Laser-Assisted Sheet Metal Working of High Strength Steels in Serial Production

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Abstract

Within the sheet metal working industry the demand for thinner sheet materials with very high strength is growing due to the increasing need to save energy and a responsible use of natural resources. The high strength and the low ductility restricts using state of art technology to sheer, bend, emboss or deep draw parts with the needed complexity and quality. The Fraunhofer IPT developed a combination of laser-assisted preheating and conventional punching to a new hybrid technology which allows to shear, bend, emboss and draw high strength materials with a high quality and complexity in a serial production.

Keywords: punching; shear; emboss; deep drawing; bend; laser; assisted; high strength steel; progressive die

1. Introduction

Due to the aim of active climate protection of the European industry, the importance of sustainable and responsible use of the natural resources and the reduction of CO₂-emissions is growing continuously. One way to reach this aim is the use of lightweight components and their energy and resource efficient production, i.e. for the importance of weight reduction in the automotive sector. Within this sector the companies turn away from aluminum and use more high strength steel materials at minimized wall thickness and reduced weight. In this context a weight reduction by only 100 kg of a car leads to a CO₂-emission reduction of 3,5 tons within its usual lifetime [1].

These high strength materials are not only used in macro parts but also in smaller parts such as valve springs. The needed level of strength normally causes a low ductility and a minimized deformability, so that the sheet fabricating industry reaches the technical limits according to the possible complexity and quality of produced parts.

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doi:10.1016/j.phpro.2011.03.078
2. State Of The Art

The conventional shearing process is divided into three phases, cf. figure 1.

Figure 1. Phases of the conventional shearing process [2]

In the moment the tool touches the sheet metal, the material is bended due to its elasticity and the slightly larger size of the shearing plate in comparison to the tool dimensions. With rising forces the material is plastically deformed and starts to flow. Due to the flowing of the material in and vertically to the moving direction of the tool the edge warps. With rising tool movement, this edge warping merges to a smooth shearing zone (clear cut surface). The size of this area is characterized by the flow ability of the sheet metal. If the flow ability of the material is exceeded cracking starts, emerging at the shearing plate. These cracks lead to a material separation by fracture. According to the three phases of shearing the cutting zone shows a typical cut surface, cf. figure 2a.

Figure 2. (a) Cut surface of the conventional shearing; (b) Aim of the laser-assisted shearing

In the moment the tool touches the sheet metal, the material is bended due to its elasticity and the slightly larger size of the shearing plate in comparison to the tool dimensions. With rising forces the material is plastically deformed and starts to flow. Due to the flowing of the material in and vertically to the moving direction of the tool the edge warps. With rising tool movement, this edge warping merges to a smooth shearing zone (clear cut surface). The size of this area is characterized by the flow ability of the sheet metal. If the flow ability of the material is exceeded cracking starts, emerging at the shearing plate. These cracks lead to a material separation by fracture. According to the three phases of shearing the cutting zone shows a typical cut surface, cf. figure 2a.
The aim of the laser-assisted shearing process is to increase the ductility and therefore the flow ability of the sheet metal and thus to maximize the second phase of the shearing process, cf. figure 2b. To increase the ductility the material is locally preheated directly before the sheet metal working process. Previous investigations confirmed a significant loss of material strength at increased material temperatures in, for example, stainless steel, spring steel, cf. figure 4, titanium and nickel alloys, as well as ceramic materials [3]. Based on the increased plasticity of the materials and the results in the field of laser-assisted shearing in a laboratory scale setup, the laser assisted bending, embossing and deep drawing has been developed and proven in a laboratory setup scale.

One wide spread quality sign for shearing processes is the clear cut surface ratio. This factor is the percentage of the clear cut in comparison to the sheet thickness.

For shearing it has been possible to increase the clear cut surface ratio for spring steel up to nearly 100% and decrease forces by over 70%, so the potential of this technology was clearly proven. Proving the potential not only for shearing but also for bending, embossing and deep drawing is the content of this paper.

3. Experimental Setup

3.1. Punching machine with integrated laser optics and sheet metal feeder

A conventional punching machine has been equipped with a system upgrade at the Fraunhofer IPT (cf. Fig. 1(a)) for the purpose of these developments. The upgraded machine system was operated with a dynamic deflection system with a laser spot diameter of 2 mm, to irradiate the upper or under side of the sheet metal plates. Due to the usage of a beam deflection unit it is possible to adapt the irradiation to different tool geometries instantly by changing the scanner program. So the punching geometry is only restricted by the field size of the laser-scanner. The current used optic limits this field to 100 mm times 100 mm.

For the integration of laser-assisted shearing, bending and deep drawing in industrial production the irradiation of the material and the material processing have to be locally separated. Due to the limited space in production machines it is not possible to irradiate the material through the sheering plate.

To simulate the sheet metal feeding, a linear drive has been integrated in a conventional punching machine, cf. fig. 1(a). So it is possible to test different feeding speeds and different feeding times without the need for a serial production machine.

Figure 3. (a) Experimental setup for the laser-assisted shearing; (b) Phases of laser-assisted punching
System specifications:
- High-power diode laser system (LDF 3000 - 40, Laserline)
- Laser scanner system (Raylase Turboscan-30)
- Punching machine (Boschert ECCO LINE EL 500)
- Linear axis (Schunk MLD 200L)
- Control system (Siemens Simatic S7)

Within the tests the material has been irradiated on the upper side of the sheet material. After the irradiation process the sheet is moved into the tool and processed, cf. Fig. 1(b).

For the coordination of the feeding, the punching machine and the laser scanner system an additional control system is needed. The control system communicates via a profibus interface with the machine control system, the axis and triggers the laser scanner system.

3.2. Industrial implementation of the laser-assisted sheet metal working

To test the new laser-assisted sheet metal working technology within an industrial environment the complete equipment has been integrated into a punching machine, used for serial production. Within this machine it had been possible to shear, bend, emboss and draw laser-assisted within serial production. These investigations allow to validate the laboratory trials and the industrial feasibility of this concept.

Special attention has been paid to the protection of the sensitive optical system within the industrial environment. For this reason a cross jet based protection system has been developed.

4. Investigated Materials

For the experimental proof of industrial feasibility of laser-assisted sheet metal working three different materials have been tested:

One steel type has been chosen for testing the possibility of hardening within the laser-assisted shearing process:

- 1.1248: a spring steel without thermal treatment with a tensile strength of 700 MPa can be hardened up to 1400 MPa

Two materials to show the feasibility of laser-assisted metal working technology for processing high strength steel with high quality and complexity within serial production. To show the possibility of manufacturing parts made of distinct steels with different thermal treatments, one steel type is bainit hardened and the second one is hardened by cold rolling.

- 1.4310: a spring steel with a tensile strength of 1300 MPa
- PT120: bainit hardened steel based on the 1.1211 with a tensile strength of 1200 MPa

Figure 4. Influence of the temperature on the tensile strength of 1.4310 and 1.1248 [4]
5. Process Results And Discussion

5.1. Shearing

5.1.1. Shearing geometries

Four different geometries have been investigated to show the feasibility of shearing geometries of different sizes, cf. figure 5.

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**Figure 5. Investigated shearing geometries**

5.1.2. Process Results

Within this paper two representative geometries will be evaluated, the smallest geometry (4) and the largest (3) of the above mentioned.

The triangular shape is indicative for different shapes because of the different angles within the geometry. By adapting the irradiation geometry it is possible to generate a uniform temperature within the shearing zone. This leads to a very uniform clear cut surface ratio within the entire cutting edge. Figure 6 shows the exemplary edge quality of 1.4310.

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**Figure 6: Comparison of the cutting edge quality of the conventional and laser-assisted shearing for round and triangular shapes**
Due to the laser induced heating which results in a material softening it is possible to increase the clear cut surface ratio up to 95%.

The second geometry is a 1 mm hole with a sheet thickness of 1 mm. This geometry shows an aspect ratio of 1:1 and is not producible within high strength steel with a stable conventional shearing process. Within the project it has been possible to shear this geometry into all three materials by laser-assisted shearing.

Due to the material softening the shearing forces could be decreased. This is very important for shearing high strength material, because the strength of the material is nearly as high as the tool strength, which leads to extremely high tool wear.

Especially for high strength steel the shearing forces could be decreased by more than 70%, cf. Fig. 7.

![Figure 7. Influence of laser-assisted shearing on the shearing force](image)

For the material with the highest tensile strength the 1 mm tool was tested with 90 parts per second during one hour and led to only marginal wear effects on the tool, cf. figure 8.

![Figure 8. SEM spectroscopy of a shearing tool after 5000 fabricated parts](image)
The punching diameter of 1 mm shows the potential of this new hybrid technology by not only enhancing the technical boundaries but also allowing new geometries which had not been possible before and drastically decreasing wear effects on standard punching tools.

The industrial scale tests showed that the laser-assisted shearing has the potential to increase the process limits of punching technology and to enable the industry to shear high and highest strength materials with a very high quality and complexity.

5.2. Bending

5.2.1. Bending geometry

For bending of all three materials one geometry has been chosen, cf. figure 9. According to the limitations of the conventional bending process a bending radius of one forth of the sheet thickness has been chosen. This geometry is not bendable crack free for 1.4310 and PT120 with conventional bending.

![Figure 9. Detail of the test part; (a) side view; (b) front view](image)

5.2.2. Process results

Because of the limited ductility of high and highest strength steels the minimal bending radii of high strength steels have to be larger than the sheet thickness. For example according to the the VDI the minimal bending radius of 1.4310 equals 7 times the sheet thickness. Within the sheet metal industry conventional bending of high strength steel sheets with radii smaller than the sheet thickness is not possible without cracks.

Using the new hybrid laser-assisted sheet metal working technology it is possible to increase these limitations. Due to the local heating of the material, the plasticity is increased. This allows a smaller crack free bending radius. Within the trials it was possible to bend all three materials with a radius equal to one forth of the sheet thickness, cf. figure 10.

![Figure 10. Cross sections of the bended parts](image)
5.3. Deep drawing

5.3.1. Deep drawing geometry

A geometry with a high aspect ratio have been chosen to evaluate laser-assisted deep drawing, cf. figure 11. For conventional deep drawing of 1.4310 the maximal fault free drawing length with this diameter is 0.9 mm, to show the advantage of the laser-assisted process this drawing length has been doubled.

![Figure 11. Detail of the test part; (a) side view; (b) front view](image)

5.3.2. Process results

Due to the small drawing geometry in comparison to the part size it is necessary to increase the flow ability not only in the areas with a high degree of forming but also in the surrounding areas. This will allow a material flow towards the deep drawing area. Within the trial it was possible to draw defect free parts with a drawing length of 1.8 mm for all three materials. This shows, that the laser-assisted drawing allows to double the limit of the drawing ratio in comparison to the conventional process, cf figure 12.

![Figure 12: Comparison of the drawn parts of conventional and laser-assisted deep drawing](image)
5.4. Embossing

5.4.1. Embossing geometry
According to the high strength of the investigated materials it is not possible to emboss a larger area by more than one tenth of the sheet thickness. To show the possibilities of the laser-assisted sheet metal working within the trials the aim has been to emboss a depth of 50% of the material thickness, cf. figure 13.

Figure 13. Detail of the test part; (a) side view; (b) front view

5.4.2. Process results
Due to the locally reduced strength and the increased flow ability of the material it has been possible to emboss all three steels to the half material thickness thereas the forces are reduced, cf. figure 14.

Figure 14. Results of the laser-assisted embossing of high strength steel
6. Summary

For shearing high strength steel it was possible to increase the clear cut surface ratio to nearly 100% and allow to shear with an aspect ratio which has not been possible before.

Due to the increased flow ability of the heated material it is possible to increase the limit of the draw ratio and the embossing depth and to minimize the crack free bending radius.

Within the trials it has been possible to prove the industrial feasibility of the laser-assisted sheet metal working. For all investigated processes like shearing, bending, deep drawing and embossing it has been possible to widen the process limits or even to allow complete new processes and additionally the tool wear could be minimized.

By proving the industrial feasibility of this new hybrid technology the technical limits of the conventional sheet metal working industries have been extended and it is possible to produce parts made of high and highest strength steel with an unknown quality and complexity.

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