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CAx Process Chain for Automated Laser Drilling of Tool Molds

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Abstract: Rotation sintering, also known as slush molding, is used to manufacture molded skins, such as dashboards or door interior panels for cars. At present, approximately 80% of such molded skins are manufactured using electroforms to achieve the complex free-form surfaces, and surface structures, such as leather graining that the industry demands. The manufacture of these electroforms is, however, time-consuming and expensive. This project aims to replace conventional electroforms with laser-drilled molds. Holes in tool molds should be drilled by using laser radiation as part of an automated process. The system consists of a robot with a fiber-laser beam source. A CAx (computer-aided x) process chain has been developed for this purpose in which the CAD (computer-aided design) data of the tool molds are processed, drill hole fields generated, and a machine-specific RC (robot control) program created. Process-specific fundamentals, such as suitable process windows and process control, have been devised to manufacture holes using fiber laser radiation. The advantages of the new laser-drilled tool molds may result in substituting them for conventional electroforms, allowing old markets to be re-entered or additional markets to be created and targeted through new molds or lower costs.

Key words: Laser drilling, fiber lasers, tool molds, CAx process chain.

1. Introduction

Molded skins are used, e.g., in cars for dashboards or door interior panels. An example with the typical leather grain is shown in Fig. 1. These molded skins are manufactured by using slush molding.

In slush molding, also known as rotation sintering, a tool mold closed by a powder box rotates around one or more axes. The plastic powder fuses onto the hot mold surface and sinters together. After cooling, the result is a three-dimensional skin that exhibits very even wall thicknesses—regardless of the design complexity of the part. This is a particular strength of slush molding [1, 2]. The process steps for this method are schematically shown in Fig. 2.

There are two possible ways to manufacture the necessary tool molds for slush molding. The most widespread method is to use electroforming. Due to galvanic buildup, the tool molds are porous. The porosity is necessary so that air between plastic and tool mold can outgas. At present, approximately 80% of the tool molds are produced by this method, which is both time-consuming and expensive [4, 5].

Another way to manufacture these molds is to mill the tool forms, which have a constant wall thickness of approximately 5 mm, and then drill them afterwards with laser radiation. The air between tool form and plastic can outgas through these drilled holes, which have diameters < 200 µm. Until now, the laser drilling process has been performed manually by using flash lamp-pumped neodymium-doped yttrium aluminum garnet (Nd:YAG) laser radiation. For each single hole, an adjustment between tool mold and drilling optic is necessary to drill holes at the right position with the right angle. This takes about 2 min per hole. This time-consuming process should be replaced by using a

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Fig. 1 Example for a molded skin produced by slush molding for interior panels in cars [1].

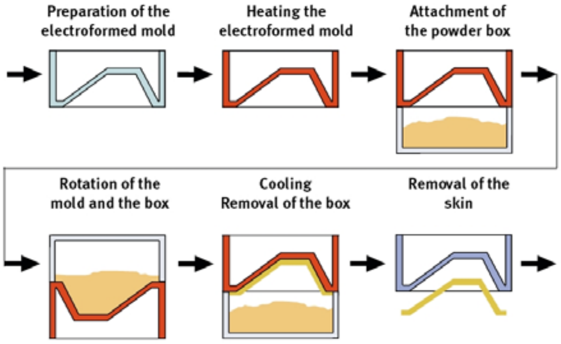


Fig. 2 Schematic of the process slush molding [3].

robot system for automated drilling including a complete CAx (computer-aided x) process chain. The paper is organized as follows: Section 2 introduces the overall concept; Section 3 describes the procedure of the process development; Section 4 contains the experimental setup for the drilling process; Section 5 presents results and discussions; and Section 6 gives conclusions.

2. Overall Concept

The basic data for the drilling process is the CAD (computer-aided design) data of the milled tool form. The concept for the following drilling process consists of two main parts:

(1) A software tool to generate a suitable hole grid onto the front side of the tool mold based on the CAD data, thus providing sufficient ventilation between the tool mold and the plastic. For this application, the distance between any two holes should be 5 mm. Due to restrictions such as supporting structures at the back wall of the tool mold, the angles of some holes have to be changed to create a grid with a constant distance between any two holes. The result is a specific RC (robot control) program to control the robot in combination with the laser system technology;

(2) The system technology for the drilling process consisting of a robot, a laser beam source and a drilling optic. This equipment is controlled by the robot control based on the generated RC program. The main aspect for the Chair for Laser Technology within this project is to develop the specific drilling process.

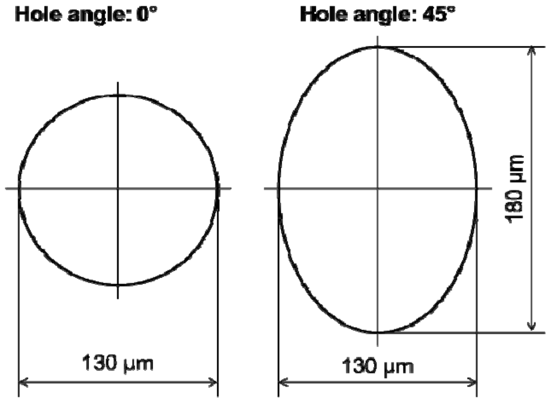
3. Procedure of the Process Development

All venting holes have to be drilled from the outer side of the tool mold so that the inner side, where the plastic is formed, is not damaged by any melt spatters. Thus, the geometrical quality, especially the size of the diameter of the hole exits, is important.

The hole exit diameter has to be smaller than 200 µm so that marks of the holes on the produced plastic products are avoided. Furthermore, the hole exit diameters should be larger than 100 µm so that a sufficient ventilation between tool mold and plastic product, such as molded skins, is available. Different hole angles are necessary to achieve an evenly distributed hole grid with a distance between any two holes of 5 mm for a ventilation over the entire tool mold. The angle should vary in steps of 5° between 0° and 45°. Thus, it is necessary to develop ten different laser programs due to different required pulse peak power and number of pulses according to the angle of the holes. The hole exit diameter at 0° should be 130 ± 10 µm. Thus the maximal extension of the hole exit at 45° is 180 µm ± 10 µm (Fig. 3).

4. Experimental Setup

A pulsed fiber laser source YLS-600/6000-QCW from IPG Photonics with a 50 µm feeding fiber is used for these experiments. The maximal pulse peak power of this laser source is 6,000 W. The repetition rate can be set from 10 Hz up to 500 Hz and the pulse duration



(a) (b)

Fig. 3 Schematic of the hole exit geometries at a hole angle of (a) 0° and (b) 45°.

from 0.2 up to 10 ms. The emitted laser radiation has a wavelength of 1,070 mm. The times-diffraction-limit-factor M^2 is approximately 7. The required pulse peak power depends on the angle the holes should be drilled.

A drilling optic from Reis Lasertec with a slim nozzle holder is used to reach difficult accessible areas of the tool mold. The collimating length is 85 mm and the focal length 125 mm. Due to this optical setup, the focal diameter is approximately 90 µm. Oxygen is used as process gas at a pressure of 6 bar. The distance from the nozzle to the work piece is 2 mm. The laser beam is focused onto the surface of the work piece.

The material, 40CrMnNiMo8-6-4, is a specific tool steel with high sulfur content, which is used especially for tool molds [6]. The work piece thickness is 5 mm for these experiments.

In order to optimize the surface quality at the hole entry side, interpulse shaping is used at the begin of the drilling process of each hole. When interpulse shaping is used, the dimension of the spatter on the work piece surface becomes smaller and can be removed easily by wiping over the surface by hand. Thus, following process steps such as grinding of the surface can be avoided [7].

5. Results and Discussions

5.1 Process Development

Thanks to experience from previous projects, high pulse peak powers such as 6 kW are known to cause large hole exit diameters. Furthermore, large pulse durations > 500 µs cause lower surface quality due to spatters or noncircular hole diameters [8].

In a first series of experiments, the pulse duration and repetition rate are varied at constant pulse peak power at a hole angle of 0°. The comparison of the results shows that combining a pulse duration of 300 µs and a repetition rate of 50 Hz leads to suitable results regarding hole exit diameter and drilling time. These parameters are fixed for all further experiments.

For different hole angles, the number of pulses and the pulse peak power have to be adapted. The numbers of pulses required for different hole angles are shown in Fig. 4 and 5, which show the required pulse peak power for different hole angles. Due to the maximum exit diameter, pulse peak powers larger than 3,000 W are not suitable. Thus, large numbers of pulses are necessary to drill a through hole at larger angles of 35°, e.g., 1,200 pulses for a hole with an angle of 45°.

As mentioned above, interpulse shaping, also known as ramping, is useful to prevent spatters on the work piece surface. The increase of the pulse peak power is shown in Fig. 6 for a hole with an angle of 45°. Within the first 25 pulses, the pulse peak power is increased linearly from 600 W up to 3,000 W. The following 1,200 pulses with constant pulse peak power of 3,000 W are necessary to drill the through-hole with a depth of around about 7 mm.

Fig. 7 shows a longitudinal section of holes with an angle of 45°. The holes are drilled from the upper side. A close up view of the hole exit is shown in Fig. 8. The hole diameter is 126 µm and the largest extension at the surface is 174 µm.

5.2 Process Chain

A software tool called “MeshLab” has been developed for this purpose. The CAD data, e.g., of a tool mold, can be imported into the software. The software puts a grid of holes with a distance of 5 mm between any two holes onto the front side of the tool mold. The angles of the hole axes are adapted based on

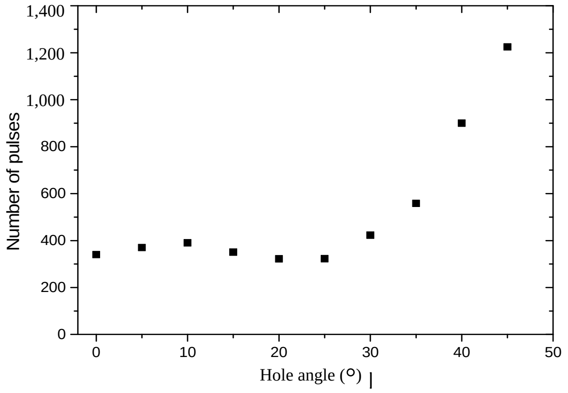


Fig. 4 Required number of pulses for hole angles from 0° up to 45°.

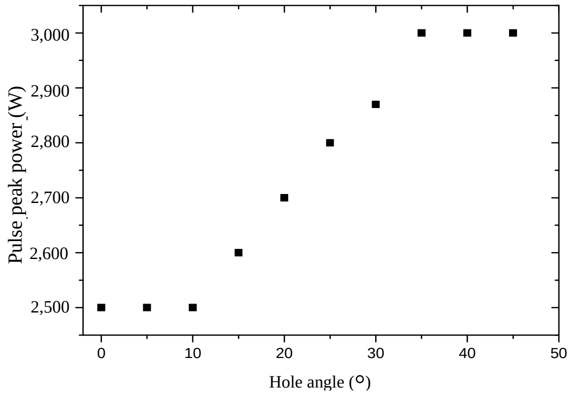


Fig. 5 Required pulse peak power for hole angles from 0° up to 45°.

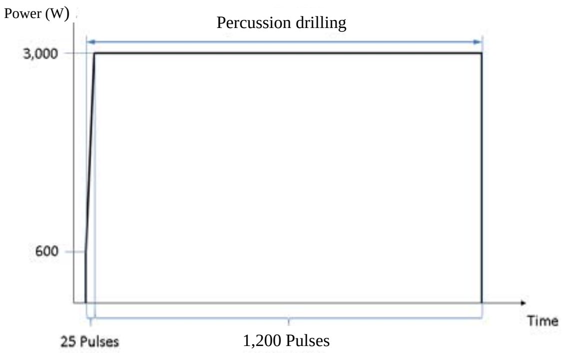


Fig. 6 Adaption of pulse peak power while drilling a hole with an angle of 45° into 5 mm thick material.

Fig. 7 Longitudinal section of holes drilled into 5 mm thick material with an angle of 45°. The holes are drilled from the upper side.

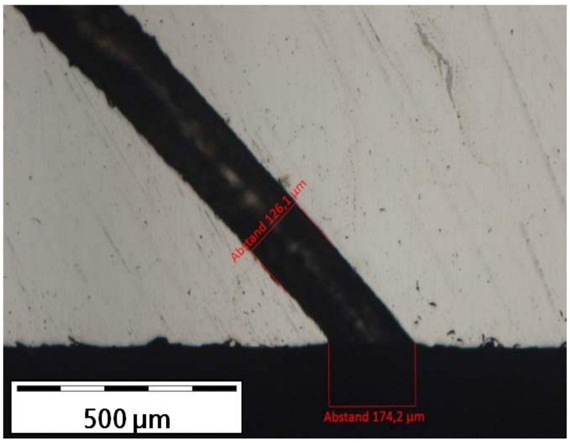


Fig. 8 Close up view of a longitudinal section of a hole exit due to Fig. 7.

certain restrictions, such as supporting structures at the back wall. Hence, each hole is not deeper than 7.1 mm. A screenshot of the back side of the tool mold is shown in Fig. 9. All holes which should be drilled are marked with a blue dot. The yellow lines mark the hole axes of each hole. The axes are not perpendicular next to supporting structures so that the distance of 5 mm between any two holes on the front side can be met.

The next step is the generation of a RC program to control the robot and the laser source by using a specific post processor including information about the axes and workspace of the robot. Furthermore, the RC program calls different laser programs depending on the angle of the specific hole to be drilled. In addition, the complete drilling process can be simulated by using a robot-specific tool. Thus, errors or interruptions during the drilling process can be avoided. The process chain is schematically shown in Fig. 10.

6. Conclusions

The use of laser-drilled tool molds offers the following advantages over electroforms: New, e.g., sharp-edged tool mold geometries and also new surface structures can be manufactured; Furthermore, shorter market response time and time to market are achievable; In combination with the new drilling process by using fiber laser radiation and a complete CAx process chain, the costs per tool mold are lower.

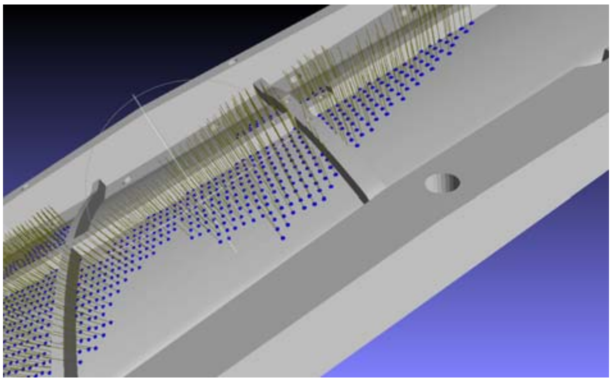


Fig. 9 Screenshot of the CAM (computer-aided manufacturing) software MeshLab showing the back side of a tool mold with supporting structures. The blue dots are points where a hole should be drilled.

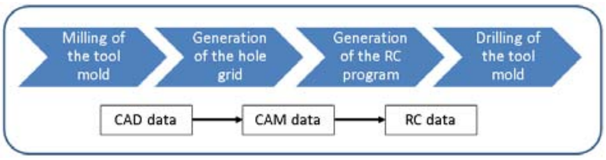


Fig. 10 Chain of process steps and data format.

The drilling time per hole with angles from 0° up to 30° is approximately 8 s and for holes with angles up to 45° is approximately 24 s. The movement of the robot from one hole to another hole takes less than 1 s. In comparison, the process time is approximately 2 min per hole using manual adjustment and flashlamp-pumped Nd:YAG laser sources for drilling.

By implementing new functions, the software MeshLab can not only be used for laser drilling processes, the plug-ins for other processes such as laser cutting could also be developed so that the robot system can be used multifunctionally.

The implementation of an on-line process control such as measurement of hole diameters or detection of the break through point into the process chain might be useful in the future.

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