Deposit-free Cutting of Polycarbonate

Generate clean cutting edges with the correct process management

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Until now, it has not been possible to cut polycarbonate free from visible deposits using laser radiation. Through a smart process control it has been possible to produce cut edges which show no visible deposits or degraded material. The polymer, its additives, the process parameters and the process equipment determine the quality. Only their correct combination leads to good results.

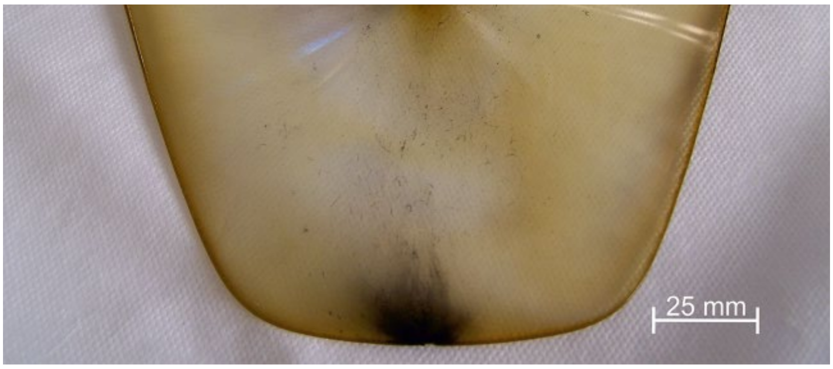

Fig. 1 Optical component in PC, cut with conventional CO_2 laser radiation. The component shows deposits of decomposition products.

Initial situation

Often, optical plastic components are made of polycarbonate (PC). It is mainly used in those areas which, in addition to a high optical transparency, also demand high requirements in respect of chemical, thermal and mechanical properties. In order to guarantee longer flow paths and wall thicknesses greater than $s > 2$ mm, the production of injection moulded optical components is done not with point gating, but with film gating. Thereby low stress components with the required optical quality are achieved. For this, film gates with sizes between 0.5 mm and 3 mm are designed.

In order to avoid rough surfaces and breakouts, the removal of the sprue does not happen automatically during the demoulding of the component from the injection moulding tool. The film gating makes a costly mechanical processing afterwards necessary. To this belong, amongst others, sawing, milling, stamping or hot cutting.

With these four possibilities, due to the toughness of the PC, often a cut edge is produced which shows microscopic cracks and an unallowable roughness. The microscopic cracks can lead to component failure and the rough surfaces ensure undesired light emission.To date, the deposit free cutting of PC using laser radiation has not been considered to be practical. Previous results show a yellowed and soot affected surface of the components, see Fig. 1. A higher surface quality, as with polymethyl methacrylate (PMMA) has not been possible [1].

Basics of cutting plastics

With laser cutting, the plastic is heated above its melting temperature. Due to the force of gravity and a cutting gas stream, the resulting molten mass is brought out of the cutting line. In addition, the plastic can depolymerise into readily volatile components due to the resulting temperature [2].

If the depolymerisation runs uncontrollably, as with PC, a series of unwanted by-products result. Amongst others, these are cyclical oligomers, phenyl and fluorenone [3].

The objective of this article is to show that it is possible to achieve a cut edge which is almost free from decomposition products. The cutting process should be able to be implemented in the industrial environment and with cut lengths up to $l = 10$ mm and below a cycle time of $t = 20$ s in order to ensure profitability. Thus it is possible in the future to cut polycarbonate using laser radiation without having to introduce limitations into the quality of the optical parts. In addition, the susceptibility to stress cracks through the molten surface is reduced.

Various sources report that PC can be cut free of decomposition using ultra short pulsed lasers (USP) because the plastic is vaporized during the process. With these lasers the process time lies in the area of $t > 10$ min and they have, therefore, been excluded from the project as a solution right from the start [4].

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The scientific core competences of Angewandte Kunststofftechnik include the themes of tool construction for injection moulding, qualification and validation of injection moulding tools and processes, laser welding and laser cutting of plastics, especially for medical and optical applications, product and process development in medical engineering taking into account DIN EN 13485 and the polymer engineering of thermoplastics.

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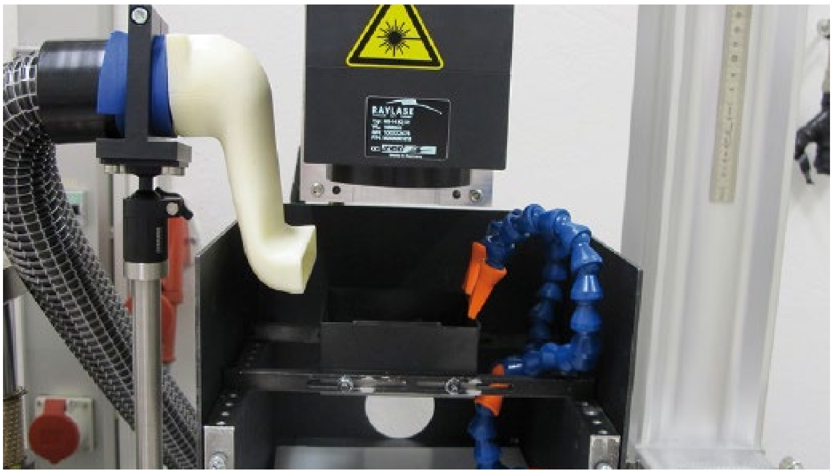

Fig. 2 CO_2 Laser test set-up for the cutting of polycarbonate.

Test method

The tests were carried out working with CO_2 lasers with a wavelength of λ = 10,600 nm and with various power ratings. First of all, a CO_2 laser from the Taufenbach company, Kiel, with an output power of P = 25 W was used, and then a laser from the Synrad company, Mukilteo, USA, with an output power of P = 200 W. The lasers were operated in continuous wave mode and pulsed mode. The processing of the test pieces was done via a scanner system and a cutting head. Fig. 2 shows the used laser set-up.

A stepped plate with heights h = 0.8; 1.5; 2.0; 2.5 and 3.0 mm was chosen for the test pieces in order to describe different sprue thicknesses. The dimensions of the test pieces were $l \times b$ = 56 × 60 mm. The test pieces were made from PC, type Makrolon 2405, Bayer MaterialScience AG, Leverkusen.

Cutting results

In preliminary tests using Design of Experiments (DoE), the parameters laser power and cutting speed were defined as decisive parameters for the cutting of PMMA.

The use of a shielding gas well with the scanner-supported laser appeared to be promising. A shielding gas (N_2 or CO_2) is fed into the shielding gas well so that the oxidation of the plastic during cutting is prevented. Fig. 3 shows the cutting result after the process under a nitrogen atmosphere.

In contrast to the initial situation, the deposits were significantly reduced. The cutting through of the test piece with a wall thickness of h = 0.8 mm was not possible without additional deposits. Due to these results a laser system with a cutting head was switched to.

Here, only in the lower area of the cut edge burnt plastic and deposits from the decomposition gases could be seen.

In order to mostly minimize the deposits, various other investigations were carried out. Amongst other things it was tested whether the use of dry ice, the prior masking of the cut edge with adhesive tape or the use of chilled compressed air would lead to better results. In addition the PC was provided with PMMA and additives in order to detect the effect on the cutting result.

None of these tests led to a satisfactory result. Either there were still deposits present on the cut edge or the

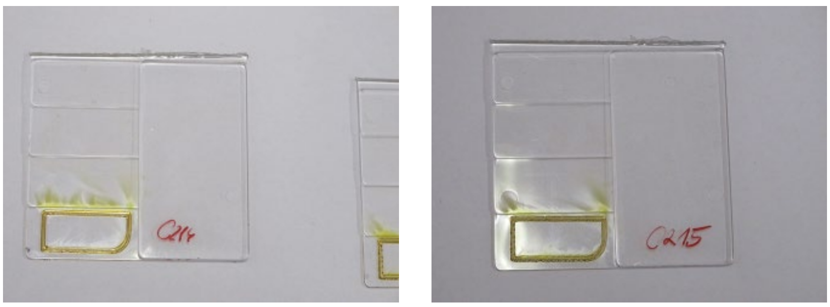

Fig. 3 Reduced deposits on the component surface through the use of a shielding gas.

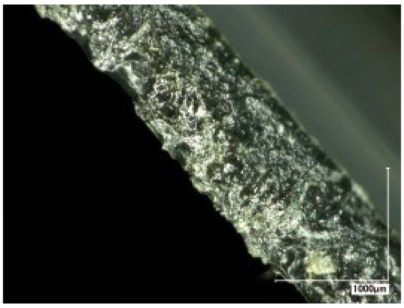

Fig. 4 Roughness of the cut edge when laser cutting PC with the use of dry ice.

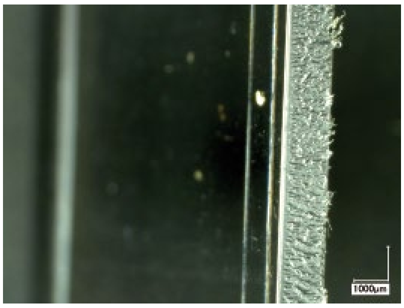

Fig. 5 Laser radiation cut PC without deposits or residues on the cut edge.

cut edge showed an unacceptably high roughness after the cutting, neither of which satisfies the desired requirements, see Fig. 4.

In order to further improve the quality of the cut edge, a change to the process equipment was made. The first tests were carried out using a scanner-based cutting system, followed by the use of a cutting nozzle. By the use of a cutting gas stream through the nozzle, the molten mass is carried out of the cutting groove and it cannot be degraded. Thus the molten mass forms fine threads which must be removed from the cutting groove. In addition, the cut edge had a wavy surface. Due to the melted surface, there are none of the microscopic cracks present which occur through separation by cutting or a similar process. This is accompanied by an increased stress crack resistance of the components. Fig. 5 shows the surface of a deposit-free separated PC cut edge. The surface appears typical for PC. The smooth cut surfaces which occur through the controlled depolymerization when cutting PMMA are not achievable with PC.

Summary and outlook

From the knowledge gained so far it can be concluded that the factors plastic, plastic additives, process equipment and laser parameters have a significant effect on the cut edge quality and / or the optical purity, see Fig. 6.

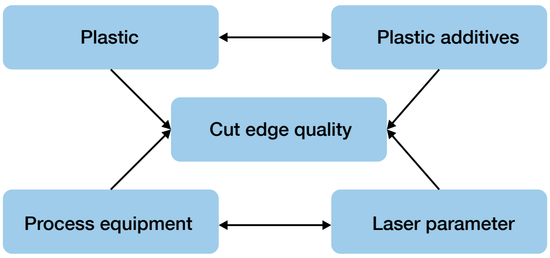

Fig. 6 Effects and interrelationships on the cut edge quality when laser cutting plastics

Finally it should be noted that the molecular structure of the PC and/or the additives has an influence on the results. Plastics with a lower viscosity lead to better results than PC types with a higher viscosity. The additives of the PC have a direct effect on the properties of the plastic and the quality of the cutting. It can be seen that, depending upon type, thermal and UV stabilizers and flame retardants tend to lead to a worse cut edge or are not separable.

The process equipment is another sucess factor, that is, the yellowing and deposit free cutting of high-performance plastics. According to the length of the cut edge and its course, cutting can be done with a scan system or a cutting nozzle. If a cutting nozzle is used, the formation of PC fibres on the cut edge must be reckoned with. These must be removed in order to avoid their accumulation in the component fixture or other machine components. In addition, extraction must be provided in the area of the cutting in order to prevent contamination of the air with the products of decomposition and to protect employees.

The use of inert gases as the cutting gas is not necessary. Through the use of compressed air, PC can more easily oxidize and forms mainly CO_2 as a decomposition product. Under an inert atmosphere, PC forms significant aromatic soot-like compounds (c = 20 to 30 weight %), which leads to the worsening of the cut edge quality and build-up of deposits [5].

In addition the laser parameters must be itemized as influences. The temperature occurring at the cut edge is decisively determined by the laser power and the interaction time between the laser and the component. The interaction time is determined by the cut length and the cutting speed. Based on a constraining minimum cutting speed to ensure the efficiency of the process, a low laser power should be selected. In our tests, line energy of $E_S = 0.4 - 8.3$ J/mm showed itself to be suitable.

If all important parameters are taken into account, components with a wall thickness of up to $t = 2.5$ mm can be cut without visible deposits. The process must be so carried out that the separation of the component is made in one cut.

Beside the new possibility of being able to machine PC using lasers without visible deposits on the cut edge, the following restrictions occured: Round contours cannot be detached from a component or a semi-finished product. Simple linear contours are better to cut. Furthermore, plunging the laser into the component is not possible deposit-free. The cutting must always start on an edge of the component. Additionally, steps in wall thickness during cutting lead to the formation of deposits on the surface of the component and should, therefore, be avoided. If the wall thickness of the component is greater than $t \geq 3$ mm only certain deposit-free cut edges are possible or, depending upon PC type, not possible.

Smooth cut edges such as those known from the laser cutting of PMMA cannot currently be achieved. Here, subsequent laser polishing can be a remedy.

Further efforts and investigations in the process research are necessary in order to remove the current restrictions. Thus improvements in the process control for round contours, the determination of the process requirements for steps in wall thickness and for components with a wall thickness greater than $t \geq 3$ mm. In addition, strategies for laser polishing the cut edge in one clamping should be developed.

Conclusion

Until now, the statement that PC cannot be cut with laser radiation without yellowing and soot formation in the area of the cut edge has been valid. However, it has been shown that, through the intelligent combination of plastic, additives, parameters- and machine configuration, a deposit-free cut edge is achievable. Thus, there is a cutting process which creates a stress crack resistant cut edge.

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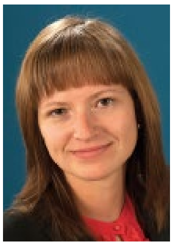

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