LASER BASED GIRTH WELDING TECHNOLOGIES FOR PIPELINE CONSTRUCTION

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To increase efficiency in pipeline construction, examinations on new welding processes for joining of pipes are indispensable. To this end, increasing productivity of the welding process but also requirements on the material are of immediate importance. Hence, a possible alternative is laser-GMA hybrid welding. The technological approach is the use of the laser typical deep penetration effect for the generation of a high quality free root pass or a complete weld in one step. The results of the technology and equipment developments and their performance under construction site similar conditions are given by this presentation. A high laser power and the advantages of its guidance via fiber optics allow the use of orbital welding.

Keywords: *arc welding, hybrid laser-arc welding, pipelines, welding technology, equipment, productivity of welding, construction site conditions*

For years well tested and proven arc welding processes have been applied for welding of large pipes of oil and gas pipelines. Depending on the length of the pipeline to be produced, the wall thickness of the individual pipes and the material they are made of, versatile variations of these processes are used, with a scope extending from manual arc welding with stick electrodes (Figure 1) up to the application of so-called orbital welding units using the MAG process. In this case the welding movement is not performed manually by the welder but fully mechanised using motor-driven systems and clamping rings across the entire circumference of the pipe. If permitted by the length of the pipeline and the profile of the ground, a number of these orbital units are used at the same time with every single station having been designed for welding of one or two passes and then being displaced to the next pipe joint to produce the same weld seam there. Such production aggregates often rely on several welding heads per unit [1] thus representing a high state-of-the art, both in relation to equipment and welding. This, however is connected with a high expenditure on personnel and plant engineering (Figure 2).

Particularly with regard to the increasing focus on the supply of energy in Germany and Europe in the future the question of new and high-performance technologies in pipeline construction has arisen, in order to substantially meet the demand in the future.

A further increase of the performance in this area bears some problems, since the arc processes applied have obtained their physical limits concerning deposition efficiency and welding speed. Here, no essential increases can be achieved by optimizing the arc welding technology.

The development of welding processes of increased performance must be carried out under the following aspects:

- reduction of the number of passes at constant and improved seam quality, respectively;
- reduction of the number of welding stations and thus the expenditure on equipment and personnel.

Welding processes based on laser beam, on the one hand, offer the technology and, on the other hand, the equipment needed to fulfill this demand. In the following the proof of this shall be given.

Point of origin of technology and equipment. The application of laser-GMA hybrid welding is a promising technology for the future.

In laser-GMA hybrid welding both processes are combined, such that both the laser beam and the arc

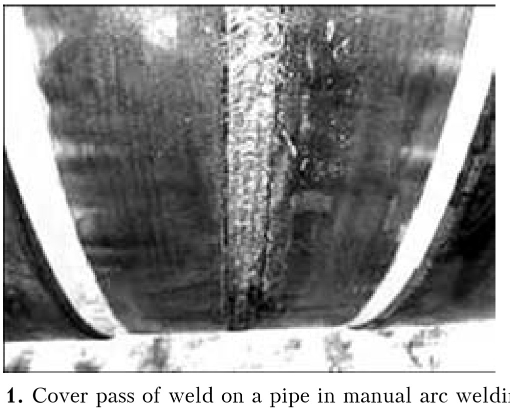


Figure 1. Cover pass of weld on a pipe in manual arc welding

Figure 2. Building site in pipeline construction

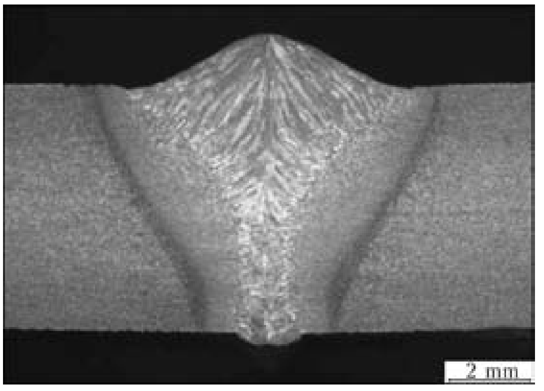


Figure 3. Formation of the weld in hybrid welding

act in a common melting pool. The result is more than simply adding both of the energy sources and the filler metal put in; it is rather that the resulting synergetic effects combine and enhance the advantages of the single processes. Thus, a joint profile is generated that is similarly deep as that obtained by laser welding, but has a considerably better gap bridging capability. Hence, on the field of thin sheets very high welding speeds can be obtained, which partly are many times the amount of the state-of-the-art of welding with shielding gases. With larger plate thicknesses the advantages are not within the area of welding speed, but there is rather the possibility of reducing the number of layers by single pass layers, often without additional joint preparation.

A typical formation of the seam for a sheet plate thickness of 8 mm using GMA, laser beam and hybrid welding are shown in Figure 3.

The fact that today the application of laser beam sources under construction site conditions is possible, is based on the rapid development in this field. Thus, beam sources of the latest generation, the so called fiber lasers, do not only cover the two-digit kilowatt range but also distinguish themselves by a sturdy and compact structure. In connection with a very high efficiency and an excellent beam quality the preconditions for a mobile application are given, which could not be executed using state-of-the-art conventional laser beam sources (CO_2- or Nd:YAG lasers). In the last five years fiber lasers have been used as a mobile application in shipbuilding and in the production of pipes [2].


Figure 4. Gullco orbital system for welding pipes

Laser-GMA hybrid welding of pipe connections under conditions similar to those on construction sites. *Objectives and technological approach*. The objective of the examinations on technology and equipment described in the following was the transfer of the state of knowledge of laser-GMA hybrid welding for the production of pipe joints, incorporating all necessary aspects such as tolerances, environmental influences, mobility of the entire equipment and welding out-of-position.

The focus of examinations was laid on the use of the laser typical deep welding effect for the production of a high quality free root pass at root faces of 6–10 mm. To this end, the different arrangements of the laser beam and the arc possible for hybrid welding of butt joints were compared to the different types of joint preparation.

The approach for the production of pipe joints was welding of two vertical-down seams being a common practice in pipeline construction and considerably reducing the types of freedom in the arrangement of laser beam and arc required for the technological optima of the seam formation.

For the generation of a closed seam profile the weld head was extended by a further arc torch, thus enabling to weld the first pass using hybrid welding and the cover pass using GMA welding during one welding run. The objective was to produce a closed seam profile up to a plate thickness of 12 mm in one rotation. Further, this trailing process is a good opportunity to have a positive influence on the mechanical-technological properties of the weld seam.

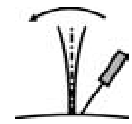
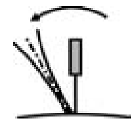
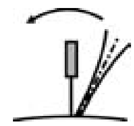
Equipment. In order to verify the principal feasibility of the laser-GMA process during girth welding the proven techniques were used.

The equipment for the examinations was a commercially available system for pipe welding by the Company Gullco (Figure 4). This system was equipped with a tractor on a ring guide for the generation of girth welding as well as with a contact seam tracking and weld scanning system based on two control axes for the transverse and height positioning of the process components to the weld groove. The arrangement of the contact sensor forwarding the welding process was executed in direction of movement.

Equipped with various stiffening elements, the adaptation of the weld head to the control axles for height control was executed. For transferring the possible serial types of arrangement of laser beam and GMA arc shown in Table 1, the hybrid welding head was equipped with additional degrees of freedom (Figure 5).

As shown in Table 1, either the laser or the arc was considered at neutral position each, for reasons of simplification. No intermediate levels were used.

Table 1. Serial arrangements of laser beam and welding arcs

Variation	Neutral process	Arrangement of the 2nd process	Schematic representation
1	Laser beam	Arc forward travelling	
2		Arc trailing	
3	Arc	Laser beam forward travelling	
4		Laser beam trailing	

Two different fibre lasers were used as laser beam sources. In the first phase, with the focus of investigation on root faces up to 6 mm, a system with an output of 4.5 kW (Figure 6, *a*) was used, and for phase 2 at a root face of 8 mm, a mobile 10 kW laser from the SLV Mecklenburg-Vorpommern was integrated to the test built-up (Figure 6, *b*). The 4.5 kW fiber laser from the year 2003 was one of the first sources of fiber lasers for welding within this performance class, having proven its long standing stability in many applications.

Figure 7 shows the completed welding head with the equipment for hybrid welding and the integrated second arc torch for welding the cover pass during one vertical-down weld movement.

Welding was performed on pipe pieces at lengths of up to 6 m. In this case larger tolerance results compared to a pipe with calibrated ends, in particular with regard to quality and misalignment of edges.

Through the integration of the components described, the entire test set-up shown in Figure 8 was realized.

Execution and results of the technological examinations. As already described in the previous section,

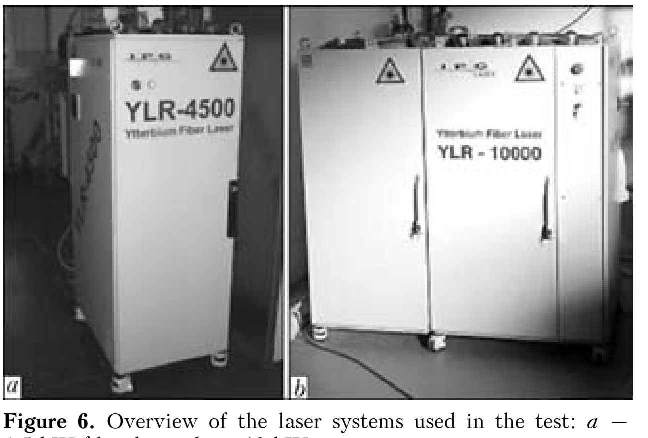


Figure 6. Overview of the laser systems used in the test: *a* — 4.5 kW fiber laser; *b* — 10 kW

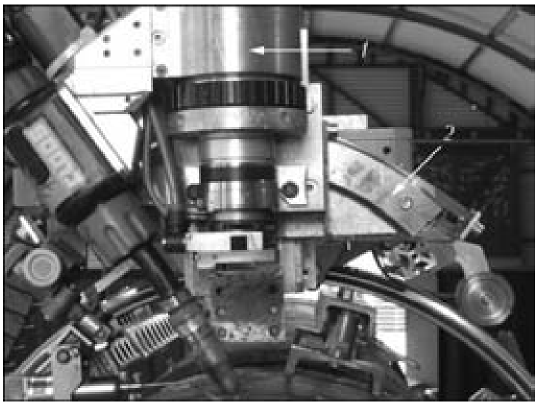


Figure 5. Mechanical realization of the degrees of freedom for changing the arrangement of laser and arc in series: *1* — hinge with holding device for sviveling the arc aroung the optic; *2* — curved guide for changes of angle of the process axes for joining

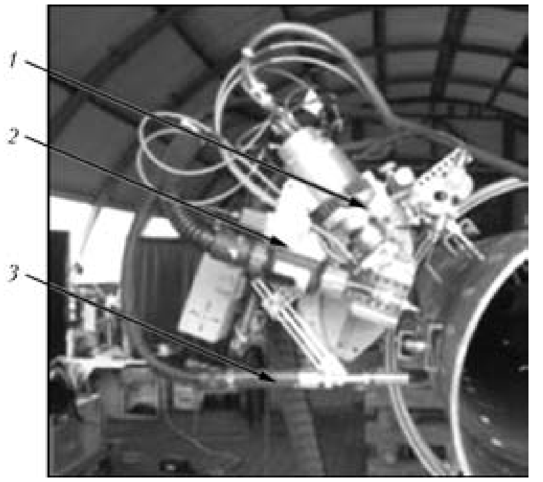


Figure 7. Welding head with hybrid equipment for root pass welding and arc torch for filler pass welding: *1* — laser optics; *2* — hybrid arc; *3* — arc torch for filler pass welding

Figure 8. Entire test set-up on the pipe

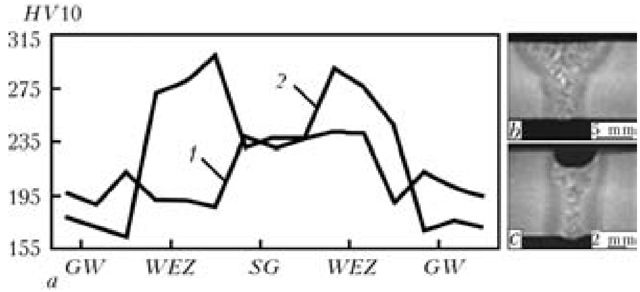


Figure 9. Influence of the trailing arc on distribution of hardness in the root area [3] (*a*), and macrosections obtained with (*b*) and without (*c*) backing: *GW*, *WEZ*, *SG* — spatial positions of the welding head

the test was performed using two laser beam sources of different output. In doing so, first the principal test series for determining the basic parameters for the hybrid arc and for determining the tolerance susceptibility of the hybrid process at continuously changing welding positions across the pipe circumference was performed in phase 1 using a 4.5 kW fibre laser. Test phase 2 served to estimate the potential of the hybrid process at higher laser performance at a simultaneous increase of the root faces for the root pass from 6 to 8 mm. To his end, a 10 kW fibre laser system was used.

For the execution of all test welds the following specifications were given:

• removing the internal coating from all edges;

• measuring the wall thickness, height and width of the root face of each edge;

• tacking of the joint with outside centering under the following parameter: longitudinal seam of the pipe to be joined abutting the longitudinal seam of the fixed pipe (increased conditions of tolerance);

• measuring the edge offset and air gap at tacked joint;

• adjusting the focus position and geometrical parameters is carried out for each joint again;

• guide edge for contact seam tracking is the fixed pipe;

• welding was performed in two vertical-down weld;

• aimed preparation of macrosections at 45, 90 and 150°, and at 315, 270 and 210° respectively.

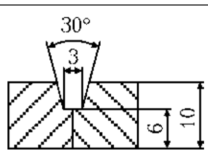
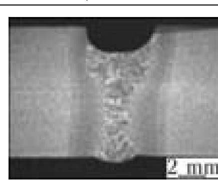
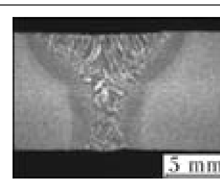
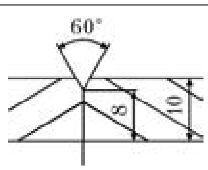
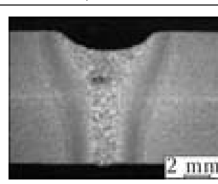
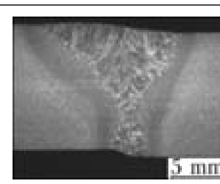
In the following the results are shown in the form of macrosections both for the first hybrid welded pass and the closed seam profile by the trailing arc at a different variation of seam preparation at a laser output of 4.6 and 6.5 kW (Table 2).

Through the tolerances measured at the pipe joints and the welding parameters assigned today, there are considerable results on the different tolerances of the process.

The examinations were concluded by the determination of the distribution of hardness in particular in the root area of the weld seams, since this laser beam dominated area in the heat-affected zones could be susceptible to increased hardening. During these examinations, pure root welding without cover pass was compared to welding with closed seam profile through the trailing arc with the results being shown in Figure 9.

A decisive object of investigation was the determination of typical tolerances in pipeline construction and the examination of the influence of these tolerances on the hybrid welding process. During the trials

Table 2. Seam preparation and macrosections of hybrid-welded joints

Seam preparation	First pass	Closed seam profile
4.6 kW laser, root face of 6 mm		
		
6.5 kW laser, root face of 8 mm		
		

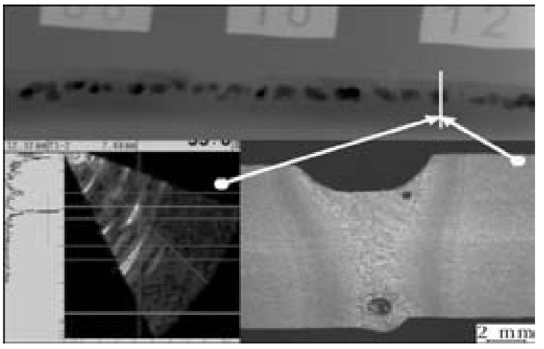


Figure 10. Correlation between cross section of weld and non-destructive methods

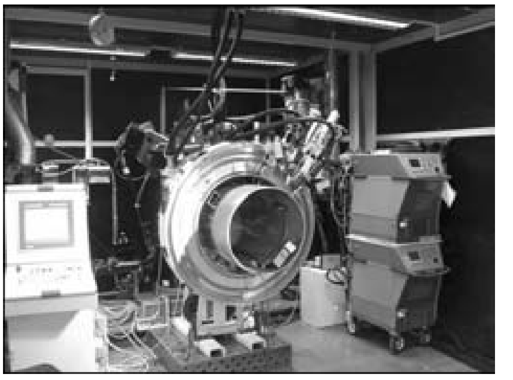


Figure 12. Specialized prototype of equipment for hybrid welding

the pipe joints were positioned and fixed using typical tools and methods resulting in tolerances typical of pipeline construction. In order to draw conclusions from these tolerances during the future evaluations, the joining edges and the welded joints were measured.

The evaluation and interpretation of the weld quality took place on the basis of methods of non-destructive and destructive testing. First the welded pipe segments were investigated by phased-array (ultrasonic) and X-ray testing. Objective was to verify the detectability of imperfections by non-destructive methods and to establish the correlation to the cross section of the weld regarding dimension and location of these imperfections. The result of these investigations is shown as an example in Figure 10 [4].

The data recorded in such a way served both for developing different diagrams to show peak positions and directly comparing them to the welding result and with regard to the tolerances.

Further development of equipment and technology. The major objective of the investigations shown was to prove the principal suitability of hybrid welding for pipeline construction with regard to the more rough climatic conditions in this field of application. Here, important information with a great influence on the structural design of the equipment was obtained.

The following deficiencies could be summarized:

- the welding speeds to be obtained were too low;
- the objective is to obtain 3 m/min;
- a position depending adaptation of the laser performance is necessary;
- the modification of direction and orientation, respectively, requires much time and is a source of failure due to the high number of adjustment steps;
- the existing technology does not comply with the requirements of the process as far as the mechanical properties are concerned.

The objective of the further development of the equipment was to increase the stability of the rotational movement along the pipe and to adapt it to the conditions of the hybrid process. Figure 11 shows the design of the more specialized prototype for hybrid girth welding.

The specialized prototype developed on the basis of this (Figure 12) for the realization of a girth welding movement for laser-GMA hybrid welding has the following technical data: traveling speeds in positioning — up to 6 m/min, in welding — up to 3 m/min; pipe diameters processed — 500–700 mm; change of the parameters depending on position; and seam tracking and guidance system.

The integrated laser working head allows coupling with all fiber guided solid-state lasers of outputs of up to 20 kW.

A further focus of the current examinations has been laid on the optimization of the process for pipe wall thicknesses starting from 10 mm at different root faces for the first pass to be welded using a laser, namely the 12 kW fiber laser system available at the SLV Halle since January 2009 (Figure 13).

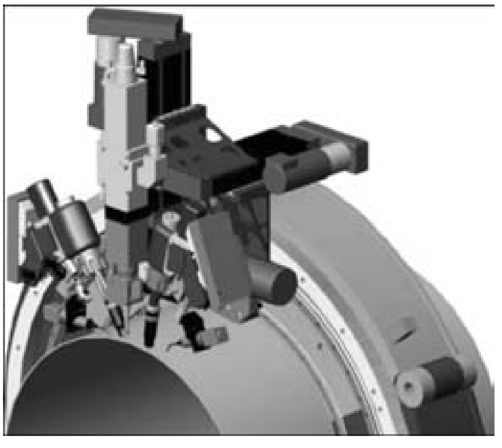


Figure 11. Design for the further development of equipment for hybrid welding of pipe joints

Figure 13. Fiber laser system YLS-12000

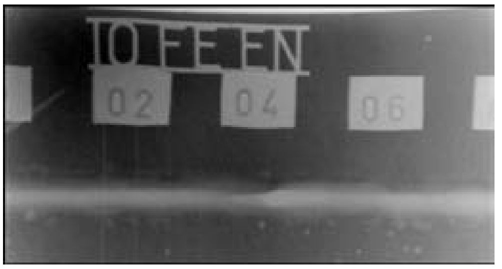


Figure 14. Radioscopic exposure of overlapping of the weld starts (12 o'clock position)

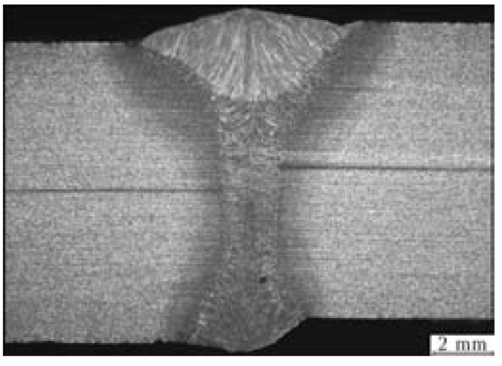


Figure 15. Macrosection of welded joint at misalignment of edges of 1 mm

The focus of the examinations, on the one hand, was directed to investigate the possibilities of the formation of the seam and the root with the laser output available and, on the other hand, on the overlapped areas at the weld start obligatory when welding two vertical-down seams at the circumference of the pipe. Figure 14 is showing the result of the radiographic testing in the overlapping area of the start areas for a pipe wall thickness of 10 mm.

The weld areas were tested on internal imperfections metallographically. To this end, pipe typical tolerances were considered in order to make statements about the influences of higher laser power and increased welding speeds on the weld formation with regard to different tolerances. Figure 15 is showing the formation of the seam at 3 o'clock position for a pipe wall thickness of 10 mm, for higher laser outputs too.

This phase of examinations was concluded by performing material tests for determining the mechanical-technological characteristic values for the test material L360NB. The results of the tensile test are shown in Table 3, while the notched bar impact work at a temperature of 0 °C is shown in Table 4.

Table 3. Results of the tensile test*

Yield strength $\sigma_{0.5}$, MPa	Tensile strength σ_t, MPa	Elongation of fracture δ, %	Contraction of fracture ψ, %
345	532	42	71
368	539	39	69

*Position of fracture — base metal.

Table 4. Results of the V-notched bar impact test

T, °C	Demensions, mm		Impact toughness, J/mm^2, at impact work, J			
	a	b	1	2	3	M
0	7.5	8.0	201	128	77	136
	7.5	8.0	180	181	169	177

Summary and outlook. In order to increase efficiency in pipe line construction, examinations of new welding processes for joining of pipes are indispensable with the focus on increasing the welding speed at a reduced number of passes. A possible alternative is the laser-GMA hybrid welding process, since due to the development of the fiber laser a beam source with new fields of application is available [3].

The objective of the investigations presented was to prove the principal suitability of hybrid welding for pipeline construction as well as the behaviour of this process in out-of-position welding which is required for its application.

Furthermore, both closed seam profiles were produced and hardening increase of the heat-affected zones of the root area were reduced for a pipe wall thickness of 10 mm for an arc process trailing the hybrid welding.

The results distinctively show the potential of the hybrid process at high laser output and with brilliant beam qualities. In a next step of the examinations the results are to be transferred to larger pipe wall thicknesses.

As an alternative of the existing approaches [5] there is the idea of using the hybrid process for the production of a high quality root pass at root faces of 12–15 mm. This approach is the basis of the examinations currently performed.

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