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Nd:YAG-laser – gas metal arc – hybrid welding: a chance for the use of the advantages of laser technology and flexible automation in shipbuilding and steel construction

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Abstract

The paper deals with the Nd:YAG-laser – GMA – hybrid welding process for the use in shipbuilding and steel construction.

The advantages of a laser – arc – hybrid welding process in comparison with a laser alone or an arc alone welding process are shown. The current possibilities of the Nd:YAG-laser – GMA – hybrid welding process are shown by some results from hybrid welding of steel and aluminium alloys.

Furthermore the advantages of the Nd:YAG-laser technology, especially for a simple and flexible automation are described. The Nd:YAG-laser – GMA – hybrid welding is a process which demands a higher degree of automation in shipbuilding. Regarding to the advantages and related to the available Nd:YAG-laser sources a perspective for the use of the Nd:YAG-laser technology in shipbuilding and steel construction is pointed out.

A current German research project under participation of the authors is presented in the paper. One aim of this project is to develop a system for the automatically programming of robots and other welding systems in shipbuilding. Therefore the new programming tool should use the real geometrical data of the component before welding, resulting from a image processing tool.

Concluding, the first manufacturing system in shipbuilding (a welding gantry for 12 meter T-joints) outfitted with Nd:YAG-laser – GMA – hybrid welding equipment at a German shipyard is presented. The retrofitting of this welding gantry has been planned and accompanied by the company the authors are with.

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keywords: laser-arc-hybrid welding; laser-GMA-hybrid welding; Nd:YAG-laser; shipbuilding; automation

1 Introduction

The process of laser beam welding is today a well established joining process in industrial applications. The advantages, e.g. deep and narrow welds with high speed and low heat input are accompanied from some disadvantages like the necessary precise preparation of the edges of parts to be joined and the precise clamping of the work pieces.

Especially in shipbuilding and steel construction the advantages of the laser technology are to be used only with high costs and efforts due to the boundary conditions in the production line. With the coupling of the laser beam and the arc it is possible to extrude the range of application of the laser technology and their advantages.

Since the fundamentals of a laser-arc-hybrid process have been described in the 70th [1] different options of this technology were studied, like the laser-GMA-, the laser-TIG- or the laser-plasma-process. In the most cases of this variations a CO_2-laser was used as a laser source because of the higher laser power and better beam quality. With the now available higher laser power up to 6 kW in case of Nd:YAG-laser this laser source will be more interesting for the laser-arc-hybrid welding in shipbuilding and steel construction. The gas-metal-arc welding is today the preferred welding process in shipbuilding and steel construction in Germany. Therefore and because of some important advantages of the Nd:YAG-Laser the coupling of this type of laser with the GMA-welding process will be contemplated.

2 Process fundamentals

The fundamentals of the coupled process are nearly the same for both, the CO_2-laser and the Nd:YAG-laser. In **Fig. 1** the general principle of the process is shown. Laser process and arc process have a common process zone and weld pool. Only one shielding gas flow is necessary, mostly the gas flow is realised via the GMA-torch.

The superposition of the arc and the laser leads to different interaction between the two processes. The stabilisation of the arc under the influence of laser radiation or a laser induced plasma is one of the main advantages. The wandering of the arc is prevented, because the laser beam evaporates material and ionising the atmosphere, producing good conditions for ignition and burning of the arc. So the transfer of the energy of the electric arc is more efficient and the thermal effect of the coupled process is in excess of a simple sum of the effects of the laser and arc heat sources taken separately [2].

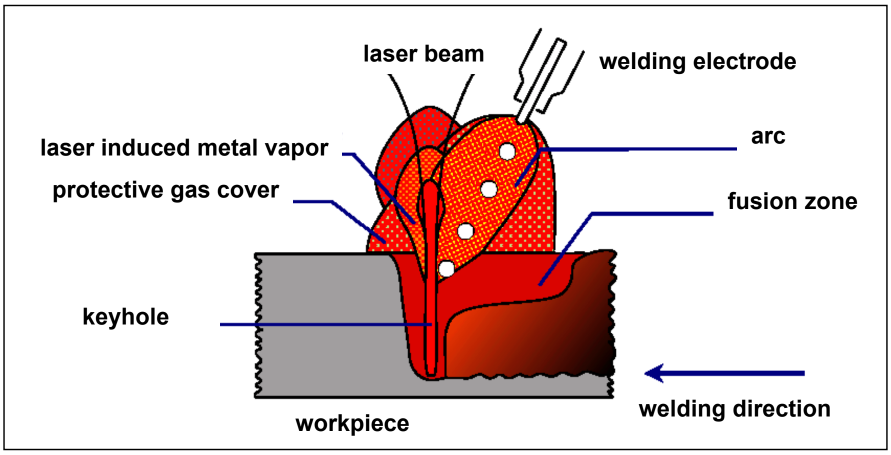


Fig. 1 Principle of the laser-GMA-hybrid welding process

Depending of the energy ratio of the two energy sources the character of the coupled process may be either more arc-like or more laser-like. The welding depths increases with the increase of laser energy whereas the weld width increases with the arc energy. For a given sheet thickness to be joined the proportion between the "laser part" and the "arc part" of the hybrid weld pool give us an estimation about the process character. The transverse sections in **Fig. 2** are showing an example for such different process characters.

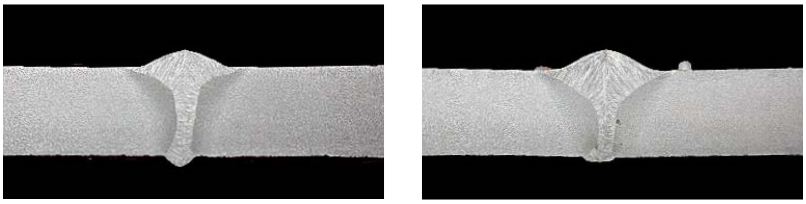


Fig. 2 Comparison between a more laser-like (left) and a more arc-like (right) laser-GMA-hybrid weld (sheet thickness 5 mm, I-groove)

Depending on the welding task the one or the other process character may be preferable. For the control of the process character and the utilisation of the advantages of the coupled process (**Fig. 3**) the effects of a great amount of welding parameters have to be known.

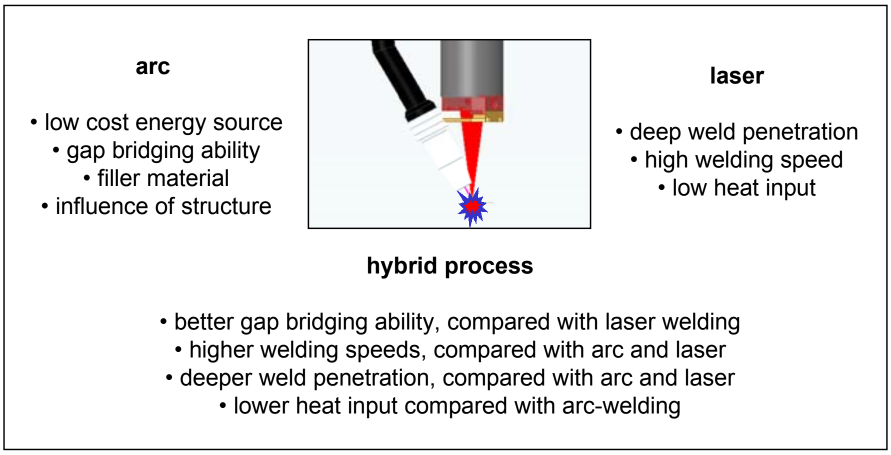
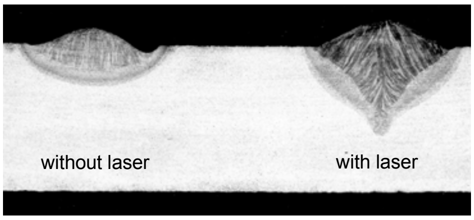


Fig. 3 Coupling of the advantages of arc and laser welding in a hybrid process

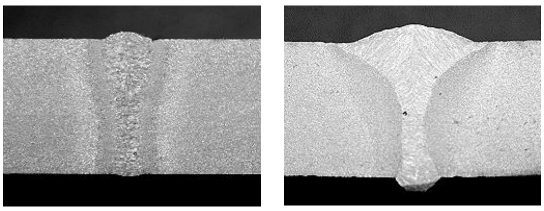
The effect of the laser beam in a hybrid weld is well illustrated by comparing transverse sections of GMA welds and hybrid welds with the same welding speed (**Fig. 4**). The welding depths increases from 1,5 mm to 5,1 mm using a 4 kW Nd:YAG-laser beam. Despite the high welding speed the quality of the top bead shape is good in case of hybrid welding, resulting from the laser-stabilized arc.



sheet thickness: 8 mm
laser type: Nd:YAG
laser power: ~ 4 kW
welding speed: 2 m/min
shielding gas: 82% Ar / 18% CO_2

Fig. 4 Transverse sections of a GMA-weld and a laser-GMA-hybrid weld

The effect of the arc, resulting in a better gap bridging ability and a better weld geometry then in a pure laser weld is illustrated in **Fig. 5**. The addition of the arc power and the process stabilisation in hybrid welding leads to a significant higher welding speed. So the heat input per unit of length remains almost constant in comparison with the laser alone welding process.



laser weld,
welding speed: 1,1 m/min

laser-GMA-hybrid weld,
welding speed: 2,5 m/min

sheet thickness: 5 mm
I-groove
laser type: Nd:YAG
laser power: ~ 4 kW
shielding gas: 90% Ar / 10% CO_2

Fig. 5 Transverse sections of a laser weld and a laser-GMA-hybrid weld

Besides the parameters laser power and arc power (arc voltage and arc current) and welding speed the geometrical formation of the laser beam and the torch and also the type of shielding gas are very important.

The arbitrary geometrical formation of the laser beam and the torch (torch before or behind or besides the beam in welding direction) and the possibility to couple more than one GMA-torch with the laser beam offers a great variety of geometrical formations for the solution of welding tasks.

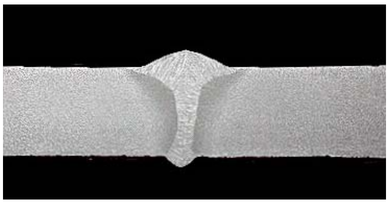
The usable shielding gas is one of the biggest difference between the hybrid welding with CO_2-laser and Nd:YAG-laser. For the work with the CO_2-laser gas mixtures with a high Helium content are necessary. In case of Nd:YAG-laser also Argon and active gases, e.g. mixtures from Ar, CO_2 and O_2 are usable. So it is possible to influence the metallurgy of the weld pool like in case of pure GMA welding. Pure Argon and active shielding gases are not usable for hybrid welding with a CO_2-laser, because of the risk of ignition of an protection plasma above the weld pool. This plasma interrupt the absorption of the laser radiation into the work piece and the hybrid welding process discontinues. This disadvantage of the CO_2-laser is caused in the different wave lengths of the radiation of the two laser types mentioned above. The CO_2-laser with a wave length of 10,6 µm offers other optical conditions then the Nd:YAG-laser with a wave length of 1,06 µm.

The practical qualification of the Nd:YAG-laser-GMA-hybrid welding for different shipbuilding applications is the main content of two research projects the authors company is involved. Besides the welding of constructional and shipbuilding steel also the welding of aluminium alloys for shipbuilding has to be done in one of the projects. In a lot of welding tests the hybrid welding of square butt joints and T-joints of the mentioned materials is carried out under laboratory conditions. Welding tests at a real welding gantry at the shipyard "Kvaerner Warnow Werft" in Rostock, Germany, for the qualification of the hybrid welding process also have been started.

Despite the high welding speeds reachable with the coupled process the technical and economical effects of the new welding process are not only resulting from the higher welding speed compared with GMA-welding. The main aspect of the positive effects is the lower energy per unit of length, leading to lower distortions and less postweld straightening.

Some results of the welding tests are shown in **Fig. 6** and **Fig. 7**.

root formation



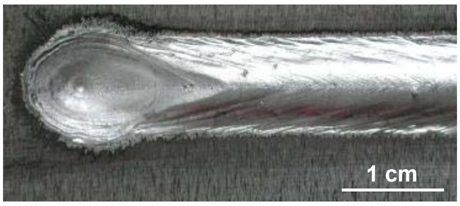
transverse section

Parameters:

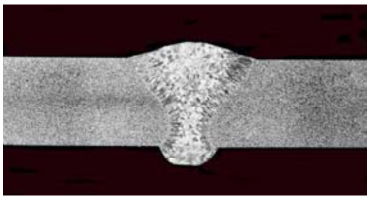
sheet thickness:	5 mm	*current type/ polarity /arc type:*	DC / + / pulsed arc
weld type:	I-groove	*arc current / voltage:*	290 A / 29 V
welding position:	PA	*wire feed rate:*	12500 mm / min
laser type:	Nd:YAG	*arc power:*	~ 8,4 kW
laser focal length:	200 mm	*welding speed:*	3000 mm / min
laser power:	~ 4 kW	*shielding gas:*	12 l /min (Ar / O_2)

Fig. 6 Laser-GMA-hybrid weld on constructional steel

For aluminium alloys the laser-GMA-hybrid welding offers an additional advantage over the pure laser welding compared with the welding of steel. During laser welding of aluminium alloys the keyhole is very instable due to the lower viscosity of the aluminium melt versus steel melt. This leads to numerous collapses of the keyhole and to a lot of big pores, so called process pores. The outgassing of these pores are very difficult due to the very small weld pool and short cycle time in case of laser welding. The phenomenon of process pores is limiting the welding depths in case of laser welding of aluminium. To solve this problem some strategies were developed, e.g. the welding with two laser spots for the enlargement of the weld pool. In principle all these strategies leads to a higher necessary laser power at constant welding depths.



typical top bead shape



transverse section

Parameters of the weld (transverse section):

sheet thickness:	5 mm	*current type/ polarity /arc type:*	DC / + / pulsed arc
weld type:	I-groove	*arc current / voltage:*	162 A / 24 V
welding position:	PA	*wire feed rate:*	12.000 mm / min
laser type:	Nd:YAG	*arc power:*	~ 4,0 kW
laser focal length:	200 mm	*welding speed:*	2500 mm / min
laser power:	~ 4 kW	*shielding gas:*	45 l /min (Ar / He)

Fig. 7 Laser-GMA-welds on aluminium alloy 5083

The laser-GMA-hybrid welding is a good possibility to realise the higher power at the working piece. With the coupling of the laser beam and the arc high welding depths and high welding speeds are also possible on aluminium alloys without the danger of process pores. The bigger weld pool geometry and the modified flow conditions in the melt allows the outgassing of pores. Furthermore the override of the metallurgy of the weld with the melting filler wire is much better compared with pure laser welding.

3 The equipment of production lines

3.1 Theoretical aspects

The possibility for transferring the Nd:YAG-laser beam via a flexible laser light cable is a second big advantage of the Nd:YAG-laser caused in the lower wave length. In contrary, the CO_2-laser beam must be transferred via a mirror system to the working point.

Laser light cables and laser working heads are manageable by industrial robots, a lot of such solutions in automobile manufacturing are making these solutions to state of the art.

But the flexible beam transfer in connection with the higher available laser power of modern Nd:YAG-laser systems up to 6 kW makes the use of this laser type also very interesting for production lines in shipbuilding and steel construction. In case of using a Nd:YAG-laser only the working head has to fulfil the high requirements on the dynamical behaviour and not the whole beam transfer way, the complete machine tool respectively, as in case of using a CO_2-laser. A common welding gantry or another welding machine, respectively the point of the working head, should be fulfil the requirements according to [3] as a supposition for refitting with a Nd:YAG-laser source.

In connection with the laser-GMA-hybrid welding process the advantages of laser technology are usable for conventional production lines. Nevertheless the Nd:YAG-laser-GMA-hybrid welding demands a higher degree of automation in the production line. A precise seam tracking system including measuring of the gap size and the control of laser- and / or arc-power is an elementary equipment. The control system of the welding gantry must be able to control higher welding speeds than in case of pure GMA-welding and a lot of new functions, connected with the use and control of the laser system. But the effort for refitting a conventional welding gantry with Nd:YAG-laser equipment is much lower than the purchase of a new special designed laser welding gantry.

Another advantage of the Nd:YAG-laser sources is the possibility to connect one laser source with up to 6 handling systems and to add the radiation of two or three laser sources into one laser light cable. So also with solid state lasers a power of more than 12 kW at the work piece is possible. As already realised in the automobile industry so called "lasernetworks" with several laser sources and several handling systems are also thinkable for production lines in shipbuilding and steel construction. Such a "lasernetwork" can be installed "step by step", regarding to the actual demands of the shipyard. Also a occasionally insert of laser technology for special manufacturing tasks is possible. This flexibility is only caused in the type of laser source, the Nd:YAG-laser and the possibility to transfer the laser beam via laser light cable.

In the two already mentioned German research projects the predicting problems with the use of Nd:YAG-lasers in shipbuilding, e.g. the occupational safety and health and the necessary higher level of control systems and automation should be solved. One of these projects is going on in a regional network of the authors company and two other research companies, attended by several German shipyards and related firms.

Besides the qualification of Nd:YAG-laser-GMA-hybrid welding and problems regarding to safety and control of the laser system the aim of this project is to develop a system for the automatically programming of robots and other welding systems in shipbuilding. Therefore the new programming tool should use the real geometrical data of the component before welding, resulting from a image processing tool. Thus the expensive manual work for the programming of welding machines and the dependence from not up-to-date CAD-data should be replaced in the future. Further on with such a automatically programming tool it is possible to react without delay on short-term changes in the manufacturing tasks, the flexibility and reactivity of the production line increases.

For the automatically programming the data resulting from the image processing tool are independent from any kind of machine control system and should be therefore usable for all programmable welding machines in a production line. The further processing of the data should be realized with a general software solution, usable for the different programmable robots and welding machines in a production line. Despite this great variability of the planned system an adaptation to existing machines and manufacturing lines will be necessary.

Additionally to the specific adaptation of programming tools and laser-GMA-hybrid welding equipment the theoretical and practical training of the staff is a focus point in the project of the three incorporated research companies.

3.2 Practical applications

The first industrial application of the laser-GMA-hybrid welding process in a shipyard was realized with a CO_2-laser (**Fig. 8**) at the German shipyard “Meyer-Werft”. This production line was designed especially for the hybrid welding of plates and stiffeners with a CO_2-laser. Panels with a geometry of 20 m *20 m are welded completely at this line.

“Meyer-Werft” is specialised in great cruise liners for the international market. Therefore a lot of panels with lower sheet thickness are used for their products.

Fig. 8 CO_2-Laser–GMA–hybrid welding from panels and stiffeners at shipyard “Meyer-Werft” in Papenburg, Germany [4]

At the German shipyard “Kvaerner Warnow Werft” in Rostock (**Fig. 9**) a common welding gantry has been refitted with equipment for the Nd:YAG-laser-GMA-hybrid welding. During the above mentioned regional research project the problems regarding with such a refitting should are solved. The refitting was done after measuring the dynamical behaviour at the point, were the future hybrid working head shall be located. The results correlated well with the requirements regarding to [3]. The first test welds made with the refitted conventional welding gantry also verified the suitability of the gantry for use with laser technique.

In the meantime also other German shipyards are interested in such a refitting solution.

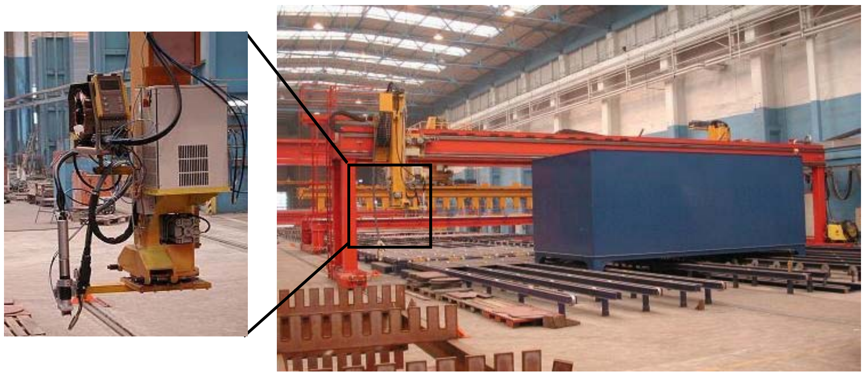


Fig. 9 Welding gantry (right) and Nd:YAG-laser-GMA-hybrid welding head (left) at the shipyard "Kvaerner Warnow Werft" in Rostock, Germany

5 conclusions

The Nd:YAG-laser in connection with the gas metal arc welding offers great possibilities for the use of laser technology in shipbuilding and steel construction.

The lower energy per unit of length resulting from laser based joining processes leads to lower distortions and less postweld straightening. Besides the higher welding speed compared with conventional welding methods the laser-GMA-hybrid welding offers a better gap bridging ability compared with pure laser welding and makes the advantages of laser technology usable for manufacturing under the conditions in shipbuilding and steel construction.

The high flexibility of the Nd:YAG-laser equipment, resulting from the wavelength of the Nd:YAG-laser radiation and their optical properties enabled an implementation of laser technology according to the actual demands of a company. In principle the refitting of conventional welding machines with Nd:YAG-laser equipment, such as robots and welding gantries is possible.

The implementation of laser equipment and technology into shipbuilding and steel construction leads to an higher level of automation in this branches, connected with a higher level of product quality and reproducibility. Besides the technical requirements for the introduction of laser technology in the mentioned industrial areas the qualification level of the staff, workers as well as technicians and engineers must be increased.

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