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Friedberger Hochschulschriften

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Hybrid Welding Technology (WWT)
a flexible method for industrial applications

Friedberger Hochschulschriften Nr. 7

Das vorliegende Manuskript ist ein Preprint.
Es wurde zur Jahrestagung des
International Institute of Welding (IIW)
veröffentlicht unter
IIW-Nr.: IIW Doc. - 777 - 2000
Florenz, July 2000

Friedberger Hochschulschriften
Herausgeber:
Die Dekane der Fachbereiche des Bereichs Friedberg der FH Gießen-Friedberg
Wilhelm-Leuschner-Straße 13, D-61169 Friedberg
http://www.fh-friedberg.de

Friedberg 2000
ISSN 1439-1112

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Hybrid Welding Technology (HWT),

a flexible method for industrial applications

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July, 2000
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Introduction

Production technologies typically are characterised by specific advantages as well as disadvantages. These characteristics have to be considered within the whole process of product development, manufacturing and life time cycle. Modern quality management tools as quality function deployment (QFD) or failure mode and effects analysis (FMEA) are used to compare different technologies which can be used to carry out a certain step in the production of a component.

To ensure that different functions, as defined mechanical properties like strength and toughness or chemical properties like corrosion resistance or design elements like bending radii and shadow edges for example, can be united in one part or structure one have to accept compromises in the construction as well as in choosing the production technology.

Another possibility which is used more and more is the serial or parallel combination of different technologies so the advantages of each of these technologies are used to improve the functional properties of the component. The parallel use of different technologies at the same time are so called hybrid technologies.
Examples of technology combinations in joining applications in the automotive industry are adhesive bonding / resistance spot welding or adhesive bonding / clinching /1/.

Laser beam welding is a relative new technology which is used in a lot of different applications since several years and which will have a big potential in the future. The specific characteristics of this technology, as concentrated heat input or small interaction zone, can be advantageously used in production for high speed welding of tubes or tailored blanks for example. In other welding applications, if gaps have to be filled up or metallurgical reactions have to be taken into account for example, the same characteristics hinder or prevent the use of laser beam welding.
In a similar way other welding techniques are characterised by comparatively enlarged heat input, feeding of additional material or extended interaction area for example. Those specific characteristics are used advantageously if the material needs additional alloying during welding in the weld zone, gaps have to be bridged or the temperature cycle ($t_{8/5}$ - time) has to exceed a minimum level for example. On the other hand these characteristics are limiting the maximum welding speed or the aspect ratio of the seams (depth / width).

Consequently the combination of laser beam welding with another conventional technique to a hybrid welding process is one possibility to design product-, material- and function adapted welding processes.
Within this publication the technical principles of different hybrid welding technologies using laser beam welding will be described. The discussion of weld results will show the possibilities, potential and also the limits of the different combinations. First applications which are under development or transferred into industrial production will show the actual state of the art.

Motivation for HWT

Comparison of technical as well as economical features of laser beam welding and conventional welding techniques as arc-, plasma- or induction welding show that there are different synergetic effects usable by combining the laser welding process with another one. This can be deduced out of the following table 1.

Features		**Laser**	**Arc**	**Plasma**	**Induction**
Technical	Speed	+	0	0	++
	Heat Input	++	-	-	++
	Thermal Load	++	--	--	+
	Flexibility	++	+	+	-
	Automation	++	+	+	0
	Wear	+	-	0	+
	Geom. Tolerances	--	++	++	0
Economical	Invest - Welding	--	++	++	0
	- Clamping	-	0	0	+
	- Handling	0	+	+	++
	Efficiency - System	--	+	+	+
	- Welding	+	+	+	+

Tab. 1: Comparison of technical and economical features of different welding techniques with regard to a beneficial combination

In table 1 it is shown that there are some advantageous features in laser beam welding especially regarding technical aspects, as high speed, low heat input and thermal load. Also laser beam welding is a flexible technique which is quite good usable in automated production.

In opposite to this one can imaging that because of the high precision one need typically high sophisticated clamping systems which enable a nearly gap free fixturing of the parts to be welded. This lead also to disadvantages regarding investment cost as it is with respect to the laser itself.

The reason for the low system efficiency of lasers is the physical high quality of the energy of laser beams. As it can be seen by analysing the cross section of weld seams in connection with the heat input which is necessary to weld a certain material thickness the welding efficiency (i. e. heat input / primary electrical energy) in laser beam welding is comparatively the same as using other welding techniques /2/.

The compared conventional welding techniques using electrical arcs or a plasma are characterised by relative low speeds and high heat input resulting in increase distortion.

But there is a big technical advantage in these techniques, i. e. the compensation of tolerances which is positively influenced by the comparatively high system efficiency, the large diameter of the interaction zone as well as by an easy use of additional material in form of separate wire (TIG or Plasma) or molten electrodes (GMA).
Also the investment costs for the welding system and for clamping is lower than in case of laser beam welding.

Induction welding is a technique which allows a rapid and intensive heating of metallic material. This results in higher welding speeds compared to laser beam welding. Also the energy can be controlled easily adapted to the process situation by regulation of the rf – power.
Main disadvantages of this technique are the limited flexibility and limited quality of the weldseams. The first aspect is caused by the necessity that the electrodes have to be designed especially with respect to the form of the component. The quality of induction welded seams is limited because this technique is mainly used as a press welding technology, in pipe production for example. The pressing operation lead to a directed solidification perpendicular to the material surface with the result of lower strength and toughness capability.

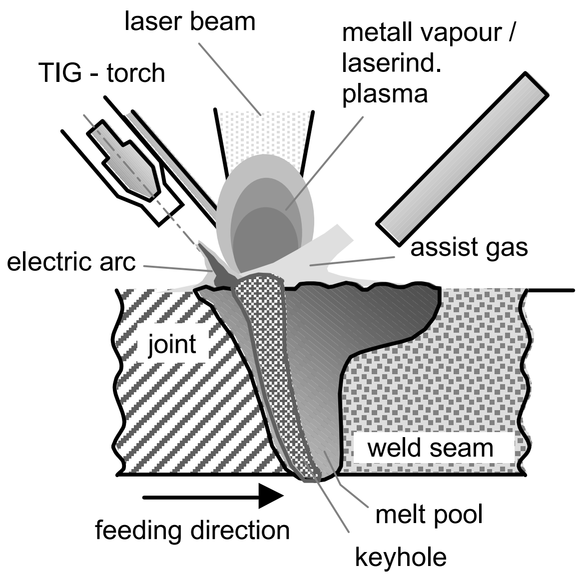
As it clearly can be seen in tab. 1 it should be possible to reduce a part of all the disadvantages and to use synergetic effects /3, 4/ by combination of laser beam welding with another one.

Principle of HWT

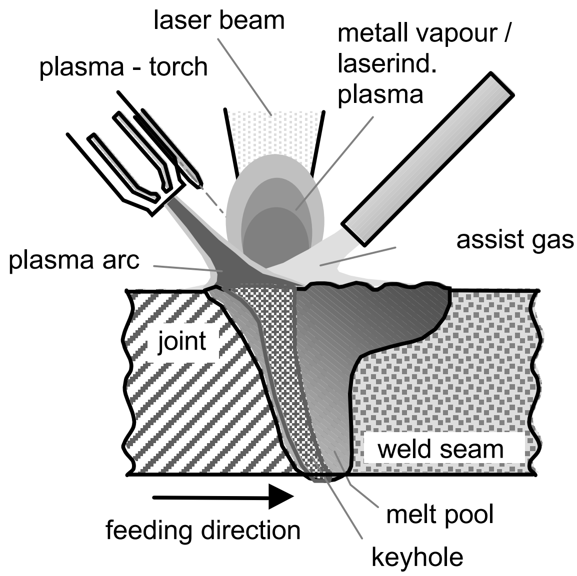
HWT processes (Fig. 1)are functional differentiated because of the different interaction mechanisms of the used welding techniques:

- The laser beam and it's high quality energy is mainly used to achieve a deep penetration.
  This is possible because of the deep penetration effect caused by the high beam intensities and the small spot diameters. The low heat input of laser beam welding results on the other hand in a relative low cross sectional area and small seam width.
- The second energy source in HWT is used with respect to special requirements caused by the material, the geometrical tolerances or the required productivity for example.
  A lot of materials, as high Carbon contenting steel or aluminium alloys out of the 6000 - series, tends to internal imperfections, especially cracks if the cooling rate after the welding process is to rapid. The second energy source can be used to reduce the cooling rate (increase the $t_{8/5}$ – time) in case of cold cracking sensitivity or to adapt the weld metal to another metallurgical behaviour especially in case of hot cracking.
  Geometrical tolerances like gaps or grooves need additional material volume to be filled up. One can solve these problems by laser beam welding with additional wire but this reduces the efficiency because one uses the high quality and expensive energy to remelt the volume which can also be done by a lower and cheaper energy quality which is typically delivered by thermal processes. So the second energy source is used in this case to fill up the defect volume of the gaps with additional material which is fed separately, taken out of an integrated volume (TIG or Plasma) or which is delivered by melting of the electrode (GMA).
  Improvement of productivity in welding means typically to increase the welding speed. Because laser beam welds are deep and narrow there is only less

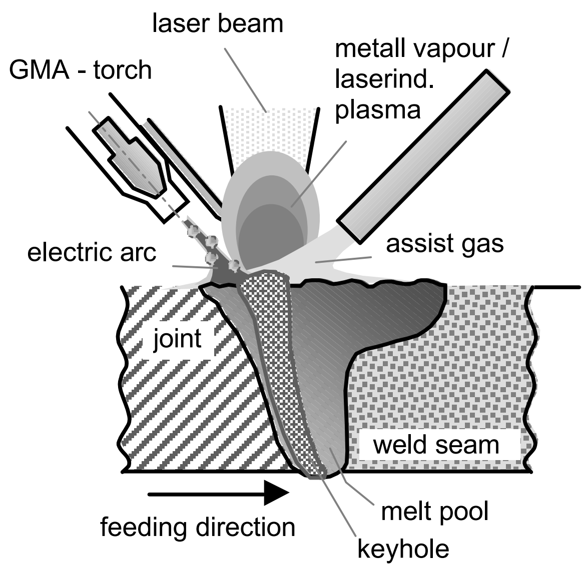
potential to increase the welding speed above a certain limit using a defined laser power. One possibility is to use another laser with increased power but in this case one have to invest in a new more expensive system. Another possibility is the adaptation of an additional energy source to an existing laser beam welding system or to design a HWT system with reduced laser power from the beginning. In both cases the additional energy of the second source can be transferred into higher welding speeds causing only small amount of additional costs.



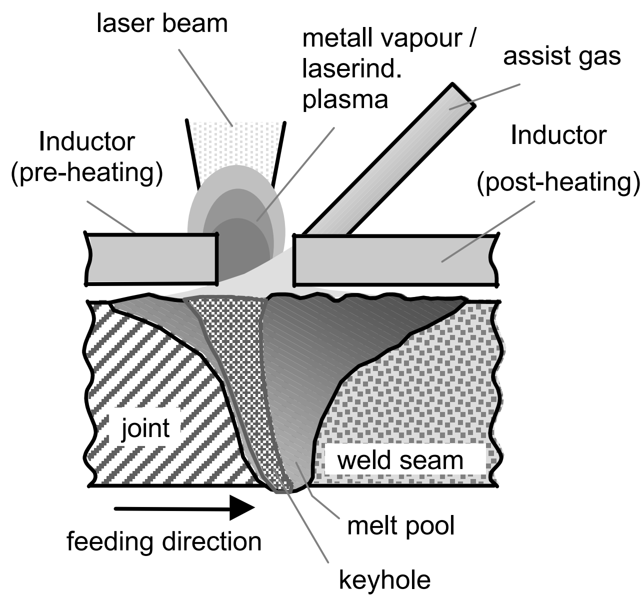
1a) Laser beam / TIG



1b) Laserbeam / Plasma



1c) Laser beam / GMA



1d) Laserbeam / Induction

Fig. 1: *Principles of different HWT possibilities*

In all the different cases the main aspects of HWT are synergetic effects coming out of the combination of laser beam welding process with another one. From the physical / technical point of view there are actually four main different solutions:

- The energy of the second welding tool is delivered via an electric arc without integrated melting of additional wire (1a); 1b)) → TIG- or Plasma welding

  If additional wire has to be used it has to be fed separately into the interaction area or the melt pool of the whole process. Because this increases the complexity of the whole process, three different tools are used simultaneously (arc or plasma, laser beam and additional wire), it might cause some problems regarding accessibility or process control.

- The energy as well as additional material is delivered by an electric arc of a melting electrode (1c)) → GMA-welding

  In this case additional wire is fed in the liquid phase which could be advantageously used for the adaptation of the chemical composition of the melt zone. Because additional material is fed into the interaction zone in any case one has to keep in mind that the additional volume of material might lead to some problems in configurations where no gap or only small gaps occur.

- The energy is delivered by a rf-circuit and a geometry adapted electrode (1d)) → Induction welding

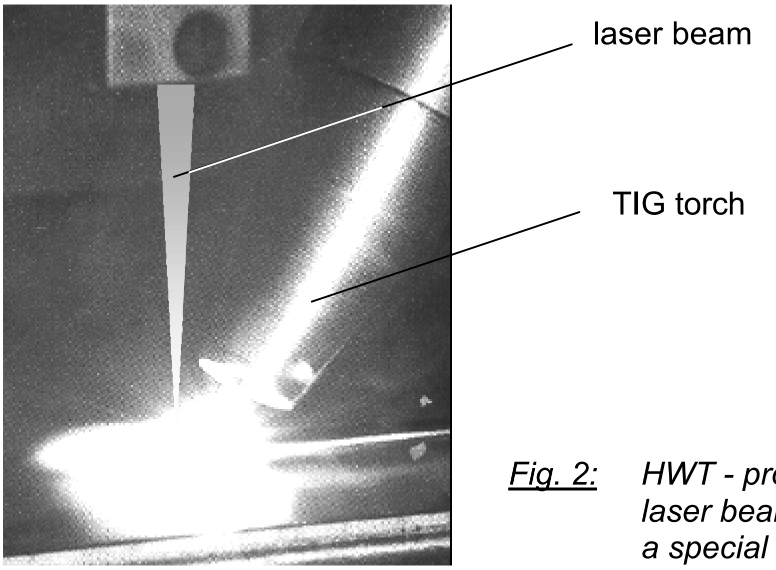
  In induction welding additional material cannot be fed into the interaction zone because of the nearly closed gap between the two parts to be joined, the high welding speed and the small size of the melt pool. But induction heating in HWT can also be used easily as a second tool not to remelt the material but to control the heat transfer, especially the cooling rate, in the weld metal and the heat affected zone.

Laser beam / TIG and Laser beam / Plasma

The principle is shown in Fig. 1a) and 1b). The laser beam is focussed onto the workpiece creating the deep penetration effect. In addition to that the TIG- or Plasma process is directed to the same interaction area. The additional energy flux can be used for the different effects mentioned above.

Special aspects have to be considered regarding the design of the HWT processing head as well as the complexity of the whole system and process (see Fig. 2):

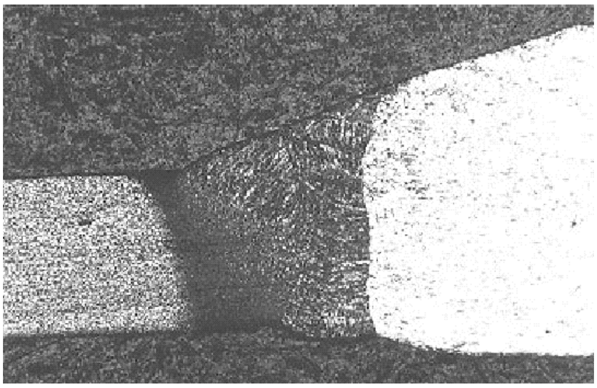
- The combination with TIG welding actually allows only an off - axis design, because the electric arc is directed from the tip of the electrode to the interaction zone. One can think about special coaxial electrodes inside a “hollow” beam or circumferencial an axial beam but this needs additional work in research and development. It seems to be easier to design a coaxial arrangement in case of the HWT - Plasma variant because the plasma arc is enhanced or transferred by the gas flow from the nozzle to the workpiece. In addition to that plasma nozzles which seems to be usable for a coaxial process after a limited redesign are available on the market.



<u>Fig. 2:</u> *HWT - process using an infrared laser beam of a CO_2 - laser and a special designed TIG - torch*

- If separate additional wire is used one need an additional nozzle which will increase the complexity of the whole arrangement.
  In case of the combination with a plasma source it might be possible to feed additional material in form of powder through the plasma nozzle. This has to be investigated in the future.

The TIG-arc as well as in some cases the plasma-arc is a transmitted one, i. e. arc voltage between electrode and workpiece. In these cases the base of the arc is directed by local tips or edges of the workpiece because of the concentration of the electric field. This can be used to remelt a so called "integrated" additional material which is originally a part of the workpiece. An example is given in fig.3 /5/. The edge of the thicker material of a tailored blank is used as additional material to fill up possible gaps and to smooth the concave edge between the two sheet metals. Beside this feature of filling up gaps the TIG - variant of HWT can also be advantageously used in tailored blanking to increase the welding speed and to smoothen the surface in the area of the weld seam if sheets with different thickness' have to be welded. Especially the last aspect lead to improved properties regarding the mechanical load to the stamping tools during the forming process (see fig. 3).



Material:	DC 04	1mm / 2mm
CO_2 - Laser:	P_L = 4 kW	
TIG:	I = 200 A	
Speed:	v_S = 10 m/min	

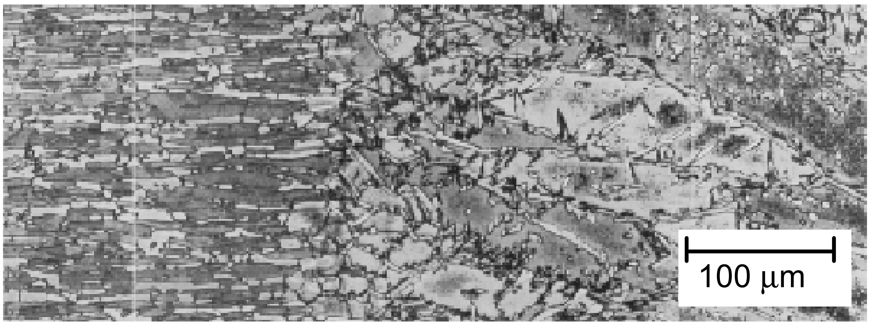
<u>Fig 3:</u> *Cross section of a tailored blank, welded by a Laser / TIG process /5/*

Laser Beam / GMA

The combination of a laser beam and a gas metal arc in one welding process area can be used advantageously in different production applications because of positive effects and interactions of both welding tools. The principle of the process situation is shown in fig. 1c).

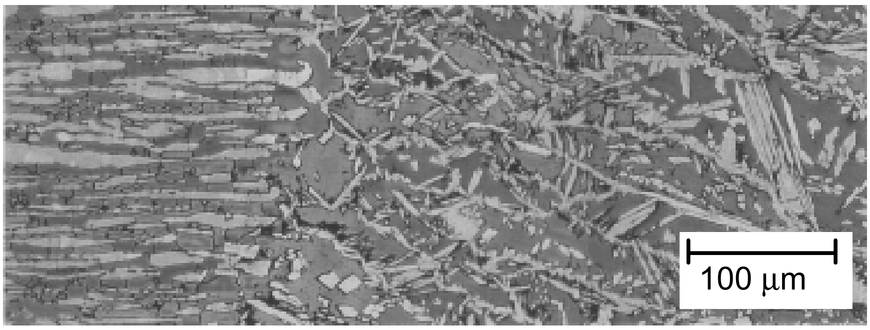
- In a lot of welding applications additional material have to be used because of tolerances caused by the edge preparation or the fitting of the parts to be welded.
  Another reason for the use of additional material is the metallurgical reaction of materials during solidification. Depending on the alloy in combination with the cooling process hot cracks can occur for example. This can be observed in welding aluminium alloys out of the 6000 - series which are critical against this effect because of its Mg and Si content.
  Also additional material in combination with an adapted control of the temperature cycle during welding can be used to weld special designed materials as dual phase steels for example (see Fig. 4) /6/. It is possible to influence the content of ferrite and austenite in the weld zone very exactly using the HWT process in the laser beam / GMA variant.

Material: Dual Phase Steel s = 6,6 mm



Heat Input:
E_S = 300 J/m
Speed:
v_S = 1,2 m/min

Laser beam welded: $t_{12/8}$ = 0,9 s F / A = 88 / 12



Heat Input:
E_S = 500 J/m
Speed:
v_S = 2 m/min

Laser / GMAW - Hybrid welded: $t_{12/8}$ = 2,4 s F / A = 72 / 28

<u>Fig 4:</u> *Control of the content of austenite and ferrite in welding of dual phase steel by the HWT – process /6/*

- The main point in these different examples is the use of additional wire.
  One can use the high quality and expensive energy of the laser beam to ensure a certain depth and a high speed of the welding process.
  To remelt the volume of the used additional wire it is better to use a cheaper energy, i. e. the electric arc. One can describe this method also with the feed of additional material in a liquid phase, so the laser beam energy must not be used to remelt the wire and to transfer heat input into the width of the weld seam. This gives as well an optimised process regarding energy as economical aspects.
- Another effect is reported in /7/. Laser beam welding of aluminium requires a specific adaptation of process parameters because the low viscosity of the material as well as its optical properties lead to the tendency of melt pool ejection instabilities /8, 9/. Beside the stabilisation of the process by twin spot optics or the use of special assist gas also the plasma of the electric arc improves the stability of the whole process. In combination with the necessity of using additional wire in a lot of applications one can imagine HWT leads to synergetic advantages in welding of aluminium.

Laser Beam / Induction

Induction heating or welding is often used in pipe production or in tempering metallic components for example. The energy transfer into the material is limited by the Skin effect and consequently influenced by the frequency of the induction current. The transport of the heat into the volume is than defined by heat conduction. Especially in pipe manufacturing the heat input from the inductor via the edges of the sheet metal allows high welding speed and low heat input. The heat input in induction welding or heating can easily be controlled by the electric current and spatial conditions defined by the geometry of the inductor.

The combination of induction heating and laser beam welding which is sketched up in principle in fig. 1d) can be used advantageously in that applications which allow the geometrical appliance of inductors and have no or less restrictions regarding accessibility of the focused laser beam.

- In pipe production the HWT laser beam / induction has been investigated several years ago /10/ to improve the seam geometry of induction welds. Typically the seam width of induction welds are smallest in the half material thickness. Also in this area the cooling rate is the strongest which in combination with the orientation of the grains of the resolidified material result in only medium quality of mechanical properties. Combining the induction welding with an inclined laser beam which is guided between the conical shaped and fed edges and focused onto the centre of the joined edges one reaches an additional heat input in this area of the weld seam. Consequently the seam width in this area is widened and the grain structure of the weld seam is more near to the base material because of lowering the cooling rate. As it is shown in /11/ improved mechanical properties in Charpy testing for example can be reached.
- Material which is sensitive against cold cracking is consequently specified as non or limited weldable especially if methods are used which are characterised by rapid cooling. One knows that these materials, with a high carbon content (more than 0,25 % in low alloyed steels) can be welded with additional pre- or post heating. This can be done by a furnace or a flame for example but in these cases the heat input has to be led into the material by heat conduction.

Using induction heating the energy is coupled into the material volume near the surface and than guided into the depth of the material.
This can be used to lower the temperature gradient and to increase the cooling time after the welding process as it is shown in principle in fig. 5. The smoother cooling of the material results in a better relaxation of the welded material and as a consequence of this in a reduction of cracks /12/.

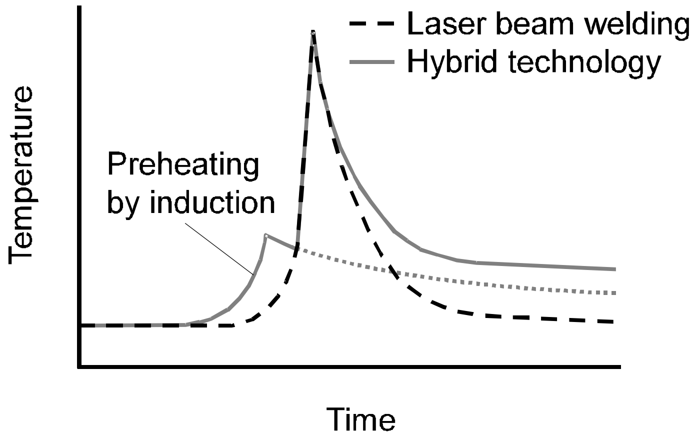


Fig 5: *Comparison of the temperature cycle of the laser beam welding process and of the hybrid process using an inductor*

Showing the principle set-ups of different HWT - variants in combination with technical problems which have been or might be solved by different techniques one can imagine the potential of HWT in principle. But to transfer the principle technology into real situations one have to look at experimental dependencies and results to ensure that the transfer is possible and will be successful.

Exemplary Experimental Results

Welding speed and penetration depth

One aim to use HWT is to increase the weld depth or the welding speed to produce the same weld depth. Fig. 6 shows the weld depth using different welding speeds as well for a pure laser weld (I_B = 0 A) as in dependence of the used current for a TIG - arc. The material was steel and the used laser a Nd:YAG - laser with a power of 1,8 kW /7/.

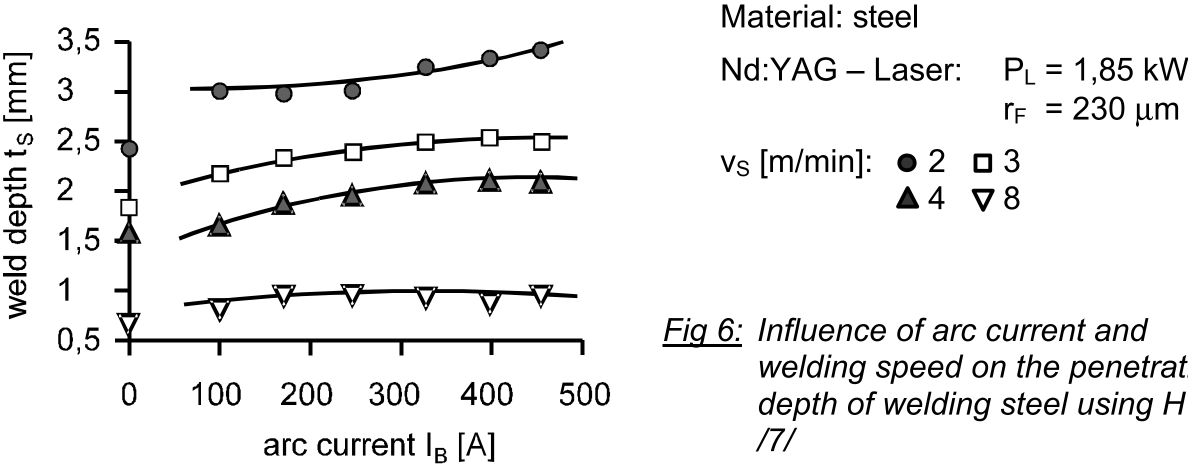


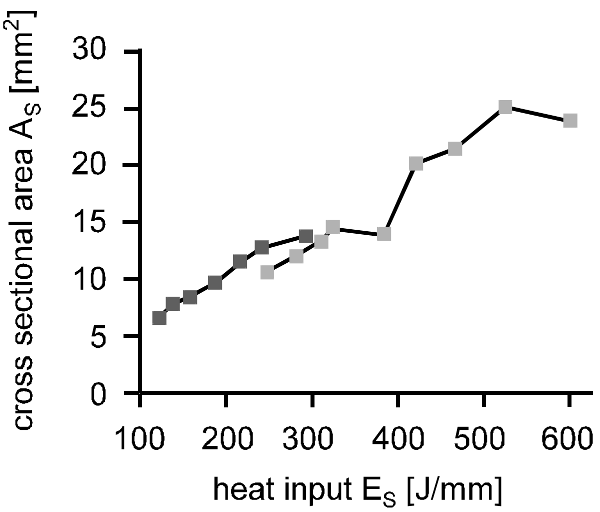
Fig 6: *Influence of arc current and welding speed on the penetration depth of welding steel using HWT /7/*

It can clearly be seen that the increase of the weld depth at constant speed using the HWT compared to the pure laser beam welding process will be stronger at lower welding speed and lower weld depth respectively. Also the increase of the weld depth with increasing arc current is in case of a lower speed stronger than at higher speed. All the different results show that the speed which can be used to reach a certain weld depth is very much faster than in case of a pure TIG - process.
These results can be explained by the deformation of the melt pool by the plasma pressure of the TIG process /7/. This deformation reduces the effective material thickness which the laser beam has to penetrate. Consequently the weld depth or the welding speed can be enlarged.

Heat input and cross sectional area

Another aspect which shows the potential of HWT is the flexible use of two energy sources, i. e. the laser beam and an electric arc for example, to influence the cross sectional area of the weld seam. This feature can be applied to equalise geometrical tolerances or to accommodate the seam geometry to technical requirements. The main advantage of HWT in this area is the independent shaping of the cross sectional area because the laser beam influences the cross sectional area in the deeper region as well as the added energy source gives an influence mainly in the top of the weld seam /13/. Fig. 7 shows the influence of the heat input onto the cross sectional area.

Using only a laser beam the material will be nearly full penetrated at a heat input of 300 J/mm. The hybrid process laser beam / TIG at low heat input results in a reduced cross sectional area. This is caused by the effect that the additional arc improves slightly the weld depth so the 6 mm sheet metal is full penetrated which results in



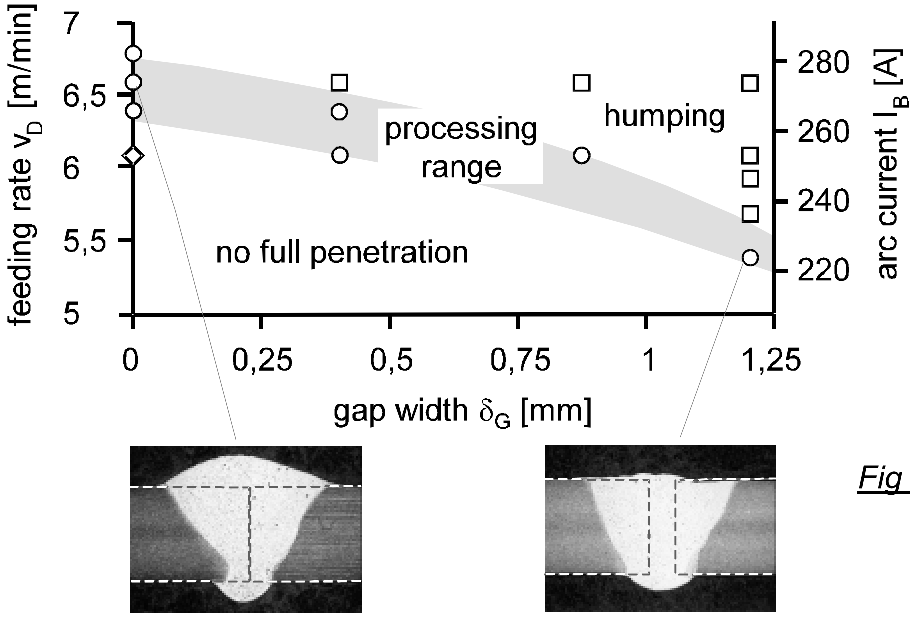
Material: 1.4301 s = 6 mm
CO_2- Laser: P_L = 3,4 kW
TIG: I = 200 A
■ CO_2- Laser ■ HWT
0,7 m/min ≤ v_S ≤ 1,7 m/min

Fig 7: Dependence of the cross sectional area on the heat input /13/

transmission losses for the laser beam and a reduction of the deposited energy. If the heat input is larger than 300 J/mm the weld seam becomes wider especially at the top bead which improves the weld seam surface because of a smoothing effect. Heat input of more than 400 J/mm results in a strong increase of the cross sectional area because of a stronger effect of the electric arc in the depth of the weld seam so the geometry of the weld seam is characterised by a nearly constant width and an aspect ratio of 2. The large weld seam volume in this process regime is usable to compensate gaps or other tolerances or to increase the cooling time of the weld metal and the heat affected zone influencing the metallurgical structure for example.

Tolerances

If the gap between two joining partners will increase a certain level depending on the material thickness, it can only be compensated by using additional material. As it is discussed before the additional material can be fed in a liquid phase if the HWT Laser / GMA is used. This improves the energy costs because the expensive laser beam energy is mainly used for the deep penetration process and the energy of the electric arc is only used to fill up the defect volume.



<u>Fig 8:</u> Gap bridging ability of HWT using the gas metal arc welding process /7/

Nevertheless the welding process becomes more complex compared to the pure laser beam- or gas metal arc welding processes. Depending on the material thickness and the gap width it is necessary to feed a minimum volume of additional material. But as it is known from the arc welding process wire feeding is influencing the current of the electric arc, i. e. the faster the speed is the higher is the electric current. Investigations of the combined process show that there are two regions which are limiting the process area of equalising gaps /7/ in welding aluminium, see fig. 8:

- If the speed of wire feeding and consequently the electric current is to low this results in not full penetration of the weld seam.
- Using high speed of wire feeding combined to larger electric current the so called “humping effect” can occur, a negative issue regarding the weld seam quality.

Fig. 8 shows the process area as well as the limits regarding bridging of gaps in welding of 4 mm thick aluminium /7/. It can be seen clearly that there is a limit in equalising gaps with a width of 1,2 mm because the limit in wire feeding regarding the occurrence of humping. If larger gaps have to be equalised with relative high welding speed there are two possibilities tested in principle:

- As it is shown by Maier /7/ it is possible two overcome the humping effect by adapting another additional wire, fed as a cold one.
- Also an additional arc can be applied to the process to equalise large gaps at high welding speed. This option has been developed by Wieschemann /14/, it is the so called “HyDRA-process” (Hybrid welding with Double Rapid Arc).

Metallurgical effects

During and after welding the material of the weld seam as well as of the heat affected zone is strongly influenced by thermo - physical and chemical processes. This typically results in a change of the material properties, the grain structure or in imperfections. Beside their main aim of connecting to joining partners welding processes have to be adapted with regard to the material in that way that no imperfection outside a defined limit occur and the properties are changed as low as possible.

One example is given in fig. 4 which shows exemplary results in welding dual phase steels.

Another example is shown in fig. 9:
Components which have to transfer high mechanical load are often made out of steel contenting a high amount of carbon. As it is known in welding of steels contenting more than 0,25 % cracking occur in the fusion or heat affected zone if no additional heating process (pre- or post-) is used. These kind of steels are used in the transmission area of machines as gears, shafts or axles for example.
The crack occurrence can also be influenced in a positive way by controlling the heating as well as the cooling process during welding. A method especially developed for applications in this area is the combination of laser beam welding and induction heating /12/. The effect of the additional induction heating process near by the laser beam welding area is shown in the cross sections in fig. 9. One can see clearly that a lot of cracks occur if a pure laser beam welding process is used. Adding induction heating results in crack free weld seams.

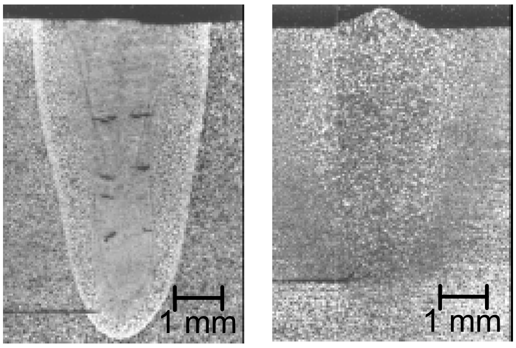


Fig 9: *Crack free welding of high carbon contenting steel using HWT laser / induction /15/:*

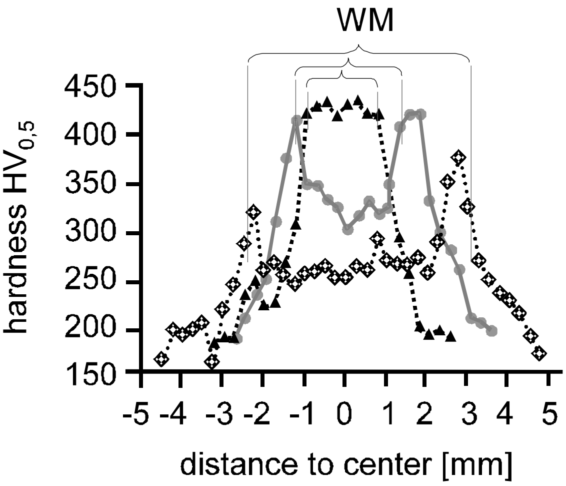
Left side: CO_2 - laser
Right side: CO_2 – laser / induction

Properties

Influencing the properties of hybrid technology welded seams depends on the total amount of the heat input, its sharing to the different processes, the distance between the two energy sources and the material which is optional fed into the processing area. The accommodation of all the different parameters has to be carried out keeping in mind the material as well as the geometrical specification of the components.

The possibilities to improve the properties of welded components by using HWT are shown in figures 10 to 12. Different mechanical properties as hardness, strength and toughness are comparatively measured after welding 6 mm thick metal sheets out of the material S 355 using different laser oriented welding methods. In all the different cases the processes were controlled in that way that a full penetration with adequate quality was produced /16/.

- In fig. 10 the hardness distribution is compared using the laser beam welding process without and with additional wire and the HWT laser / GMA.



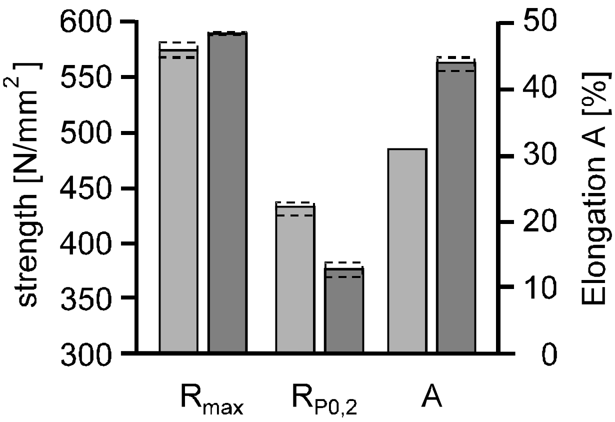
Material: S 355 NL s = 6 mm
CO_2 - Laser: P_L = 5 kW
▲ Laser E_S = 200 J/mm
● Laser / add wire E_S = 350 J/mm
◇ Laser / GMA E_S = 585 J/mm

Fig 10: *Hardness of weld seams using different processes /16/*

The process with the lowest heat input results in a maximum hardness of more than 400 $HV_{0,5}$.
This can be reduced to less than 350 $HV_{0,5}$ by using additional wire because a larger amount of energy is required and the metallurgy in the weld metal is influenced in a positive way. But because there is no metallurgical influence in the heat affected zone the hardness in this area increases up to more than 380 $HV_{0,5}$.
Using HWT the hardness is lowered as well in the weld metal as in the heat affected zone because an additional increase of the heat input.
In all the different cases the welding speed was the same, 1,5 m/min.

- The influence of HWT on static properties like strength and elongation can be imagined in fig. 11.

It is compared the tensile strength, the proof strength and the elongation of the S 355 base material and of the hybrid welded seams. As it can be seen the tensile strength is on a comparable level. The proof strength of the welded probes are roughly 15 % lower compared to the base material. This fits with an improved elongation capability (+30 %) and with the occurrence of the damage of the probes in the base material beside the weld seams.
This behaviour is well known from laser welded seams in the same group of materials.



Material: S 355 NL s = 6 mm
CO_2 - Laser: P_L = 5 kW
v_S = 1,5 m/min
base material Laser / GMA

Fig 11: *Mechanical properties of hybrid welded seams compared to the base material /16/*

- The toughness of different probes, base material, laser with additional wire and HWT, has been investigated by Charpy - V impact tests. Fig. 12 shows the condensed results:

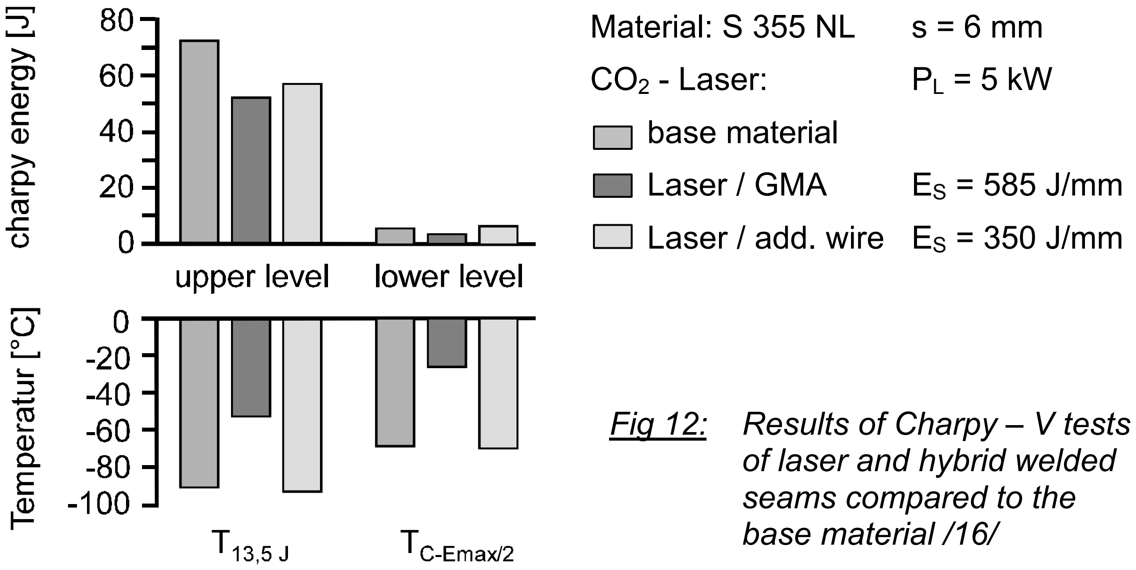


Fig 12: *Results of Charpy – V tests of laser and hybrid welded seams compared to the base material /16/*

The upper level of the impact energy is 10 % to 20 % lower in case of welded specimen compared to the base material.
The lower level is on a nearly constant value.
The transition temperatures are compared using an impact energy of 13,5 J, because of the small specimen and material thickness of 6 mm, and on the bases of 50 % of the maximum impact energy. The transition temperatures of the laser welds using additional wire is comparable to the base material. This is caused by crack path deviation so it gives no real result of the weld metal. In contrast to this the transition temperatures in hybrid welded seams show a 40 °C shift to higher temperatures whereas no crack path deviation occurs. This result is comparable to laser welded seams using additional wire and an increased heat input /16/.

Applications of the hybrid welding technology

Meanwhile the development of HWT results in different first applications which are or will be in the near future transferred into industrial production.

Laser beam / TIG and Laser beam / Plasma

The first industrial system applying HWT was a laser beam / TIG process for the production of special profiles out of steel. This system was installed in 1995 at the Zwick Company in Germany as a substitution of serial TIG welding processes.

Another application using the combination laser / plasma is the production of planar aluminium structures out of extruded profiles /17/. These aluminium structures are used for the side walls of trucks or carriage structures. An example of a HWT weld seam produced with the so called PALW technique (plasma assisted laser welding) is shown in fig. 13. Main effect of the additional plasma is a stabilisation of the welding process and an improved gab bridging ability. So gaps up to 1,5 mm width can be bridged while the wall thickness is roughly 3 mm /17/.

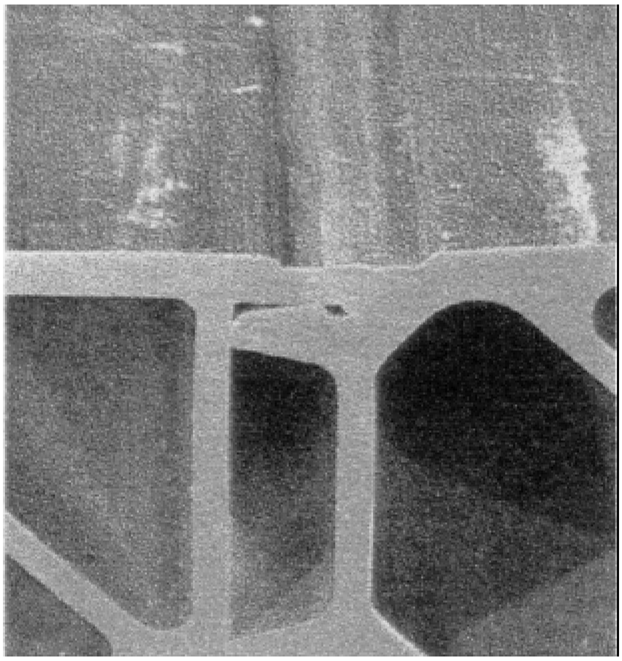


Fig 13: *Welding of extruded aluminium profiles using the HWT laser beam / plasma /17/*

Laser Beam / GMA

In this combination there are two actual examples of technology transfer into industrial production. Because of the specific features of this variant it will be at first used in heavy section welding, i. e. the production of vessels or structures for the shipbuilding industry.

Fig. 14 shows a system and the process in welding of oil tanks /18/ . The process is now accepted by the classification society and production will start in the near future.

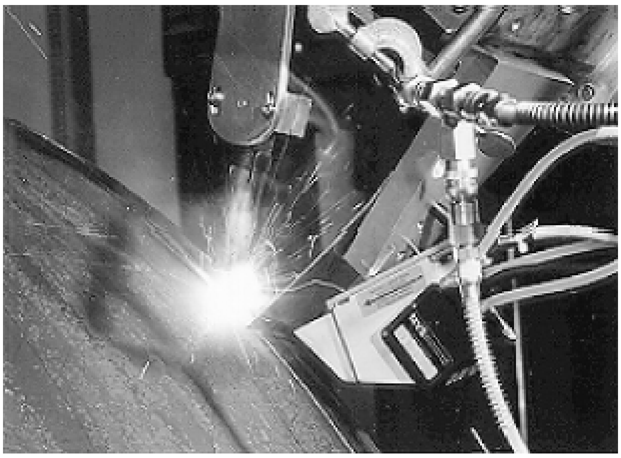


Fig 14: *Welding of oil tanks using the HWT laser beam / GMAW /18/*

Another system actually is being installed in a German shipyard for the production of panel structures /19/ as well as there are developments in other ones /20/. The processing area is shown in fig. 15.

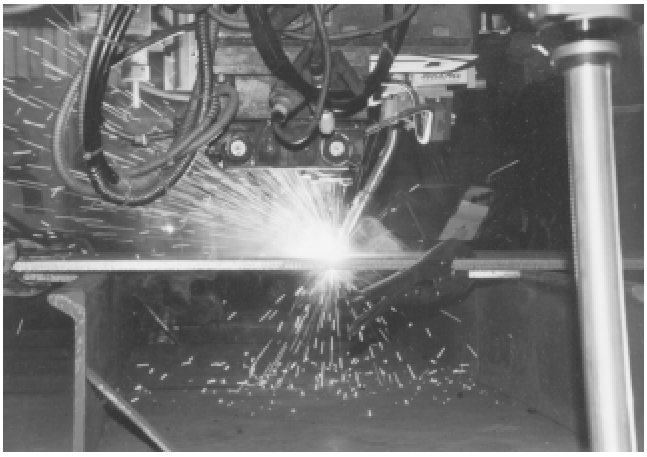


Fig 13: *Welding of panel structures using the HWT laser beam / GMAW /20/*

Laser Beam / Induction

The combination of laser beam and induction heating in a hybrid process has been introduced under mass production conditions in the automotive industry. The drive shafts in the transmission area of cars are produced out of carbon contenting steels as the C45 (AISI 1043) for example. These materials can be welded using an additional induction heating process as it is described before. Fig. 14 shows a drive shaft which is produced by the Ford Company in Germany using this technology /15/.

Fig 14: *Drive shaft welded using the HWT laser beam / Induction /15/*

Conclusion

Different welding methods as laser beam-, electric arc- or induction welding are characterised by specific advantages as well as disadvantages.

From different point of views as material-, manufacturing technological-, constriction and design- as well as economical oriented it is possible to optimise joining of different components by welding processes using a combination of different ones in the same processing area. This is the so called “Hybrid Welding Technology” (HWT).

This combination leads to a higher complexity but mainly it yield an improvement in different aspects mentioned above by synergetic effects. The improvements which are used in applications which are running in industrial production since a few years or will run in the near future are for example:

- Increase of productivity
- Reduced distortion and post processing
- Equalisation of tolerances
- Avoidance or reduction of imperfections
- Adaptation of metallurgical and technical properties

HWT seems to open new technical areas for welding regarding material, design, construction and technical requirement. And it is not limited in the discussed variants using a laser beam in combination with electric arcs or induction heating but also other combinations are possible as different laser beam sources, CO_2- or Nd:YAG and diode lasers, high power beams in general with friction or resistance welding methods respectively.

The development of the different HWT variants gives the industry new possibilities and potential solutions to solve actually existing problems and to develop new ideas in the field of welding technologies.

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