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Feasibility study for the automation of a selective laser deburring process

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Abstract

In the field of deburring processes a totally automated solution is not available. Selective Laser Deburring (SLD) is a laser based edge-refinement process for sheet-metal parts which is being developed at the LZN. It is wear-free and one laser source is used to remelt burrs and edges of different materials to a defined edge radius. This study analyses the feasibility of the laser-based deburring in automated industrial plants. The aim is to clarify if a deburring of complex sheet metal parts is possible.
Preceding studies examined the SLD process parameters and a thermographic quality assurance with short and linear edges. Based on these studies the deburring quality over long edges, different orientations of the deburred edge and the transition between deburred edges are investigated in this paper. This experimental study leads to recommendations for automated SLD process chain solutions.

Keywords: Selective Laser Deburring; laser cutting

1. Introduction

Deburring is a necessary production step to grant practicality, safety and aesthetics of parts (Beier 1999; Schäfer and Breuninger 1975). In some applications up to 9 % of the production costs are used for the removal of burrs (Arrazola 2010). Therefore automated deburring is an important field for modern production. One approach for automated deburring using laser radiation is being developed at the LZN in Hamburg. It is possible to remelt, cut, sublimate and oxidate burrs with the help of laser radiation (Schmidt-Sandte 2002). The Selective Laser Deburring (SLD) process remelts burrs and edges to defined radii. A system

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consisting out of a laser scanner and a solid-state laser, grants fast and wear-free processing of different materials. This high process velocity and the adjustable deburring result are the main advantages of the SLD process.

Preceding studies (Surrey et al., 2016) showed that sharp edges and burrs like in Fig. 1(b) can be remelted to round edges. It also became clear that the laser beam needs a certain angle to the surface normal. With a angle of 45° the formation of new sharp edges is avoided and a round edge geometry is reached (Fig. 1(a)). The decisive factors for a SLD process with just one exposure are the position of the laser spot, the laser power and the deburring velocity. It has been determined that the deburring result has no strong dependency on inner contours in the sheet metal parts and that the secondary burr height h and its position a increase with increasing radius of curvature r. For this reason the main measure to value the edge geometry is the radius of curvature r (Fig. 1(c)).

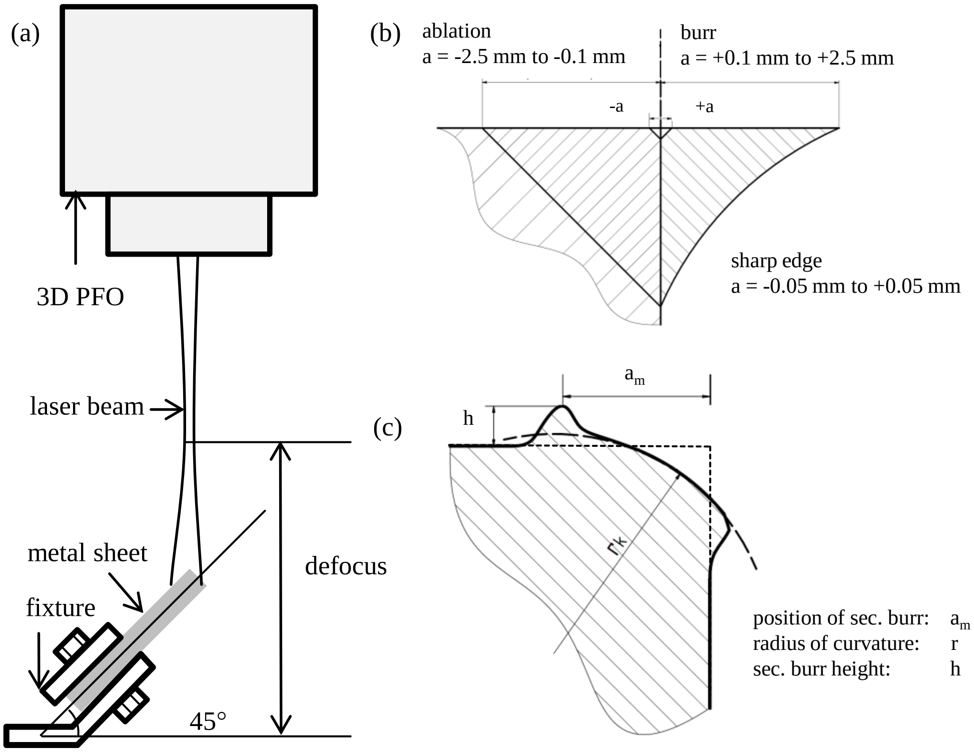

Fig. 1. (a) deburring setup; schematic cross sections of burrs (b) before deburring (DIN ISO 13715) and (c) after deburring (Schmidt-Sandte 2002)

The process automatization also requires a quality assurance for the burr geometry. For this reason it has been determined whether IR-thermography is a suitable technology to qualify the deburring results. Besides the possibility to detect different mechanical and chemical flaws, it has been shown that the edge temperature correlates with the edge radius during the SLD process and when cooling. Furthermore the positioning of the laser spot influences the temperature field next to the edge (Möller et al. 2016).

These preceding studies were executed with a limited deburring task. Only short and linear edges on the outward cutting contours have been examined. This paper investigates extended deburring tasks regarding the preceding studies. The automated deburring of a complex sheet metal part requires the deburring of long edges and complex edge geometries as well as a rotation of the workpiece to grant a deburring under the right angle. For this reason edges as long as the laser scanner work field, round edges, deburring angles and the transition from the end of deburred edges to new deburred contours are examined.

2. SLD process chain

Figure 1 shows the currently developed SLD process chain which will consist of three steps from the processed 2D structures to the finished part. An intelligent database will suggest parameter settings for the SLD process after cutting or punching. A dataset is developed based on previous findings, the given material, sheet thickness and the contour. With the given part information and the parameter settings the SLD process is executed. Lastly, a quality assurance checks the reached edge geometry and edge quality.

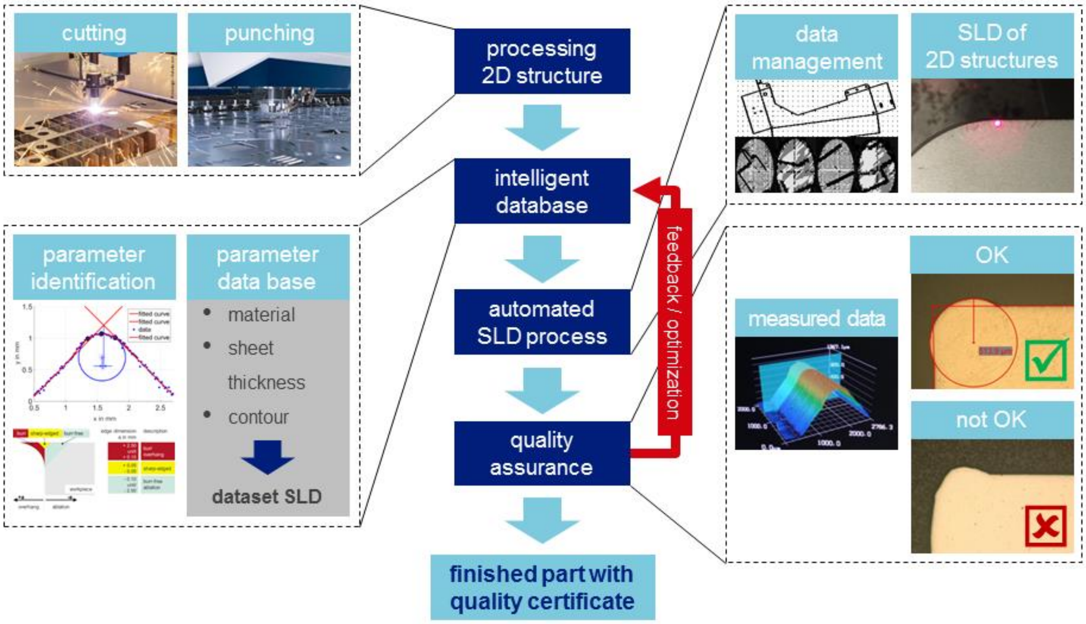

Fig. 2. SLD process chain

3. Setup

3.1. SLD set up and deburring task

All sheet metal parts are cut with the laser cutting machine TruLaser 5030 from stainless steel sheets (1.4301) with a thickness of 3 mm. The geometry of the used samples and general edge geometry before the deburring are shown in Fig. 3. The used samples have a length of 70mm and 350mm. Like in the aforementioned studies the investigations are executed with a Trumpf TruDisk 5001 multi-mode continuous wave disk laser with a laser power of 5 kW at a wavelength of 1.03 µm. Fig. 3(a) shows the used scanning optic Trumpf PFO 3D. This laser scanner enables a laser remote process under surrounding atmosphere and at an angle of 45/135 degrees between the top of the sample and the laser beam. All experiments are executed with the shown clamping. The rotation of the clamping plane is necessary to deburr a whole workpiece under the needed angle of 45°. The aim of this paper is to deburr complex workpieces like in Fig. 3(a) with the gained insights.

Fig. 3. (a) Experimental setup; (b) Samples; (c) Digital 3D image of an edge geometry before deburring (Keyence VHX-5000)

4. Methods

All experiments are executed with the parameter settings given in Table 1. Like in many other laser applications the power density is a typical characteristic to classify the contributed energy (Hügel and Graf 2009; Poprawe 2005). A constant power density over the three parameter settings guarantees a good comparison of the different parameter settings. The deburring velocity is 300 mms^{-1} for every setting. Only the power and the defocus are changed. The defocus directly sets the laser spot diameter.

Table 1. Parameter settings

Parameter setting	Defocus in mm	Power in W	Laser spot diameter in mm	Deburring velocity in mm s^{-1}
1	-10	1089	0,81	300
2	-20	2311	1,18	300
3	-30	4250	1,6	300

As a result to the preceding studies, only the radius of curvature is evaluated to classify the edge geometry, because all other edge measures depend on the radius. The edges are evaluated with the digital microscope Keyence VHX-5000 which takes 3D images of the deburred edges. The radius is determined by cross-cutting the 3D model and fitting a radius to the cross-cut (Fig. 4(a)). As shown in the cross-cut of a deburred edge in Fig. 4(a) all edges are evaluated with a angle of 135 degree between sample surface and the microscope lens. At least four cross-cuts are measured per sample.

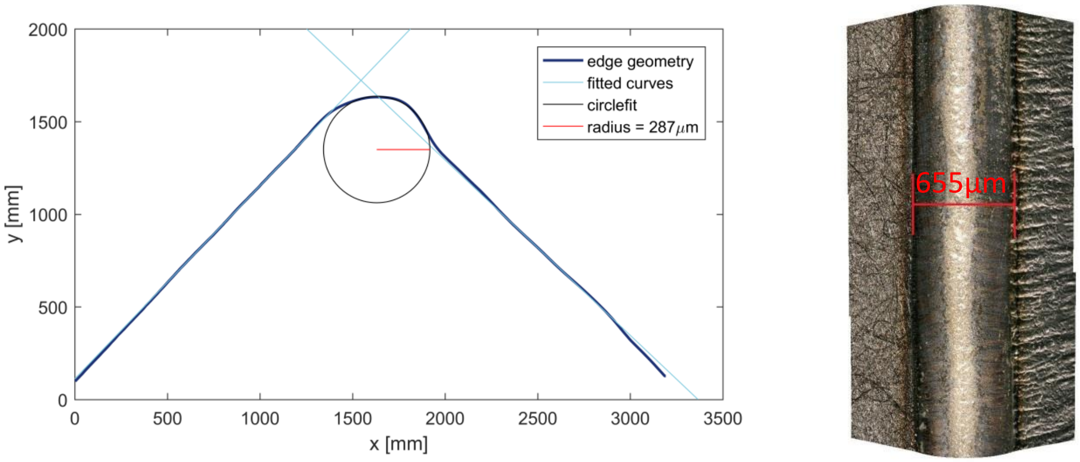

Fig. 4. (a)Cross-cut deburred edge (parameter setting 1); (b)Deburring width of an deburred edge (3D image of parameter setting 1)

This paper wants to clarify if the radius of curvature changes during the deburring of long edges. Therefore, a maximum deburring length of 320 mm is evaluated with 4 samples per parameter setting. Every sample is measured at the start (10mm-20mm), in the middle (155mm-165mm) and at the end (300mm-310mm). For each of these positions, 4 cross-cuts are measured. Additionally, the deburring width of the remelted edge like in Fig. 4(b) is measured. With the 70 mm samples, an experiment with edge orientations between 0° and 50° is executed.

Especially the edge orientation and the transition between deburred edges will be important when it comes to the part handling for automated deburring. If high orientation angles do not lead to bad deburring results it is possible to deburr one workpiece in less steps. This is why 6 edge orientations are considered. The samples are still clamped in the orientation plane (Fig. 3 (a)) but they are rotated by a orientation angle between 0° and 50°(Fig. 5).

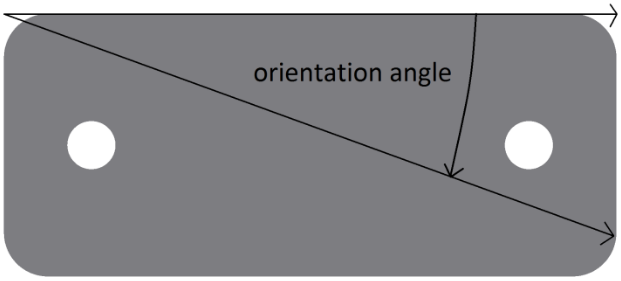

Fig. 5. Orientation angle

Table 2 shows three different transition strategies. In all cases the transition is deburred in two separate steps to assure that the first deburring cools down. In the first attempt the second deburring starts directly at the point where the last deburring ended. This strategy is executed with all parameter settings. Strategy 2 and 3 are only executed with parameter setting 2. In the next step the overlapping of contours is examined. In strategy 2 the ending deburring ramps down to 50% of the power in the last 1mm. The beginning deburring ramps up from 50% to 100% during the overlapping. In the last strategy the deburring overlaps for 2mm and the ending deburring ramps down to 20 % and the beginning deburring starts with 80% of the used laser power.

Table 2. Transition strategies

Strategy	Overlapping in mm	Power ramp ending deburring in %	Power ramp beginning deburring in %
1	-	-	-
2	1	50	50
3	2	20	80

5. Results

5.1. Long edges

All deburred samples showed a good deburring result like in Fig. 6. It was also possible to deburr round edges with the used parameter settings (Fig. 6(b)).

Fig. 6. (a) 3D image of a deburred linear edge (parameter setting 2, position: middle); (b)3D image of a deburred round edge (parameter setting 2)

Fig. 7(a) shows the influence of the spot diameter on the radius of curvature when the deburring velocity and the power density are constant. The spot diameter seems to be a good factor to adjust the radius of curvature. Furthermore, it defines the deburring width which was always smaller than the spot diameter (Fig. 7(c)). During the experiments it also became clear that the high laser power in parameter setting 3 leads to small deformations of the long workpieces because of too high thermal expansions. The mean radius over all three parameter settings is plotted against the evaluated position in Fig. 7(b). The radius of curvature did not depend on the evaluated position.

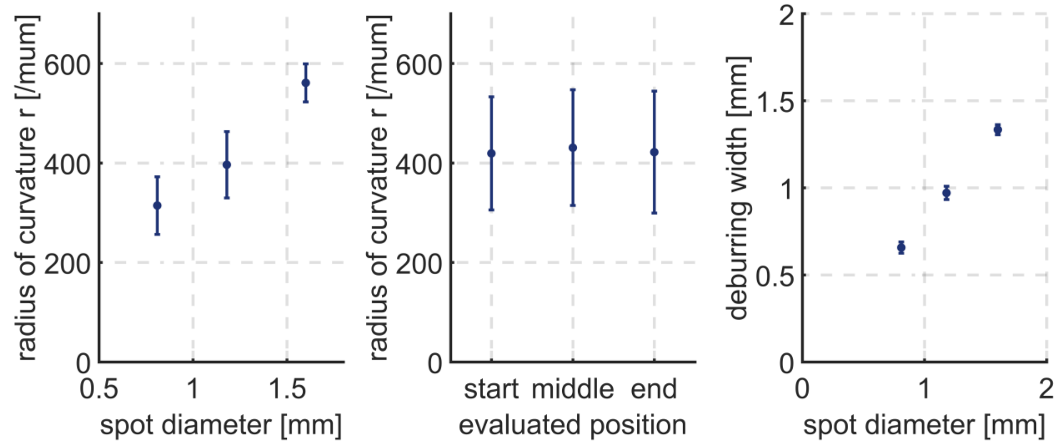

Fig. 7. (a)mean radius of curvature of the executed parameter settings; (b)mean radius of curvature of the three evaluated positions; (c)Deburring width

5.2. Edge orientation

The rotation of the edge orientation caused a deburring over several working planes of the 3D laser scanner. As a result, it was harder to position the laser spot with rising orientation angle. Another defocus had to be adjusted in order to guarantee the same parameter settings at every point of the edges. As shown in the preceding studies the positioning of the laser spot is very important. Therefore, only edges which reached a good positioning were evaluated to show if it is feasible to deburr with different orientations. According to the results plotted in Fig. 8 the orientation angle had no significant impact on the radius of curvature.

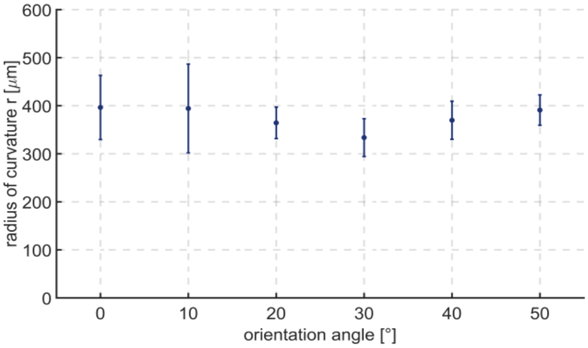

Fig. 8. Deburring results for different orientation angles (parameter setting 2)

5.3. Transition between deburred edges

Fig. 9 shows that with rising radius of curvature the transition between two deburred edges gets bumpy. The best transitions were made with parameter setting 1. Cross-cuts of the evaluated transitions showed that the edges were still deburred during the transition but the radius of curvature was not constant.

Fig. 9. (a)3D image of the end of a deburred edge (parameter setting 2); (b)3D image of a SLD transition (parameter setting 1, strategy 1)); (c)3D image of a SLD transition (parameter setting 2, strategy 1); (d)3D image of a SLD transition (parameter setting 2, strategy 1)

The overlapping of the deburred contours in transition strategy 2 led to worse transitions than with no overlapping (Fig. 10(a)). The best transition was achieved with strategy 3 where the deburring overlaps for 2mm and the ending deburring ramps down to 20% of the power while the starting deburring starts at 80% and ramps up to 100% of the power (Fig. 10(b)).

Fig. 10. (a)3D image of a SLD transition (parameter setting 2, strategy 2); (b)3D image of a SLD transition (parameter setting 2, strategy 3) ;

6. Conclusion

It was shown that it is feasible to deburr long and complex edges using a laser. The deburring of round edges and edges with different orientations to the laser scanner is also possible. With a constant power density the radius and the width of the deburred edge depend on the laser spot diameter. Furthermore, it has been shown that the deburred edge geometry is constant over the whole scanner work field and that transition strategies might lead to better deburring results. But once more it became clear that the most difficult process factor is the positioning of the laser spot. The defocusing and positioning gets particularly difficult when the edge is in different distances to the scanner. Regarding the automation of a SLD process it is possible to deburr complex geometries. A scanner system is needed which detects the edge geometry and position of the edge. Afterwards it has to develop a deburring strategy for the transitions and the rotation of the rotation plane to guarantee an automated deburring of complex sheet metal parts.

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