulse laser sources for cutting polymers [8]. [7]

3. The cutting process

All Polymers have a wavelength-dependent and material-specific absorption property. In the visible spectral range and in the nearby infrared range up to 1000 nm, most polymers have a high transmittance and a low ab-sorption coefficient. From 1500 nm onwards, areas of higher absorption are created due to vibration excitation, so called intrinsic absorption bands. If now fiber laser systems with emission wavelengths in the range of 1500 - 2000 nm are used, these absorption peaks can be addressed directly [9]. Thereby laser radiation can be deposited directly in the polymer without modification. The laser beam is passed over the polymer by a moving system along the welding contour. The deposed energy leads to melting and evaporation of the polymer. Due to the co axial arrangement of a cutting gas nozzle, the molten and vaporized material can now be blown out of the cutting gap.

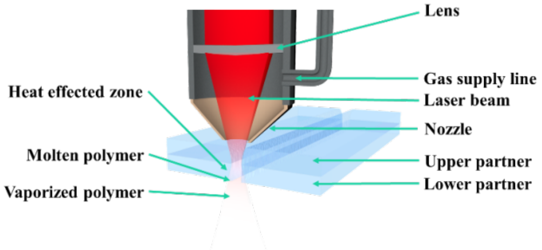

Fig. 1. Principle and experimental setup for the laser cutting investigations.

To measure the absorption of a polymer a two beam Lambda 1050 UV/VIS/NIR spectrometer from Perkin Elmer Inc. of Waltham, Massachusetts, USA with an Ulbricht sphere setup is used. Figure 2 shows the optical properties of the PE Material.

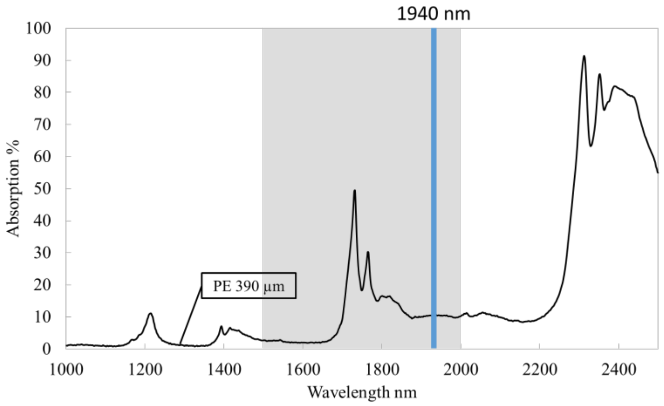

Fig. 2. Optical properties of PE Material.

For the cutting process an IPG Laser GmbH, Burbach, Germany thulium fiber laser system with an maximum optical power of 100 watts, a spectral peak emission of 1940 nm, and an M² of 1,05 is used. The cutting optics consists of a 40 mm lens, which focus the emitted laser radiation with a diameter of 5.5 mm to material surface. To measure the cutting gap a Keyence Corporation, Osaka, Japan (Modell VHX 900F) is used.

4. Influence of the feed rate and thermal analysis of the interaction zone

In order to investigate the influence of feed rate on the cutting gap width, the feed rate is varied at a constant power of 88 watts. Afterwards the width of the cutting gap is measured by means of a thin cut. For each point 5 samples are considered.

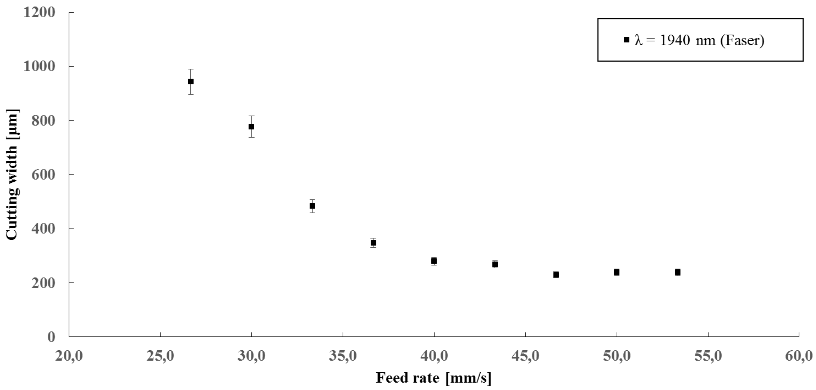

Fig. 3. Influence of the feed rate on the cutting gap width of PE.

With the thulium fiber laser system, small cutting gap widths and high feed rates can be achieved. With a feed rate of 40 mm/s and a power of 88 W, the cutting gap width is 280 µm. Especially at high feed rates short interaction times can be realized which leads to smaller cutting gap width. Compared to the established CO2 laser system, the absorption of the laser radiation of the thulium fiber laser system in the polymer does not take place near the surface, but more in the complete material volume. Due to the volume absorption in the material, a larger surrounding area of the material melts than with the classic CO2 laser. This leads to a larger melt volume which exits downwards and builds up as burrs. Due to the limited maximum power of the used beam sources and the associated low feed rate, the interaction time per path increment is significantly higher, which also leads to melting of the surrounding polymer. This effect is clearly visible by the high transmission rate of the PE material at 1940 nm (see figure 2). Accordingly, the material is completely heated through. In order to investigate this process in more detail, an off axis thermographic investigation and a thermal simulation of the cutting process are carried out in the following.

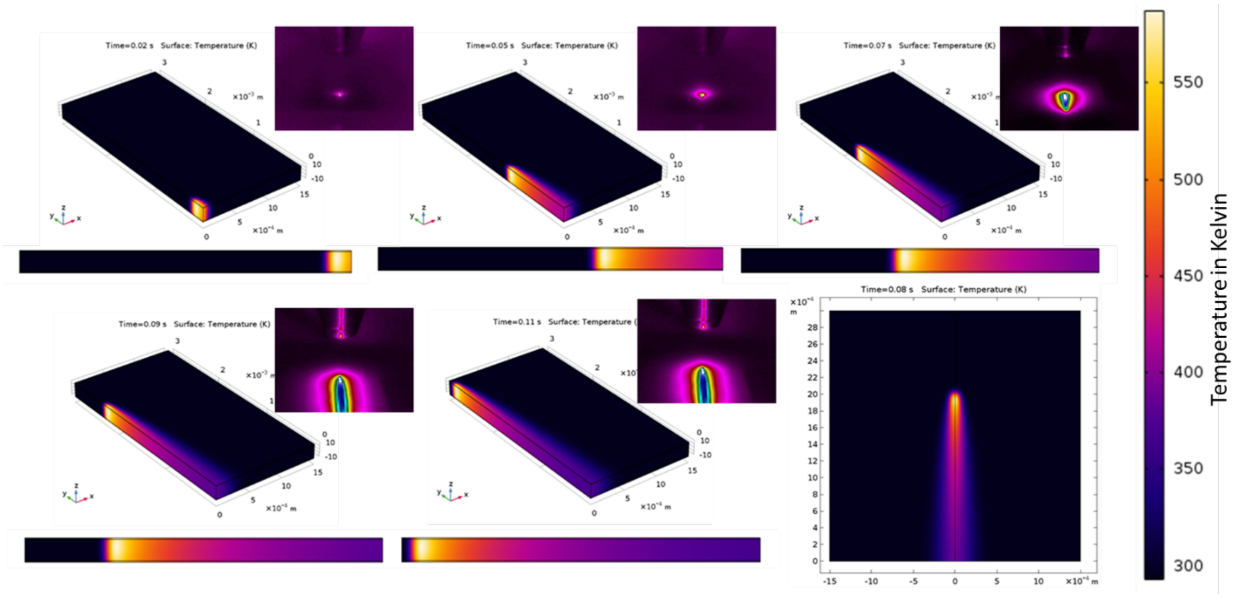

Fig. 4. Thermographic off axis recording and thermal simulation

The 3D view shows the PE material to be cut in five different time stages. The material is virtually exactly separated in the cutting joint, so there is the possibility to look into the material during the cutting process. This is done using an isometric view (1) on the one hand and with a direct view of the gap (2) on the other. For adjustment purposes, additional thermographic images taken during the off-axis process are shown under (3). However, the shown thermal simulation does not take into consideration the heat dissipated by the expelled melt. Nevertheless, it is easy to see how the highest temperatures are reached in the area of the changing interaction zone between the laser radiation and the PE material. If the temporal course of the image series is observed, the heat conduction from the cutting gap into the adjacent material can be observed well. This heat leads to a melting of the material and thus to a reduction in the edge quality and an increase in the width of the cutting gap. If the feed rate is now increased, this melted area of the surrounding material becomes smaller due to the shorter interaction time and thus lead to better the edge quality and a reduction of the cutting gap width (see figure 3) [7].

5. Conclusion and outlook

With a wavelength adapted thulium fiber laser system, the investigated PE polymer could be flexibly cut. An influence of the feed rate on the gap width could be identified. As the feed rate increases, the width of the cutting gap decreases. A thermal simulation model was set up for the detailed consideration of the temperature courses in the interaction zone. By using this thermal model the heat propagation over time during the cutting process can be observed. The experimentally determined correlations can be reconstructed here. Future investigations will be devoted to the more precise simulative and thermographic consideration of interaction time and heat input. A further scaling of optical performance should also be considered to increase by higher feed rates the interaction time and the cutting quality.

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