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Influence of Laser Cutting Parameters on CFRP Part Quality

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Abstract

Material processing of Carbon Fibre Reinforced Plastics (CFRP) parts by means of shape-cutting or jet-cutting technologies is state of the art today. These processes still perform in some applications with lack of part quality such as delamination and low productivity. Therefore, laser cutting processes have a great potential in material processing of CFRP. Laser process parameters have to be adjusted carefully in order to reduce the heat affected zone at cutting edge and influence on part quality.

Keywords: laser-based cutting, material processing, flash removal, automated material processing

1. Introduction

Laser cutting technology has been successfully established for processing of metal sheets and parts since the 1970s and is state-of-the-art today even in small and medium enterprises (SME). For processing of parts designed in Carbon Fibre Reinforced Plastics (CFRP) and similar composite materials laser technology did not yet launch industrially. In the late 1980s and early 1990s several research projects were conducted and were able to show great potential in processing of CFRP-parts by means of laser technology [1]. Since then laser beam sources have enhanced to a higher performance in terms of beam quality and industrial handling. Most promising brilliant and flexible beam sources as fibre and disc lasers were developed within the last ten years. Additionally, control and robot technology have improved and today automated and flexible material processing is state-of-the-art. The main goals of automated processing of CFRP-parts by means of laser technology are targeted at quality, high productivity and lowest cost in comparison to other technologies such as milling shape-cutting or water jet-cutting.

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2. State-of-the-art and current research for processing of CFRP material

Nowadays, water jet-cutting is used for processing of two-dimensional parts especially with high thicknesses of laminates. These processes still perform in some applications with lack of part quality and productivity. Shape-cutting technologies such as milling or drilling are state-of-the-art in nearly every application for processing parts made from CFRP today. However, because of high abrasive fibres the lifetime of expensive shape-cutting-tools is a great challenge and topic of several research projects [2].

Hence, the application of laser cutting technology has a great potential because of its wearless and forceless processing performance. Since the late 1980s and early 1990s laser processing of CFRP is topic of several research projects and is still today [3, 4, 5, 6, 7]. Because laser beam sources have enhanced to a higher performance in terms of beam quality and industrial handling laser technologies are used today in some industrial applications for processing of CFRP. One example is complete or selective ablation of first resign layer at CFRP parts for preparing these parts for varnishing or coating by means of a pulsed CO_2-Laser. Another example is trimming of thin automotive CFRP parts by means of a robot-guided CO_2-Laser system. Today, laser beam sources with a wavelength of about 1.0 µm such as solid state or fibre lasers are not yet used for processing of CFRP industrially. One challenge of laser processing of CFRP is the extension of so called heat affected zone (HAZ) at cutting edge, see Fig. 1. Because of these HAZ laser processing is not used in e. g. aerospace industry today. These HAZ is a result of big difference between the decomposition temperatures of resign and fibre material e. g. is decomposition temperature of carbon fibre about 3000 K and of epoxy resign about 550 K.

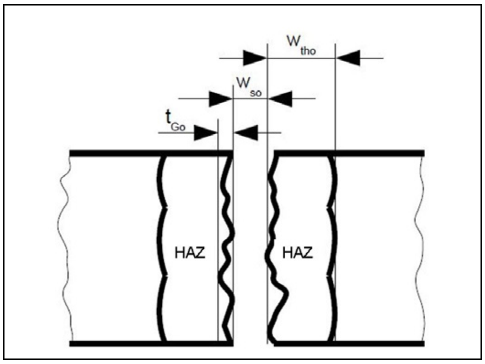

Fig. 1. Heat affected zone (HAZ) at cutting edge

In the past extension of HAZ was very high at about 1.0 to 2.0 mm [1, 4, 5, 7, 8] and therefore manufacturing engineers still do not reconsider laser processing of CFRP even though high quality of cutting kerf with a low HAZ is realisable today, see Fig. [q. v. 3, 4]. Therefore, laser beam cutting of CFRP by means of so called solid state or fibre laser beam sources has to be analysed because these laser beam sources provide several advantages concerning laser beam guidance or high degrees of electrical efficiency.

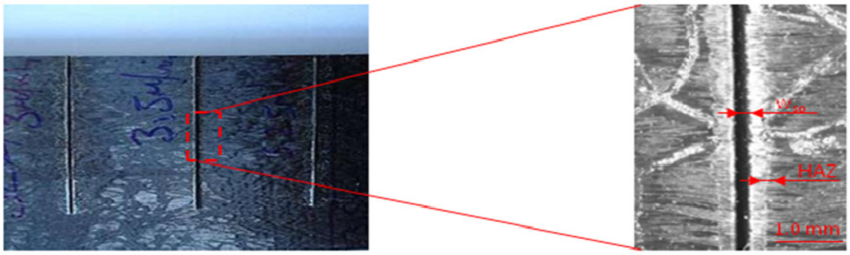

Fig. 2. Cutting kerfs and extension of HAZ

3. First results of experimental study

3.1. Determination of maximum process temperatures

In first investigations pyrolysis of used epoxy resign has been examined to determine maximum process temperatures at cutting edge. By a thermogravimetric analysis (TGA) mass reduction with rising temperature of a polymer could be analysed and maximum process temperature determined. Up to a temperature of about 280°C the epoxy resin is stable and nearly no mass reduction occurs. Mass reduction of about 0.5 to 1.0 percent is caused by evaporation of water which was bounded when a epoxy resin hardens. At temperatures above 280 °C the pyrolysis of the epoxy resin increases to a certain extend and at about 600 °C the epoxy resin is almost completely dissolved. Typically, a maximum process temperature between 80 to 120 °C is used for shape cutting or milling processes. As shown in Fig. 2 temperatures higher than 120 °C have no effect in the pyrolysis of epoxy resin up to a temperature of 280 °C. This described approach is well documented in several publications and was used for other polymer-resigns [4, 9]. Further studies will therefore focus on part quality at higher maximum process temperatures.

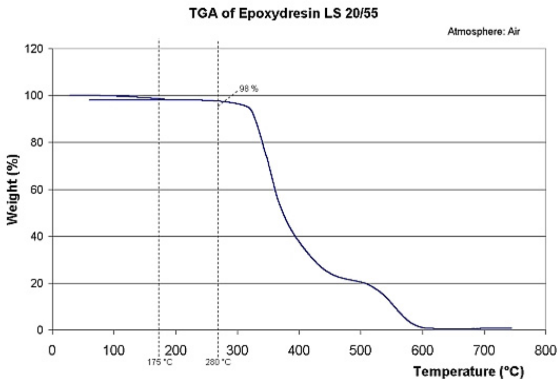

Fig. 2. Thermogravimetric analyis of a epoxy resin

3.2. Identification of relevant process parameters

Since the 1990s influence of laser cutting parameters on part quality was analysed carefully [1, 4, 5, 6, 8, 11]. The mayor parameters are shown in the cause-effect-diagram in Fig. 3. During these analysis it appeared that laser cutting parameters such as laser power, feeding rate, wavelength or laser control mode have a dominant effect on part quality. Therefore, these parameters have been varied and part quality analysed. A comparable experimental study has been conducted by Tagliaferi for processing of glas fibre and aramid fibre reinforced polymers [10].

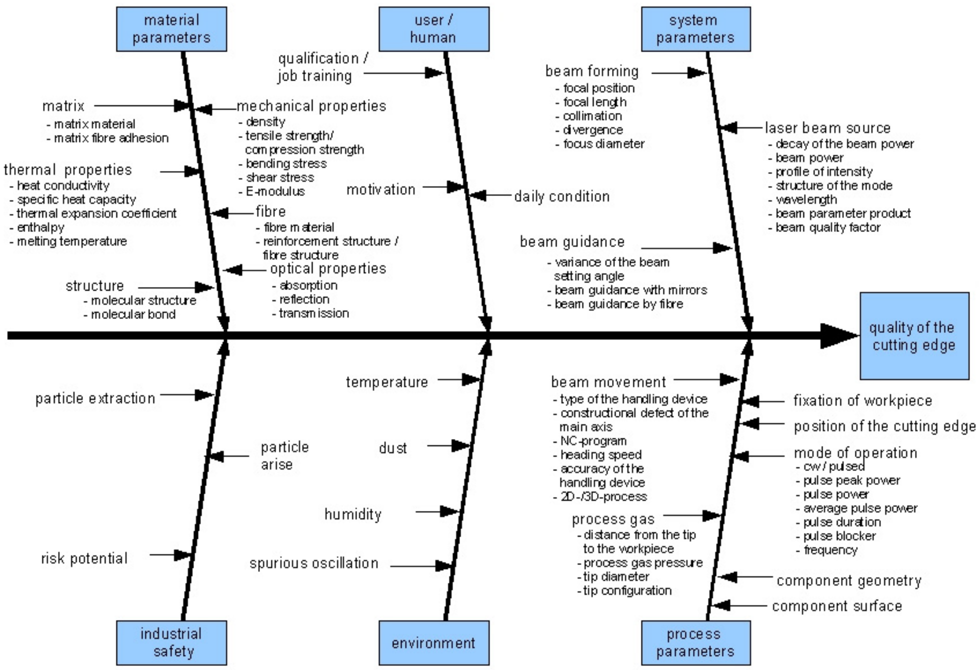

Fig. 3. Cause-Effect-Diagram of laser beam cutting of CFRP

3.3. First results of experimental study using continuous wave laser beam sources

In Fig. 4 the comparison of extension of HAZ and kerf width with rising feeding rate for laser beam cutting of a CFRP laminate by means of a Yb-doped fibre laser is shown. Both HAZ and kerf width are decreasing significantly with rising feeding rate and a constant laser beam power of 1.5 kW. Minimal kerf width is typically about focal diameter of 98 µm while the realised kerf width averages between 140 to 190 µm. This behaviour is explained due to laser-material-interaction and thermal interaction between vaporized and solid material at cutting edge. An extension of HAZ, as the area of temperatures above 120°C, between 440 and 550 µm is realised in this experimental analysis using a fibre laser. For a comparative analysis a CO_2-Slab-Laser has been used and an average HAZ between 300 and 350 µm was realised. With a rising feeding rate and therefore decreasing energy input per unit length both HAZ and cutting kerf width decrease clearly. Additionally, was demonstrated that both CO_2- and fibre laser beam sources are applicable for laser beam cutting of CFRP with high part quality. Wavelength of laser beam has still an influence on process quality and maximum feeding rate and therefore process productivity. But state-of-the-art fibre lasers have been able to show their industrial applicability even in continuous-wave control mode while other experimental studies have demonstrated these applicability for pulsed and super pulsed mode in the past [4, 12].

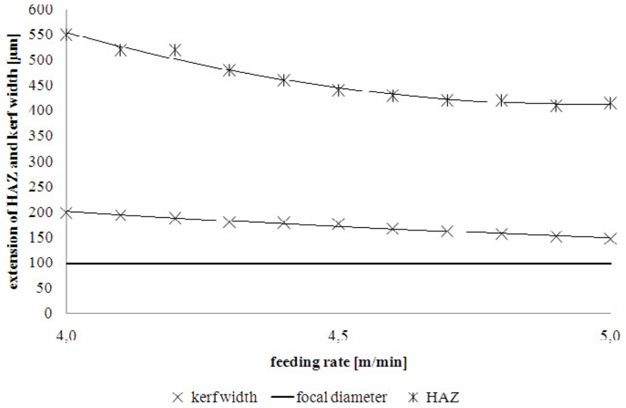

Fig. 4. Comparison of the extension of HAZ and kerf width with rising feeding rate for a CFRP laminate (1.0 mm thickness) by means of a Yb-doped fibre laser (laser power at 1.5 kW)

When processing CFRP laminates with a thickness between 1.0 up to 7.0 mm it turned out that significant higher absorption of 10.6 µm-wavelength of a CO_2-Laser has still advantages compared to a fibre laser with a wavelength of 1.07 mm. It is possible to cut CFRP laminates up to a thickness of 7.0 mm fail-safe by means of a CO_2-Laser and up to 5.0 mm by a fibre laser. A laser beam power above 5.0 kW was not yet analysed. This effect is explained by the two different mechanism of pyrolysis of polymer and fibre. The absorption mechanism for fibre laser radiation is typically called surface absorption because laser radiation is manly absorbed by material surface and heat is transmitted into material while on the other hand laser radiation of CO_2-Lasers is absorbed by material volume. Emitted laser radiation is therefore absorbed by polymer chains and is converted into heat energy by vibration excitation [q. v. 9, 13]. A higher amount of induced energy input is used for pyrolysis of CFRP laminate.

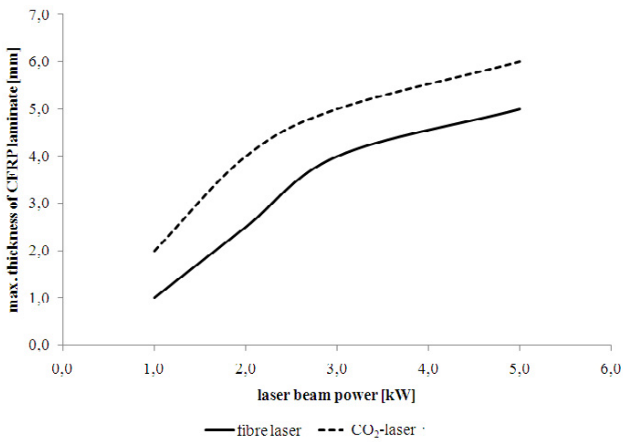

Fig. 5. Comparison of maximum CFRP laminate thickness that could be processes fail-safe by means of fibre or CO_2 laser with a constant feeding rate at 5.0 m/min

4. Conclusion

Laser technology offers great potential in processing of a great variety of materials. Especially in processing of metal it is the state-of-the-art technology. However, it has not yet been industrially used for processing CFRP. First studies concerning cutting CFRP-parts at the Institute of Laser and System Technology of Hamburg University of Technology demonstrated promising performance of laser cutting in terms of part quality and production costs.

Today, CO_2-laser beam sources are state-of-the-art for processing parts made from polymers or CFRP but fibre laser beam source demonstrated their industrial applicability especially for CFRP parts with a thickness of less than 2.0 mm. Wavelength of laser radiation and therefore absorption into material has still a significant influence on extension of HAZ and especially on maximum laminate thickness that could be processed fail-safe. A rising feeding rate leads to a decreasing HAZ and cutting kerf because of decreasing energy per unit length. It was shown that critical process temperatures could be determined by a TGA.

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