HIGH PERFORMANCE LASER WELDING SYSTEMS FOR THE PRODUCTION OF INNOVATIVE LASER WELDED AUTOMOTIVE COMPONENTS

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Today's widespread use of laser-welded semi-products in the automotive industry originated in the invention of the laser welded blank by Thyssen Stahl AG in the 1980s. What was initially auxiliary solution to produce oversize galvanized steel sheets quickly developed into the idea of the tailor-welded blank. ThyssenKrupp Lasertechnik invented and supplied laser welding production systems from the very beginning of this evolution. With this long-standing experience, the company today offers custom made solutions of either semi or fully automated systems in a modular design to manufacture a wide range of laser-welded products.

The paper will show on the example of laser-welded blank production how such systems can be configured to either highest productivity or to extreme flexibility. Furthermore it will be demonstrated how the laser welding know-how of ThyssenKrupp Lasertechnik has been transferred to other applications such as coil welding and orbital welding of engineering steels. The specific technical advantages and economic benefits of laser welding in such applications will be explained. Last but not least new application opportunities of laser welding for innovative steel products will be indicated.

Introduction

Constantly increasing demands on the safety and the environmental compatibility of automobiles require the development of improved body designs so that lighter but safer vehicles can be manufactured. In order to fulfill these fundamentally contradictory requirements, tailored blanks – custom-made steel sheets in the form of laser welded blanks – are frequently used in the manufacture of modern automobile bodies.

Tailor welded steel blanks have made a remarkable career from rather infrequent applications at the end of the 1980's to an indispensable product in today's and future automotive body design. A welded blank comprises at least two flat sheets of different steel grades, surface coatings and thicknesses that have been continuously joined together by means of a suitable welding process. This blank is then formed into the actual component in the stamping plant. The classic manufacturing sequence, i.e., first form – then join, is inverted by this innovative product. The processing of welded blanks in the stamping plant only requires minor adjustments to the drawing process, so that no additional investments are necessary. The different sheet thicknesses joined together in the welded blank must be correspondingly worked in the drawing die. The different flow characteristics of the individual sheets and in particular of the weld seam determine the design of the drawing process in the final analysis. Drawing simulation is an important aid for the advance study and optimization of the drawing process and blank design. Depending on the specific application and the design of the welded blank, the following potential for optimization is available to the automobile designer [1]:

- Improving the safety characteristics of the body structure.
- Reducing the vehicle weight.
- Increasing the stiffness of the body.
- Reducing the number of components.
- Reducing the total manufacturing costs.

The analysis of the technical feasibility and advantages and the evaluation of the cost-to-benefit ratio form the central criteria for a decision on whether to utilize tailored products.

The most important cost contributions to producing a welded blank are the laser welding and the blanking of the individual sheet components. Consequently by reducing the manufacturing cost of a welded blank the cost-to-benefit ratio is improved and hence the decision to apply a laser-welded blank is facilitated.

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 blanks. 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.

Laser-welded blank production concepts

For laser welded blank production various manufacturing concepts are used in the industry [2]. 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 characterised 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 to maximize the utilisation of the laser welding equipment, to optimize production flexibility and to reduce cost.

Fixed optics laser welding systems are characterised by a stationary welding head while the sheet assembly to be welded is passing underneath. 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 performing a 2-dimensional trajectory. In this way weld seams of more arbitrary shape can be made. The choice of the welding machine concept largely influences the way of positioning and clamping the sheets to be welded. Moving optics systems generally require a fixture tool also called “jig”. The jig is often specially made for a particular blank configuration and, thus, represents a part specific investment cost. Another disadvantage of these systems is the more complicated beam delivery requiring multiple mirrors and special devices such as a beam telescope to compensate beam variation over the work envelope. Each mirror within the optical part contributes to the cumulative loss of available laser power at the working point. Here the YAG laser due to the beam delivery by an optical fibre brings a major progress. Since the length of the fibre is constant, beam properties remain the same at each point within the work envelope.

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 a fixed optics welding 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 set of non-welded sheets to the weld process as soon as the welding cycle on the previous sheet set is finished. This scenario allows a maximum productivity of the capital-intensive welding equipment and thus leads to minimisation 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, the blank layout may induce an extended intersection between consecutive weld seams due to geometrical constraints of the blank contour. In this case an 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 (Fig. 1). 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, namely seam cooling. A water jet is sprayed on the already welded hot zone resulting in a distortion that leads to a closure of the gap in the area yet to be welded. The cooling water is immediately removed from the sheet surface by suction funnels so that no problems with corrosion are encountered.

In discontinuous material feed systems that are also on the market a shuttle takes a set of non-welded blanks and clamps them 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 reload times constitute an additional unavoidable beam-off time so that the overall productivity is inferior to that of a continuous feed system.

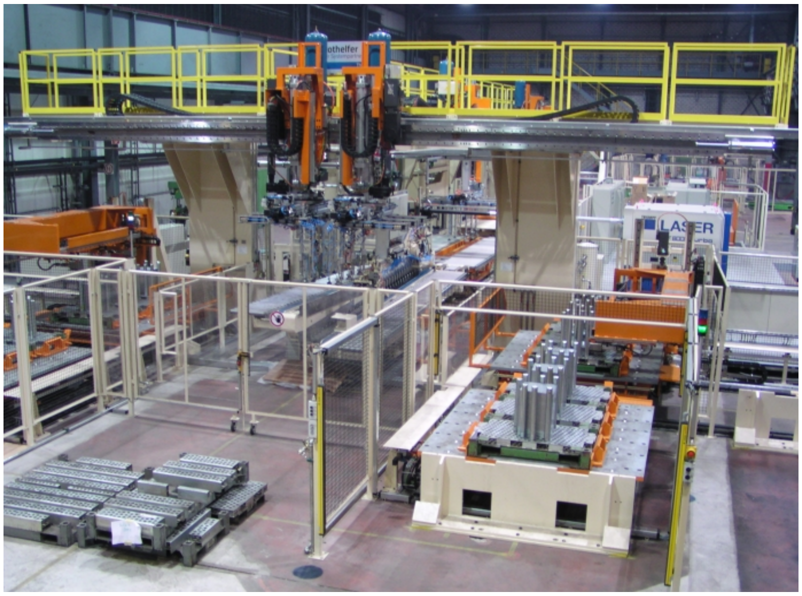


Fig. 1 Fully automatic laser welding line with continuous material feed.

Moving optics welding machines (Fig. 2) are also based on discontinuous feed systems. The part specific fixture tool is loaded with the blank set by robot. Final positioning of the different blank sets is done by actuators integrated in the jig. The handling cycle covering the blank loading and positioning before welding as well as the unloading of the welded blank represents a significant beam-off time. For this reason most machine concepts utilise a double fixture device to allow handling operation on one jig while the other is in the welding cycle. The two jigs can be mounted on a turn table revolving by 180 degrees or are attached on two shuttles moving in and out the welding booth individually. It is still necessary to keep the weld cycle time larger than the handling time. This can be achieved by grouping several blank sets into one jig driving up the weld cycle time.

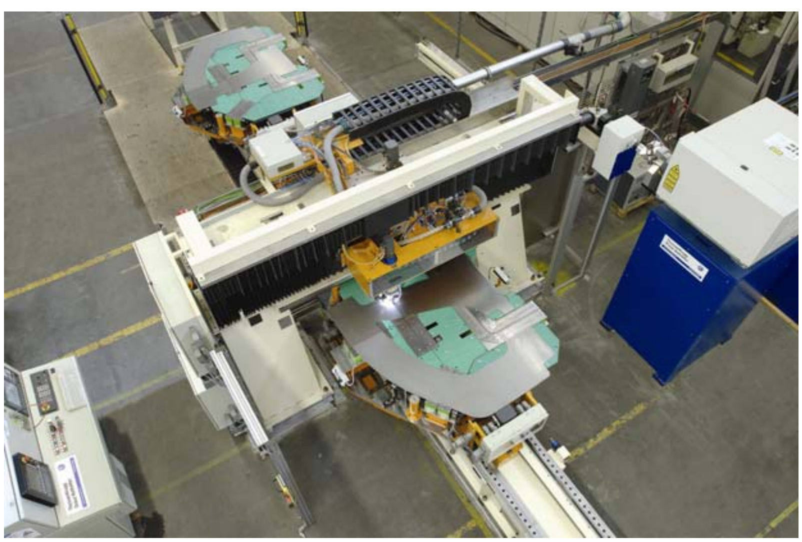


Fig. 2 Moving optics laser welding line allowing two-dimensional welding.

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 (Tab. 1).

The simplest configuration is to load and unload the blanks by manual labour. 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 favourable in countries where labour 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.

Table 1 Different configuration options for laser welded blank welding system with continuous material feed.

Manual Conti Line:

- Manual loading of pre-material
- Automatic joining and centering of the pre-material
- Manual unloading of welded blanks
- Direct operating staff: 5 people
- Budgetary investment: 2.500.000,- EUR

Semi-Automatic Robot Type Conti Line:

- Manual or automatic loading of pre-material
- Optional automatic edge preparation
- Automatic joining and centering of the pre-material
- Manual or automatic unloading of welded blanks
- Direct operating staff: 3 people
- Budgetary investment: 3.500.000,- EUR

Fully Automatic Gantry Type Conti Line:

- Automatic loading of pre-material
- Automatic joining and centering of the pre-material
- Automatic unloading of welded blanks
- Optional in-line dimpling and in-line turning
- Direct operating staff: 1 operator
- Budgetary Investment 4.500.000,- EUR

In markets where labour cost is higher and/or larger order volumes are to be produced, manual labour 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.

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 (Fig. 3). 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.

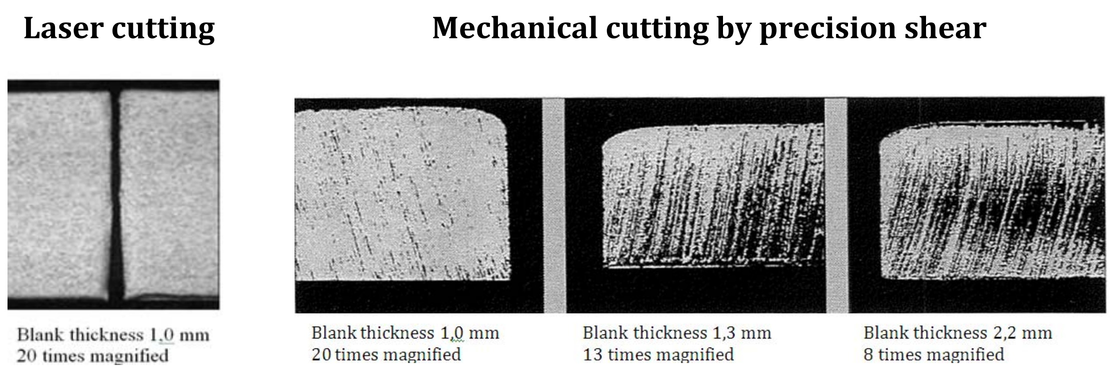


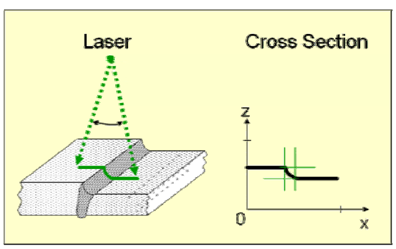
Fig.3 Typical edge preparation techniques for high quality laser butt-welding.

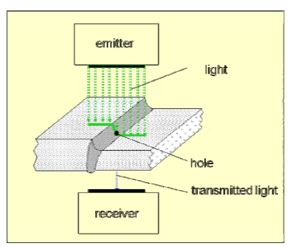
In blank preparation for tailored-blank mass production typically mechanical cutting is employed. This can be done using a precision shear or a blanking die (Fig. 3). Important is in either case that the clearance between the cutting knives is small to obtain a high shear-to-break ratio [3]. This requires a special construction of a blanking die to be very stiff with accurate guidance. Also the press blanking line has to fulfil increased demands to be suitable for such a cutting process. Naturally such blanking dies are quite costly and they are a part specific investment. Therefore such a solution is only interesting for high volume production. For smaller volumes and in situations where only a less performing press blanking line is available, 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 (approximately 5 mm). This over-dimension is cut back by a precision shear shortly before loading the blank into the continuous welding line (Fig. 4). 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 (Fig. 4).

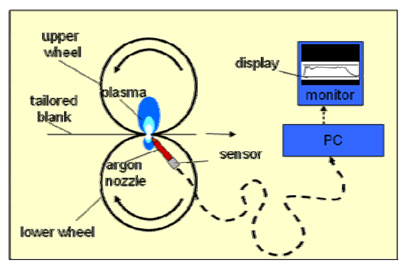
Fig. 4 Precision shears and 6-axis robots at the entry of a continuous laser welding line.

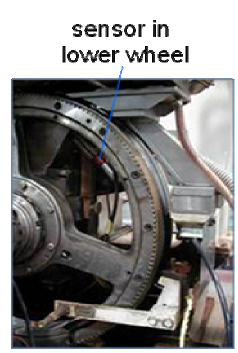
Table 2 Cornerstones of on-line weld seam quality control in a continuous laser welding line.

Geometry control | **Hole detection** | **Plasma detection**









Laser weld seam quality control

The quality of the laser weld seam is inspected in line, i.e., 100% of the produced seam is inspected. The quality control system is based on three cornerstones (Tab. 2). The geometry of the weld bead is measured by laser triangulation. A light barrier checks for holes and non-welded sections. A plasma sensor monitors the welding process itself allowing to conclude on the process stability and performance.

Other innovative laser welding equipment of ThyssenKrupp Lasertechnik

With the long years of experience gained with laser-welded blank production systems, ThyssenKrupp Lasertechnik has recently expanded its product portfolio to other innovative laser-welding systems with respect to automotive products.

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. 5). Using a laser of appropriate power allows to do the cutting operation fast enough to comply with typical line cycle time.

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.

Fig. 5 Laser coil welding device with integrated laser edge cutting and seam marking.

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. 6). This bears several advantages. The laser weld is highly loadable and formable (Tab. 3), 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 depends 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 [4]. A respective inductive annealing device for post-weld heat treatment can be integrated in the coil welding system. Furthermore an automatic quality control can be integrated according to the principles shown in Table 2.

Table 3 Performance benchmarking of laser coil weld seams (equal material pairs) produced with “Best Weld Technology”.

		
Steel grade	**Tensile test performance** **(compared to parent material)**	**Formability performance** **(compared to parent material)**
Al-killed drawing grade (DC01)	**100%**	**95%**
Dual phase steel (DP600)	**100%**	**78%**
Retained austenite steel (TRIP600)	**100%**	**80%**
Retained austenite steel (TRIP700)	**100%**	**71%**

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.

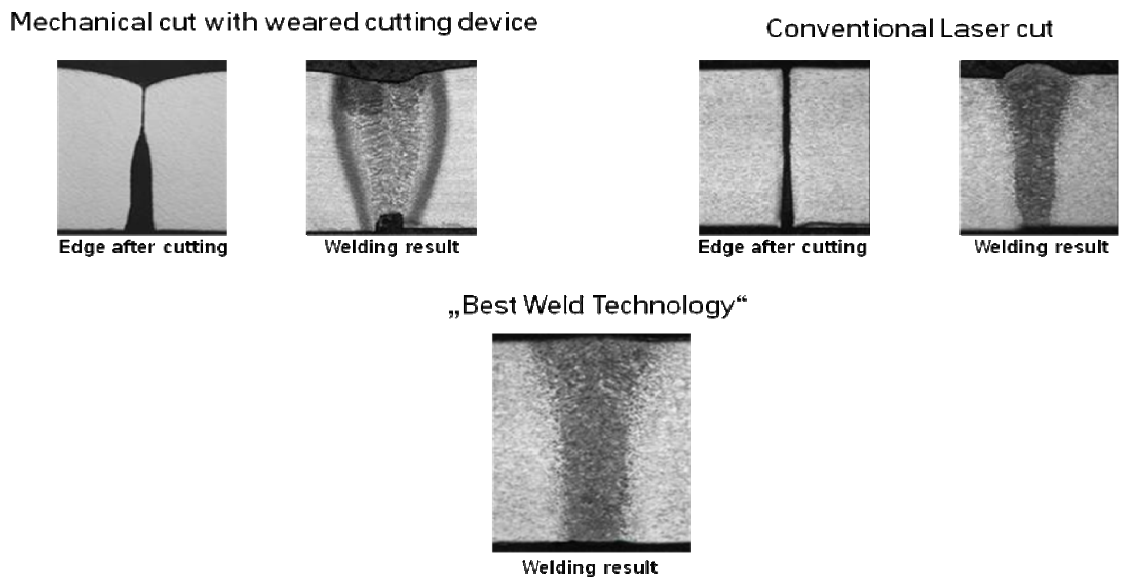


Fig. 6 Influence of edge preparation technique on the weld seam quality – "Best Weld Technology" is implemented in ThyssenKrupp Lasertechnik coil welding system.

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, powertrain and steering.

Laser-welded components offer great functional potential in shock absorber construction (Fig. 7). 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 [5]. 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 (Fig. 8).

Fig. 7 Typical examples of Tailored Orbitals for shock absorber components (Mercedes-Benz).

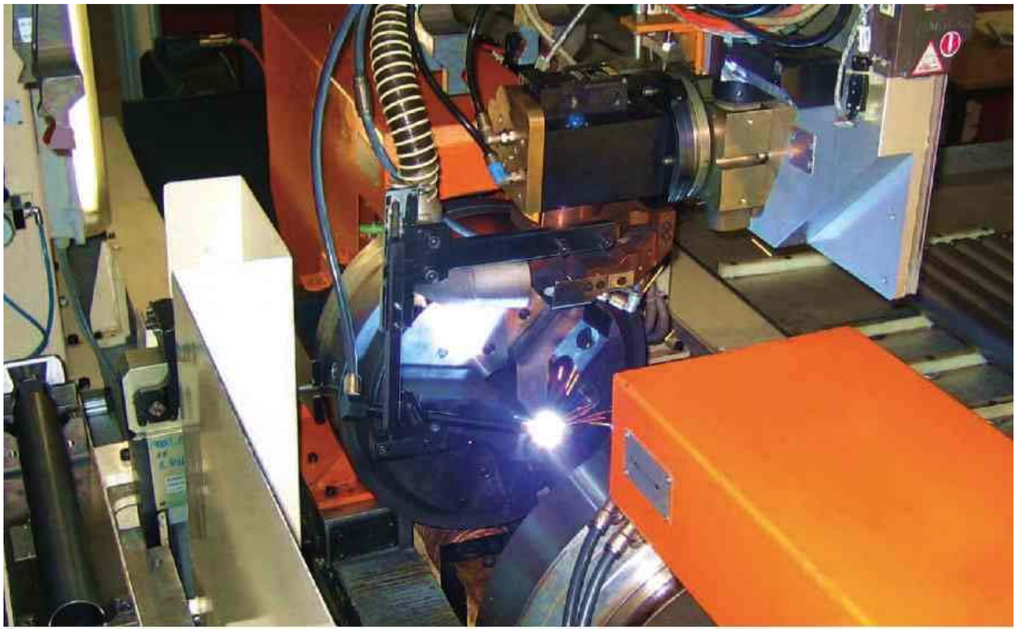


Fig. 8 Orbital welding system by ThyssenKrupp Lasertechnik: material flow from left (tube and base not welded) to the middle (welding station) to right (finished material).

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. Transfer of the laser welding and systems know-how to other applications in vehicle construction offers interesting opportunities such as demonstrated for Tailored Orbitals and coil welding. Depending on the specific challenge ThyssenKrupp Lasertechnik is ready to develop customer-made solutions.

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