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Laser-assisted Shearing of Stainless Steel and Spring Steel Plates with the Use of a Laser Scanner System - New Hybrid Production Technology for the Sheet Metal Industry

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Abstract

The Fraunhofer IPT recently developed a new hybrid laser-assisted shearing process which enables conventional punching machines to produce punched sheared edges with continuous flush-cut surfaces in stainless steel plates (1.4301), spring steel plates (1.4310) and titanium alloy plates (3.7165). The new combination of localised laser-induced softening of the plate material in the shearing zone and the shearing process significantly reduces both process forces and process-related noise emissions. A modular system-upgrade for existing punching machines allows laser-assisted shearing to be implemented without the need for expensive new machine designs. The principle of the laser-assisted shearing process is based on briefly and selectively heating the material in the shearing zone via local absorption of laser radiation on the underside of the sheet metal plate before the punching tool comes into contact on the upper side of the metal plate. Laser-induced heating softens the material in the shearing zone within the material within a few tenths of a second. The laser-induced softening mechanisms also lead to a significant decrease of cutting forces as well as a reduction of tool wear, warping and noise emissions.

Keywords: Processes, Process optimisation, laser-assisted shearing, laser-assisted blanking

1. Introduction

Due to the growing ranges of applications for stamped parts in the electrical and electronics industry (e.g. switch cabinets and transformer plates) as well as in the automotive industry (e.g. stamp, bent and drawn components), flexible sheet metal forming has become a more important process. The inner and outer contours as well as the forming operations needed to reinforce metal sheets can be carried out by punching machines without re-clamping the metal sheet. In contrast, the potential of conventional punching machines is now exhausted in terms of the material spectrum that can be processed, the tool life and the quality of the machined product. Particularly in view of the machining quality of the sheared edges, the achievable flush-cut surface rates are limited due to the limited plasticity of the sheet materials. When cracks form between the grain boundaries of the sheet material during the conventional shearing process, the cutting edge is divided into a flush-cut surface zone (approx. 30% of the plate thickness when shearing stainless steel plates: 1.4301) and a shearing zone with crack formation. This shearing zone

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can not be used as a functional surface. The shearing process is divided into the four phases (DIN 8588) "warping", "flush-cutting", "fracture" and "ejection of the piece punched out". The Development of a new hybrid laser-assisted shearing technology aimed at the following objectives (Figure 1):

- Increase of flush-cut surface ratio
- Decrease of cutting forces
- Reduction of tool wear
- Reduction of edge warping
- Decrease of process-related noise emission
- Increase in range of machinable materials (greater thicknesses, high-strength materials)

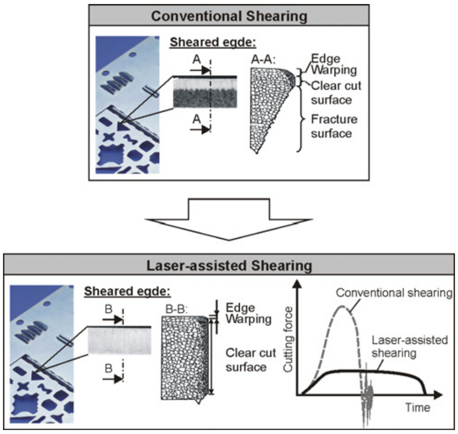

Fig. 1. Drawbacks of conventional shearing and objectives of laser-assisted shearing

The principle of the laser-assisted shearing process is based on briefly and selectively heating the material in the shearing zone via local absorption of laser radiation on the underside of the sheet metal plate before the punching tool comes into contact on the upper side of the metal plate (Figure 2). Laser-induced heating softens the material in the shearing zone within the material within a few tenths of a second. The laser radiation stops directly at the moment when the punching tool comes into contact with the workpiece, so there is no time delay between laser radiation and shearing.

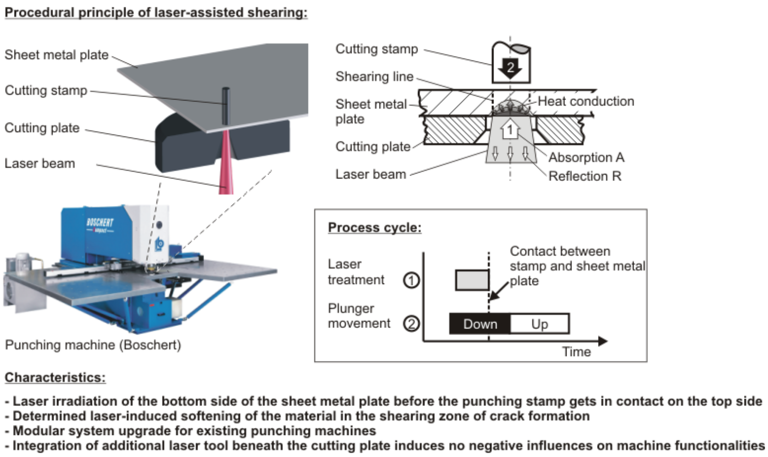

Fig. 2. Procedural principle of laser-assisted shearing

2. State of the art: Conventional Shearing Process

The conventional shearing process is divided into the following five phases [1] (Figure 3):

- Phase 1: The punching tool comes into contact with the sheet metal plate.
- Phase 2: The movement of the punching tool introduces compressive stress into the sheet metal. This stress is transmitted through the material and into the matrix. The compressive stress leads to elastic deformation of the sheet metal plate.
- Phase 3: The compressive stress exceeds the yield strength of the workpiece material, causing plastic deformation of the sheet metal plate. This leads to edge warping and the clear-cut surface.
- Phase 4: The breaking limit of the work piece material is exceeded, leading to the fracture phase. Crack formation begins at the edge of the punching matrix.
- Phase 5: After separation from the punched area, elastic stress is released, causing elastic vibrations in the workpiece.

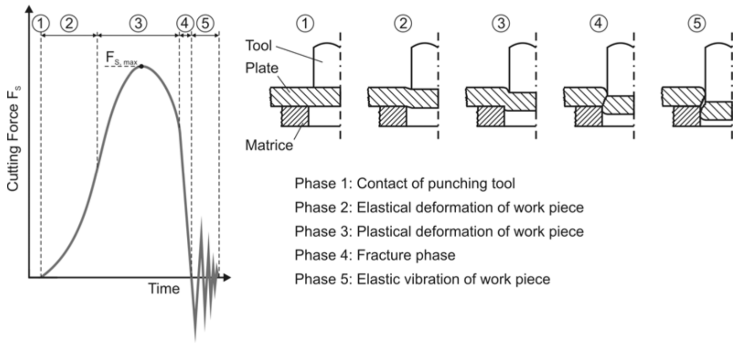

Fig. 3. Phases of the conventional shearing process

The fundamental precondition for the mechanisms of the laser-assisted shearing process is the decrease of material strength as a result of localized laser-induced heating [2]. Previous investigations confirmed a significant loss of material strength at increased material temperatures in, for example, stainless steel, titanium and nickel alloys, as well as ceramic materials [3].

3. State of the art: Laser-assisted Shearing of Circular Hole Geometries [4]

(Results of this chapter 3 have been published within “The International Journal of Advanced Manufacturing”: “Laser-assisted shearing: new process developments for the sheet metal industry” Technology, ISSN: 0268-3768, 2010)

3.1. Punching Machine with Integrated Laser Optics

A conventional punching machine has been equipped with an additional system upgrade at the Fraunhofer IPT (Figure 4) for the purpose of these developments. The laser system components are integrated underneath the punching plate. The system upgrade does not, therefore, have a negative effect on the functionalities of the conventional punching machine, e.g. the working room or the automatic tool change system. The additional shutter system with integrated cross-jet nozzles and chip guidance prevents contamination of the sensitive laser optics with material chips or dirt. The additional control system communicates via a profibus interface with the machine control system and triggers the system components »laser source«, »shutter system« and »cross-jet«.

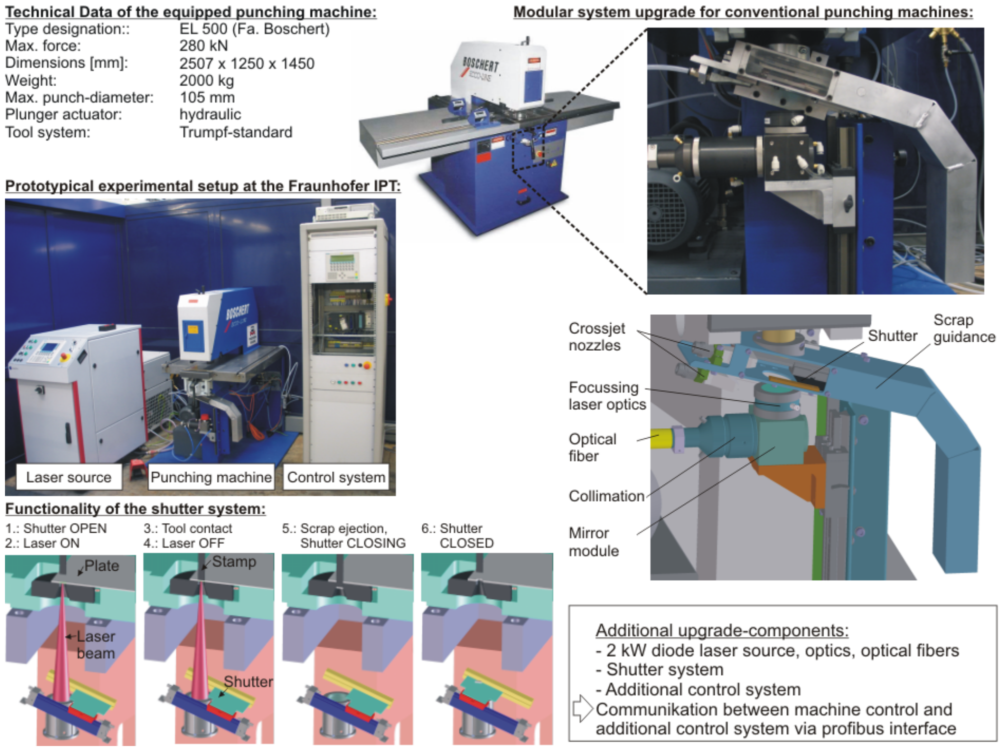

Fig. 4. Experimental setup for the laser-assisted shearing

3.2. Process Results

A conventional punching machine has been equipped with an additional system upgrade at the Fraunhofer IPT. In the following exemplary process results are illustrated regarding the shearing of stainless steel plates (1.4301) with a material thickness of 3 mm.

System specifications:

- High-power diode laser system (LDF 2500 - 1000, Laserline)
- Laser spot diameter: 6.3 mm
- Top-head laser intensity distribution
- Punched hole diameter: 6.5 mm

The upgraded machine system was operated with a static laser spot diameter of 6.3 mm to irradiate the underside of the sheet metal plates. The punching geometry was restricted to a circular geometry. Further research activities involve the integration of a laser scanner into the punching machine in order to achieve other hole geometries during laser-assisted shearing as described in chapter 4. The following process results refer to a 6.3 mm static laser spot diameter on the sheet surface and to the punching of circular holes with a 6.5 mm diameter. The laser radiation always stops directly at the moment when the punching tool comes into contact with the workpiece.

In comparison to conventional shearing, laser-assisted shearing of stainless steel plates (1.4301) leads to an increase in clear-cut surface ratio from approx. 35% to 90% (Figure 5). Here, the cutting forces are reduced by over 70% and warping at the cut edges decreased by over 60%.

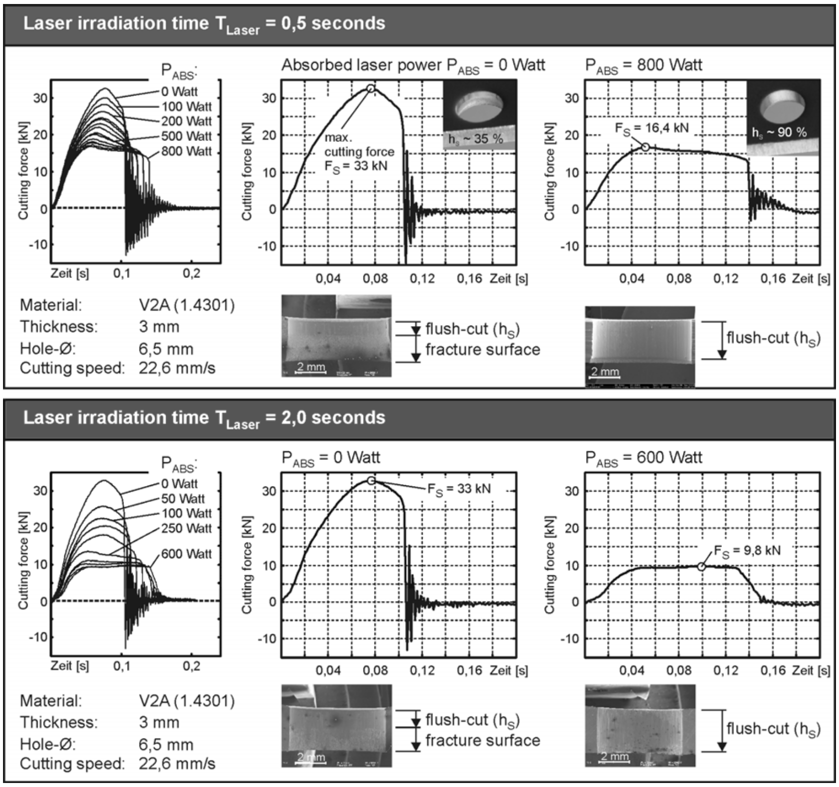

Fig. 5. Reduction of cutting forces by laser-assisted shearing

Figure 6 sows the interdependencies between laser power, laser irradiation time and the resulting cutting forces and flush-cut rates. In Addition to the machining of stainless steel plates, comparable clear-cut surfaces can be achieved regarding the laser-assisted shearing of titanium plates (TiAl6V4) with the aid of a laser. The achievable maximum clear-cut surface rate when punching 8 mm thick stainless steel plates (1.4301) is approx. 75% (laser radiation time: 0.5 seconds, laser power: 2300 Watts). Here, the maximum cutting forces are reduced by more than 40%. Furthermore the laser-induced softening of the material leads to a significant process-related reduction of noise emissions: the noise level during conventional punching of stainless steel (1.4301, material thickness: 3 mm) is approx. 93 dB(A). Laser-assisted shearing reduces the noise level by over 10 dB(A).

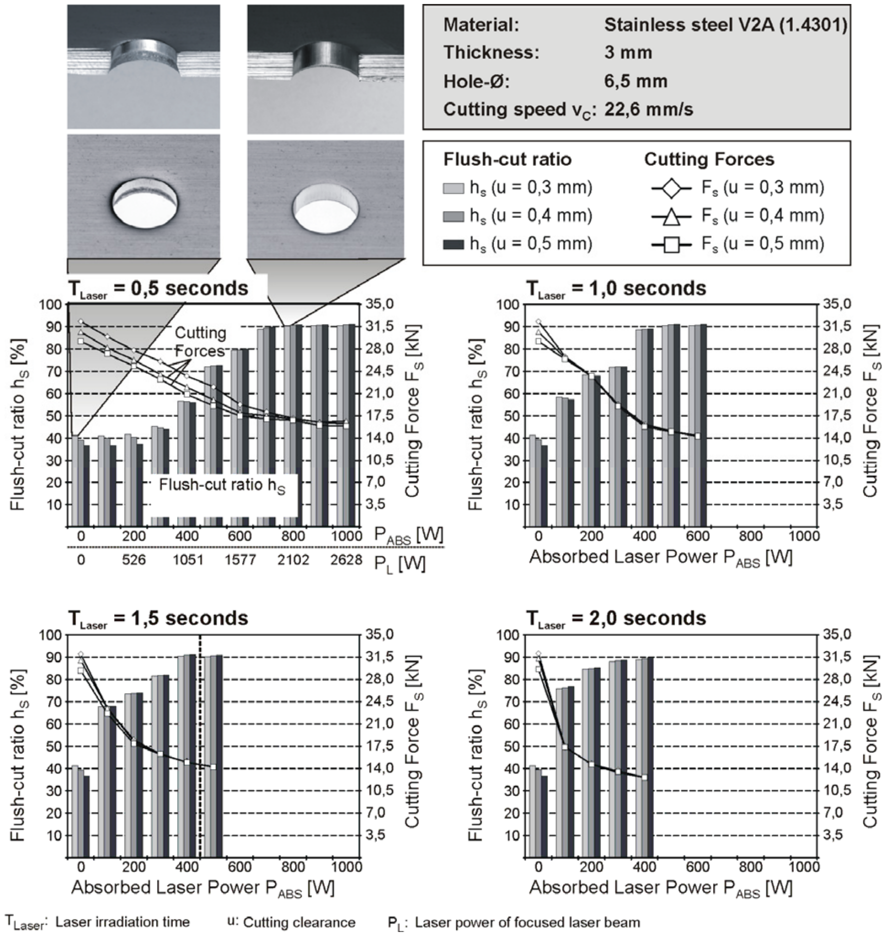

Fig. 6. Cutting forces and flush-cut rates at different laser irradiation times

Current process results for laser-assisted shearing of 1 mm, 2 mm, and 3 mm thick spring steels (1.1248 and 1.4310) show clear-cut surface rates of 100% of material thickness; cutting forces are reduced by 80% (Figure 7). Compared to stainless steel plates, spring steel has only an insignificantly lower edge warping after laser-assisted shearing.

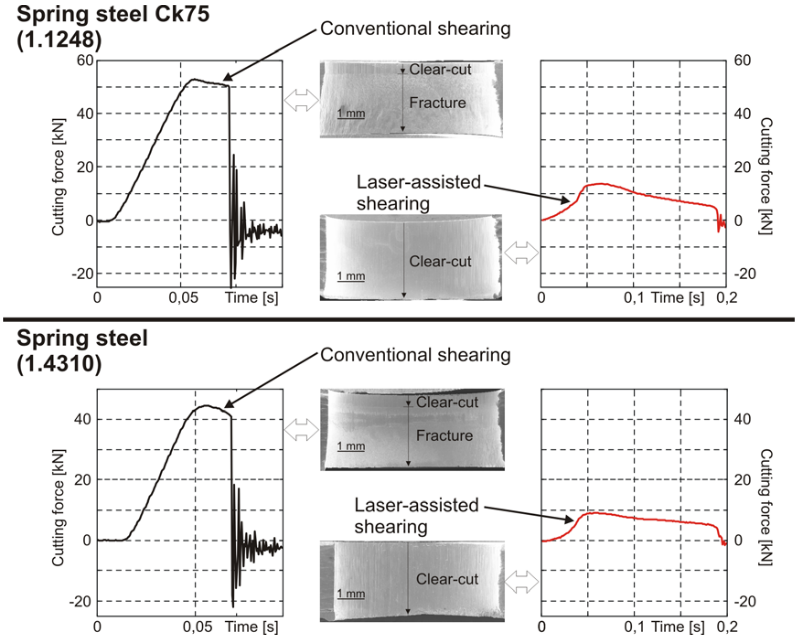

Fig. 7. Laser-assisted shearing of spring steel: reduction of cutting forces
(material thickness: 3 mm, laser radiation time: 0.5 seconds, laser power: 2000 Watts)

4. New approach: Laser-assisted Shearing of Different Hole Geometries by the Use of a Laser Scanner System

4.1. Punching Machine with Integrated Laser Scanner System

The laser-assisted shearing of different hole geometries within one punching machine requires the generation of different laser spot geometries according to the hole geometries. Within the InnoNet project “Hybrid-Punch” (funded by the BMWI, IN-7026) a laser scanner system has been integrated into the punching machine (Figure 8).

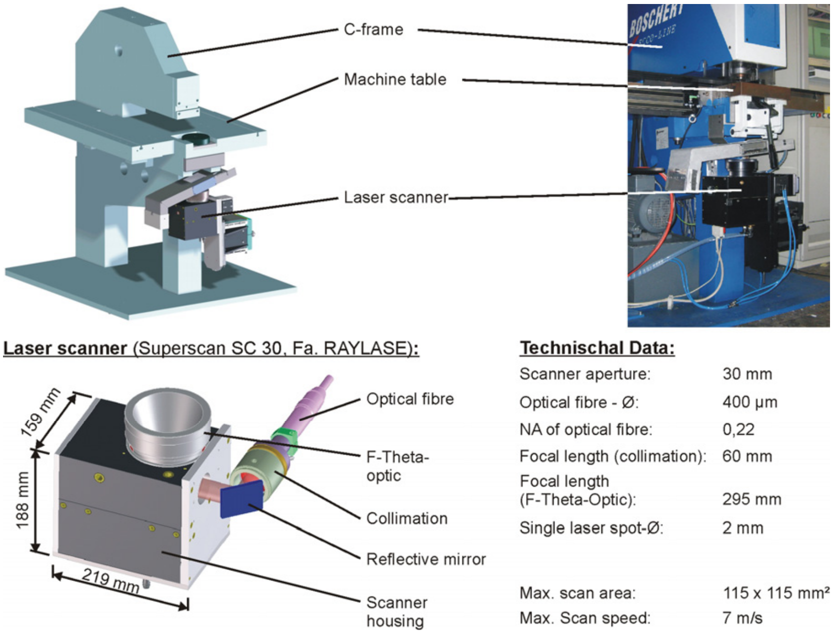

Fig. 8. Integration of a laser scanner system

The scanned laser spot geometry can be adapted within the scan area with the help of a scanner software. A first validation of the scanner-based laser-assisted shearing has been realized by the generation of a circular ring geometry of the scanned laser spot (Figure 9).

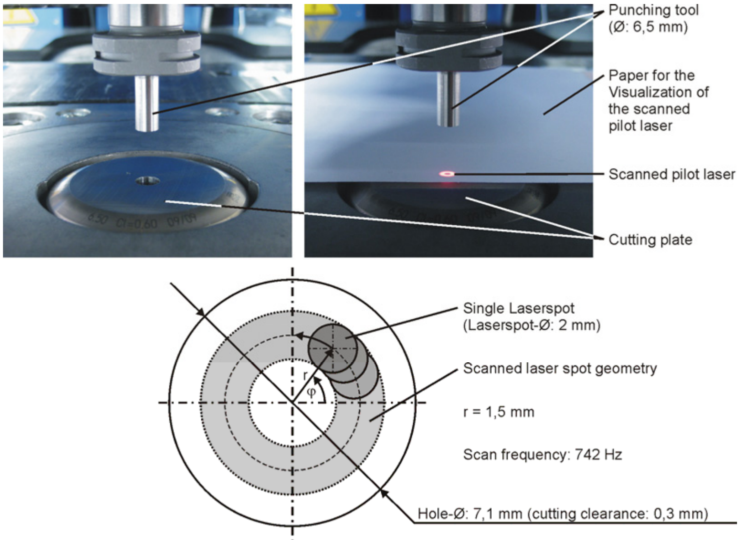

Fig. 9. circular ring geometry of the scanned laser spot

As shown in Figure 10, the maximum flush-cut rates of 90 % can be also achieved by the scanner-based laser-assisted shearing.

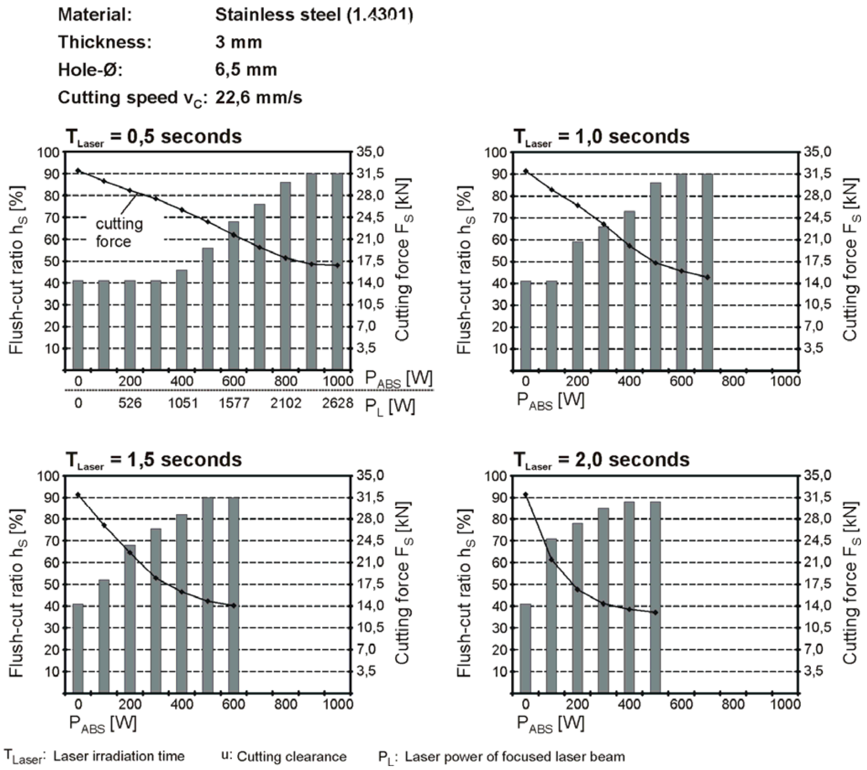

Fig. 10. Cutting forces and flush-cut rates at different laser irradiation times

Further investigations comprised the shearing of a triangular hole geometry as shown in Figure 11. In comparison to the shearing of the circular hole geometry with the hole diameter of 6,5 mm, the laser-assisting shearing of a triangular hole geometry also leads to an increase of the flush-cut ratio (Figure 12) but the maximum of 90% is not achievable due to the heat conductivity of the material. The max. flush-cut ratio is limited to 70 % of the material thickness.

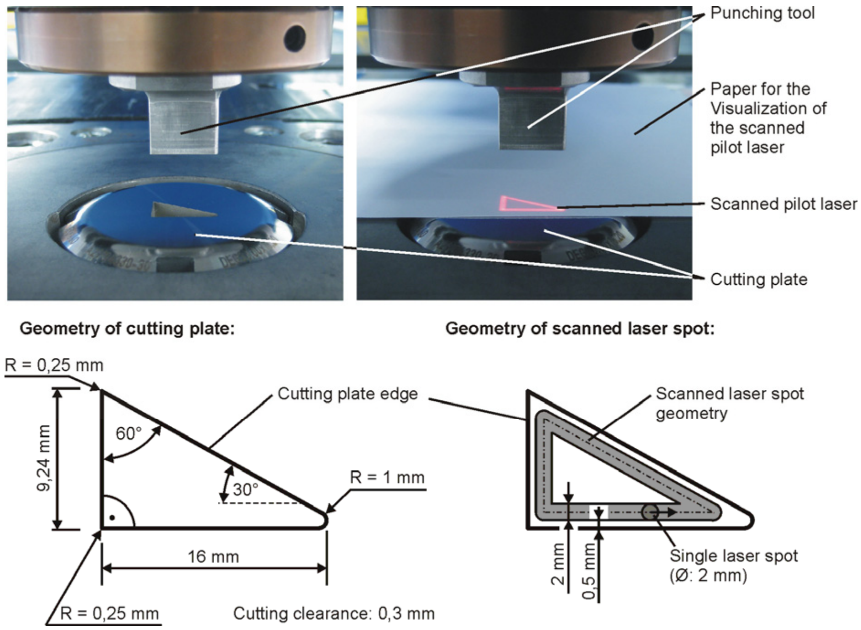

Fig. 11. circular ring geometry of the scanned laser spot

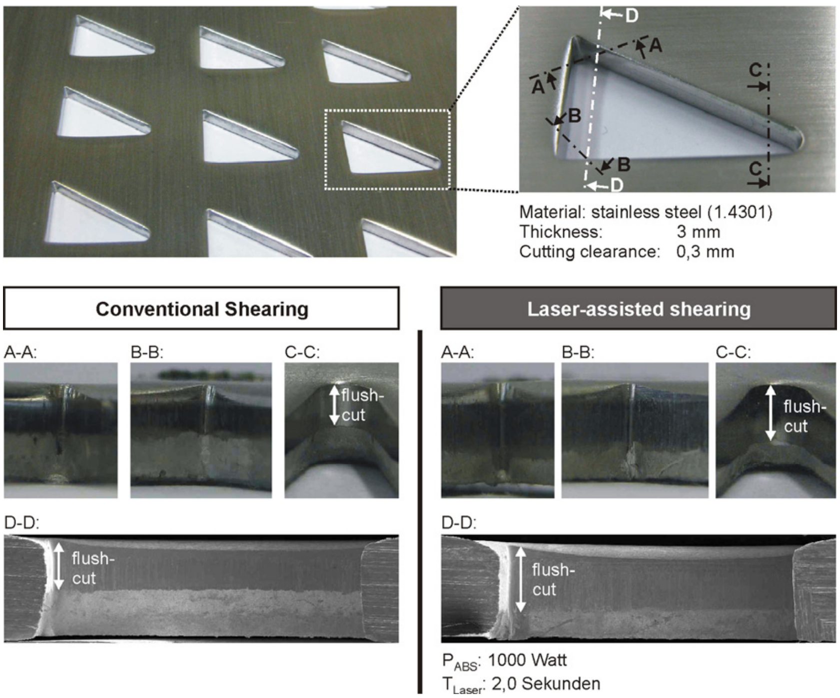

Fig. 12. circular ring geometry of the scanned laser spot

5. Summary

In comparison to conventional shearing, the laser-assisted shearing process maximizes the clear-cut surface ratio through the use of existing conventional punching machines that contain a modular system-upgrade for laser-assisted shearing. The cutting forces, edge warping and noise emissions can also be significantly reduced. Laser-assisted shearing of stainless steel plates (1.4301, material thickness: 3 mm) and titanium plates (TiAl6V4, material thickness: 3 mm) leads to clear-cut surface ratios of 90%. The cutting forces are reduced by over 70%. The process-related noise level is reduced by over 10 dB(A).

In terms of the laser-assisted shearing of spring steel plates, the achievable clear-cut surface ratios are 100% of the material thickness (materials: 1.1248 and 1.4310, material thickness: 3 mm). Here, the cutting forces are reduced by 80%.

The laser-assisted shearing by the use of a laser scanner system has been validated. The process results at the shearing of circular hole geometry (diameter: 6,5 mm) lead to a maximum flush-cut surface of 90 %. The achievable flush-cut surface regarding the shearing of a triangular hole geometry is limited to 70 %.

6. Literature

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