Innovative Laser-based Manufacturing Concepts and Equipment for Efficient Steel Processing

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Abstract: Laser welding has seen countless applications over the last two decades due to its attractive properties such as low heat input, high precision and speed as well as versatile and automatic handling. The exploitation of the full application potential of laser welding requires an appropriate manufacturing concept and the corresponding technology. The integration of laser welding (and cutting) into larger manufacturing processes or into stand-alone systems will be demonstrated using examples of ThyssenKrupp Lasertechnik's experience of over 20 years in this field. More specifically the modular setup of such manufacturing concepts and the different level of automation will be indicated to offer individual solutions for different needs and budgets of small & medium sized as well as large enterprises. The demonstrated applications range from flat sheet, profiles, tubes to rods made from carbon steel or stainless steel.

Key words: laser welding, laser cutting, coil welding, tailored blanks, tailored orbitals

1 Introduction

ThyssenKrupp Lasertechnik GmbH has been designing and producing laser-welding systems for more than 20 years and has developed a unique design and know-how for highly productive laser blank welding. The patented continuous welding process is unrivaled in terms of productivity and is being used all over the world for mass production of linear welded tailored blanks (TB). The core process of continuous laser welding can be configured with different variants of material handling and degrees of automation allowing to adapt the continuous welding system to specific market needs. The extensive experience of ThyssenKrupp Lasertechnik is nowadays also utilized for several other production processes that are relevant for automotive applications such as orbital welding of engineering steels and laser coil welding for continuous production in the steel mill.

2 Laser welded blank production concepts

For laser welded blank production various manufacturing concepts are used in the industry. These are the result of different production strategies and also of rapid parallel development of technology by different players in the market. A production concept is basically characterized by the way of achieving a relative displacement of laser beam and sheet material as well as by the manner of managing the material flow through the process. The driving forces behind any welding machine concepts are maximization of the utilization of the laser welding equipment, the optimization of production flexibility and the reduction of cost.

Fixed-optics laser welding systems are characterized by a stationary welding head while the sheet assembly to be welded is passing underneath (Fig. 1). This procedure allows producing straight weld seams of various lengths. Moving optics systems represent the opposite approach where the sheets to be welded are at rest while the laser welding head is executing the desired 2-dimensional trajectory (Fig. 2). In this way weld seams of nearly arbitrary shape can be made.

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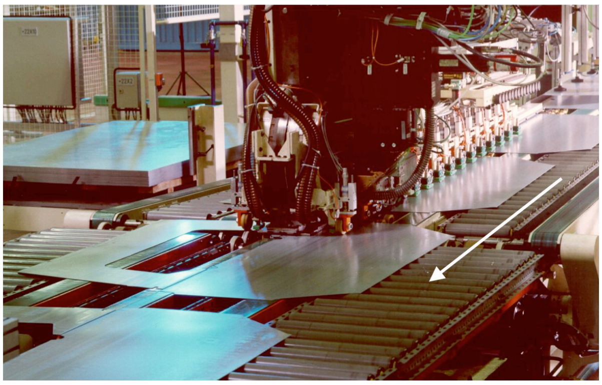


Fig. 1: Fixed-optics welding machine with continuous material feed (arrow = feed direction).

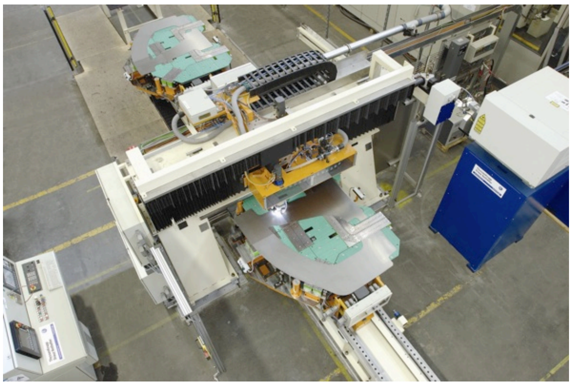


Fig. 2: Moving-optics welding machine for 2-D welding with discontinuous material feed.

For the production of single straight welded assemblies, machines equipped with fixed optics are clearly the method of choice. Each additional straight weld in a blank design requires a corresponding additional pass through the machine since only one weld seam can be manufactured at the time. This results in extra handling and machine set-up whereas a moving optics system finishes even complex multi-weld assemblies within one machine cycle. Therefore, a detailed analysis of the manufacturing cycle time is required to decide which of the two machine concepts is to be preferred.

The challenge to the material-handling concept is to offer a new batch of non-welded sheets to the weld process as soon as the welding cycle of the previous is finished. This scenario allows a maximum utilization of the capital-intensive welding equipment and thus leads to minimization of the welding cost. The ideal solution in case of a fixed-optics welding machine is a continuous material flow through the welding machine. In this case the welding speed represents the speed of conveying material into and out of the welding machine. Consecutive sheet batches are separated by a minimum intersection to keep the beam-off time as short as possible. In particular cases, accelerated material flow in between weld sections helps to reduce the beam-off time. Since welding cycles can be as short as a few seconds, appropriate buffer zones have to be foreseen at the beginning and the end of the continuous conveying system.

The continuous material flow system is based on the conveyor principle where the individual blanks are loaded and while moving onwards being positioned automatically. Naturally this method does not allow static clamping of the sheet pair during welding. Clamping is occurring by inclined friction rolls pushing the two mating blanks against each other and simultaneously moving them forward at welding speed. To avoid any risk of increased gap opening due to heat distortion especially towards the end of longer weld seams, ThyssenKrupp Lasertechnik has developed a very effective countermeasure. By specific temperature management in the already welded hot zone a closure of the butt gap in the area yet to be welded is induced. This technique supports the action of the inclined friction rolls driving the blank pair forward and towards each other. In a reversing feeding system a shuttle takes a batch of non-welded blanks that are clamped statically. Then the shuttle is passed through the welding machine. After unloading the welded blanks at the end of the welding pass, the shuttle is returning empty to the loading position. The return and refill periods define an additional unavoidable beam-off time so that the overall productivity is inferior to that of a continuous feed system. The continuous material feeding process offers the shortest possible handling time and thus represents the optimum solution. The machine availability is determined by planned and unplanned maintenance as well as by the changeover time from one production job to the next. Hence low maintenance and reduced changeover time are desired machine features. Maintenance is reduced by robust machine design building on the manufacturers experience. The changeover time is related to the material handling system. The continuous feeding system does not involve any part specific tooling that would need to be changed. The conveyor system taking care of the material flow adjusts itself to a new production job by a simple software command. Machines based on discontinuous feeding systems require a tooling change so that the setup time is usually in the order of 30 to 60 minutes. The impact of this setup time becomes the more severe the smaller the production batches are. Table 1 demonstrates the advantage of the continuous feeding system. Already the base cycle time per part is 30% shorter as compared to discontinuous feeding. Taking into account the changeover time and various batch sizes, the productivity of the continuous feeding line can be up to 40% higher.

Table 1: Cycle time and batch production time for continuous and discontinuous material feeding (assumptions: 1 m weld length, 50 mm spacing, 8 m/min weld speed, 3 blanks per load cycle for discontinuous feeding).

Feeding system	Process time per welded part (s)				Job change-over time (s)	Production time per batch (min)		
	Welding	Travelling	Reloading	Total cycle		2,000 parts	5,000 parts	10,000 parts
Continuous	7.5	0.4	0.0	7.9	300	268	667	1,325
Discontinuous	7.5	0.4	3.3	11.2	3600	433	993	1,927

2.2 Weld edge preparation

Since laser welding in tailored blank manufacturing usually is an autogenous welding process, i.e., without using filler wire, careful preparation of the blank welding edges is an important issue. Squared edges with a high straightness are mandatory to avoid undercut in the weld zone and thus insufficient mechanical properties of the weld. Squared edges can be produced quite easily by laser cutting. However, laser cutting is too slow for mass production of tailor-welded blanks. On the contrary laser cutting is very suitable to prepare welding edges for a laser coil welding operation.

For larger volumes, ThyssenKrupp Lasertechnik has developed an attractive alternative solution. Shaped blanks are cut using a conventional blanking die, however, with a defined over-dimension on the welding edge (approx. 5 mm). This over-dimension is cut back by a precision shear shortly before loading the blank into the continuous welding line. This also excludes the risk of damaging the welding edge when transporting the blank stack from the intermediate stock to the welding line. In the modular line concept, precision shears on either side of the blank conveyor are installed. 6-axis handling robots insert the blanks into the precision shear, the welding edge is being cut and the blank is immediately placed on the conveyor.

2.3 Modular production concept for continuous welding

The continuous welding line core module can be equipped with various handling facilities at the entry and exit of the line. The respective setup has influence on the investment cost and on the line productivity. The local conditions in a specific market may require an individual contemplation to find the optimum line configuration. The simplest configuration is to load and unload the blanks by manual labor. This means at the entry of the core module two workers place blanks on the conveyor. At the exit of the line one or two workers, depending on the size, unload the welded blank from the conveyor. Naturally such a mode of operation is favorable in countries where labor cost is cheap. Also the flexibility of changing between different orders is high since no hardware or tooling changes are required. Hence, this condition is very suitable for developing markets where batch sizes are small and/or product variety is high. In markets where labor cost is higher and/or larger order volumes are to be produced, manual labor can be replaced by mechanized material handling. This can be 6-axis robots equipped with a suitable handling attachment or handling gantries in case of very high volume production.

Other features like automatic blank dimpling to balance the stack height of the welded blanks and flip-over of welded blanks can be integrated as well in the exit section of the line. All features can be added ad hoc allowing the core concept to grow towards higher productivity as the market demand is developing.

3 Laser coil welding systems

For continuous production in cold rolling mills and galvanizing lines laser coil welding today is the preferred joining method. This is particularly required when processing modern automotive high strength steels such as TRIP, CP or DP steels. Like in tailored-blank production edge preparation before laser welding is a crucial step. In conventional laser coil welding systems the edges are cut by hydraulic shears. However, when working with full hard material or high strength steel it is rather difficult to provide a squared edge by mechanical cutting. Besides, the knife-blades are rapidly wearing and require frequent maintenance. Therefore, ThyssenKrupp Lasertechnik has developed an innovative coil welding system that uses the welding laser also for laser cutting the edges prior to coil welding (Fig. 3). A combined cutting and welding optics head is performing all operations. Using a laser of appropriate power allows to do the cutting operation fast enough to comply with typical line cycle time.

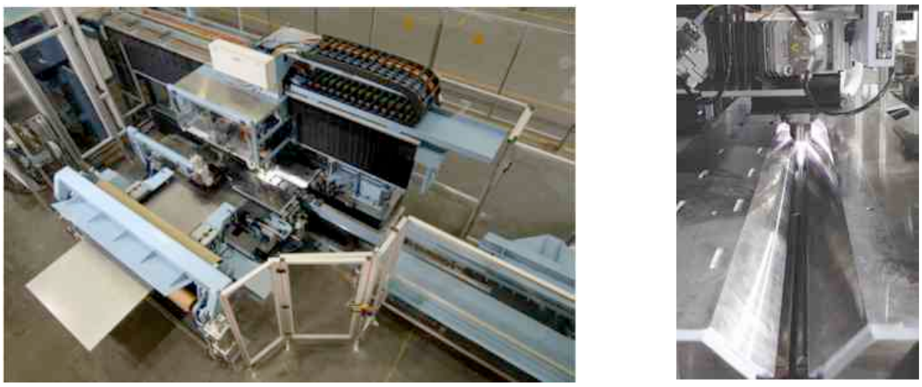


Fig. 3: Laser coil welding device with integrated laser edge cutting and seam marking.

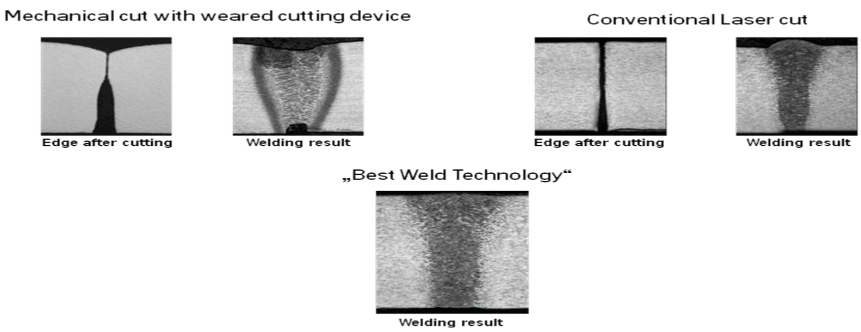
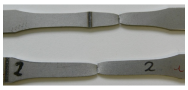
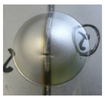


Fig. 4: Influence of edge preparation technique on the weld seam quality .

Due to the little space required by the very compact execution and erection on floor level, this system type is also suited to upgrade existing production systems. Compared with systems using mechanical cutting devices, the new system functions with a far more simple clamping technology. Furthermore inductive annealing of the seam is possible and also an automatic quality control can be integrated. In the new coil welding machine, ThyssenKrupp Lasertechnik is applying an innovative procedure for the preparation of a welding edge with optimal conditions for the laser welding process. The so-called "Best Weld Technology" allows the production of ideal seams without any excess material or undercut (Fig. 4). This bears several advantages. The laser weld is highly loadable and formable (Tab. 2), which is particularly of interest when welding modern high strength automotive steels such as DP, TRIP, CP or martensitic grades. The hardness and thus the formability of a laser weld directly depend on the carbon content of the welded steel. For steels with increased carbon levels (>0.2%) the laser weld formability can be severely improved by post weld heat treatment resulting in a tempering of the martensite in the as welded material. A respective inductive annealing device for post-weld heat treatment can be integrated in the coil welding system. Furthermore an automatic quality control system can be integrated. Due to the smooth geometry of the coil weld seam and its high reproducibility the new coil welding system is also excellently suited for application in inspection lines. Bad coil sections can be cut out and the smooth laser weld seam does not harm the strip surface when recoiling.

Table 2: Performance benchmarking of laser coil weld seams (equal material pairs) produced by "Best Weld Technology".

Test criterion	DQ steel (DC01)	DP600	TRIP600	TRIP700
Tensile test 	100%	100%	100%	100%
Formability  	95%	78%	80%	71%

4 Manufacturing of rotational-symmetric laser welded components

Until recently, rotational symmetric automobile components have usually been produced from initial materials such as tube or wire. Tailored Orbitals are composite semi-products that are made from combinations of materials of different thicknesses or types, or with different coatings. These tailored products can generate added value, similar as tailor welded blanks do in the field of body manufacture, thanks to features such as lower weight, improved function and a possible reduction in cost. The advantages are feasible even for highly dynamically stressed components. Further applications can be expected in the areas of chassis, engine, transmission, power train and steering.

Laser-welded components offer great functional potential in shock absorber construction (Fig. 5). The low heat input into the welded components associated with this joining process facilitates the manufacture of parts that are fitted with thermally sensitive components such as electromagnets and shock-absorbing elastomers like piston rods for active shock absorbers. The requirements for this component, which is important for safety (wheel guidance in the McPherson front suspension), are a controlled production process and a low heat input so that an elastomer component fitted into the piston rod, as used in the Mercedes A- and B-Class, suffers no damage. These requirements for the A- and B-Class gave rise to various approaches. Welding was the optimal process from the viewpoint of process reliability. The next step was to carry out benchmarking of the various welding processes in close coordination with the end customer Mercedes-Benz. Various processes such as capacitor discharge welding, electron beam welding, MAG (Metal Active Gas) welding and plasmatron welding were available and were all put to the test. From the point of view of process reliability and heat input, capacitor discharge welding, MAG and plasmatron welding processes were rejected after the initial trials. Because the pilot project Mercedes-Benz A-/B-Class represents mass production of 1.4 million units/year, the process has to be attractive from the viewpoint of the cycle time and the cost of production over and above the requirements mentioned earlier. Laser welding was thus the process of choice. The development of laser-welded piston rods for the A- and B-Class was carried out in close collaboration with the end customer. ThyssenKrupp Lasertechnik designed and supplied a fully automatic production center providing material feed, orbital welding and component assembling.

The technology of orbital welding has recently been extended to manufacture stainless steel exhaust tubes. In this process, tube segments are place vertically on top of each other. The gravitational force by the weight of the tube segments is sufficient to allow orbital butt-welding. For that reason the process is called Gravrolas. Robots are handling the material feed. Laser welding is done using a fixed welding head with the tube assembly rotating along the head. The technology is used to combine different tube gages and stainless steel grades to a composite exhaust line (Fig. 5) thus optimizing weight, properties and cost. Up to 5 tube segments can be joined in this machine. The very low heat input by laser welding reducing the grain coarsening in ferritic stainless steel to a minimum, which is of advantage when the weld is subjected to a subsequent forming operation.

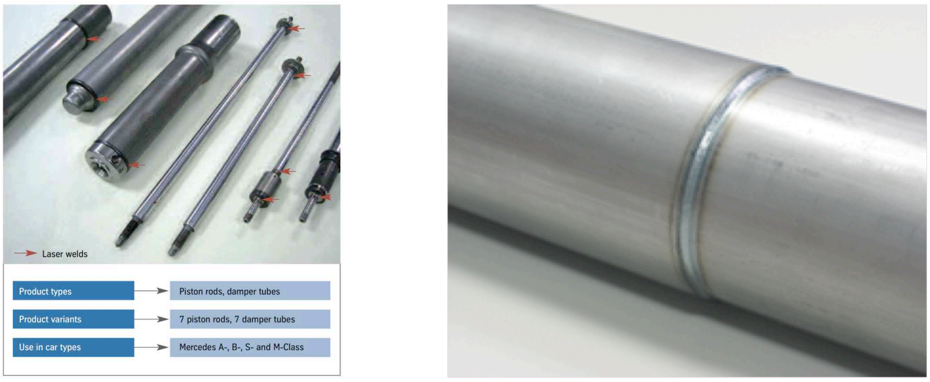


Fig. 5: Typical examples of Tailored Orbitals for shock absorber components (Mercedes-Benz) and orbital tube weld on ferritic stainless steel of two different gages for exhaust lines.

5 Conclusions

Laser welding is a key technology in the production of materials and semi-products for modern automobile construction. Tailor welded blanks are the most established products of that kind. ThyssenKrupp Lasertechnik is the leading supplier of the respective laser welding equipment offering various technologies. The productivity of the continuous laser welding system is unsurpassed by any competing technology. The combination of laser cutting and welding using one head is used in an innovative coil welding machine. This machine is excellently suited for welding high and ultra high strength strips and solves the problems caused by cutting the strip ends with hydraulic shears. Orbital welding technologies opens a whole range of new possibilities for the processing of engineering steel and tubes enabling weight reduction and selective cost-optimized material use. Depending on the specific challenge ThyssenKrupp Lasertechnik is ready to develop customer-made solutions for existing as well as new applications.