DEVELOPMENT OF THE JOINING PROCESSES IN A GLOBAL PERSPECTIVE

by Bertil Pekkari
ESAB AB
Box 8004, SE-402 77 Gothenburg, Sweden, bertil.pekkari@esab.se

Abstract

There is a continuous development of the most common welding processes like MMA, MIG/MAG, PAW and SAW. At the same time there is a conversion from stick electrodes to solid and cored wires with an increased productivity as a result. In parallel with these changes new processes are introduced and implemented. The number of Friction Stir Welding installations is starting to grow fast.
Hybrid laser welding has probably made a technical break through. The Magnetic Pulse Welding process is taking off. The different mechanical joining methods; clinching and self-piercing riveting; must not be forgotten. Structural adhesive is another method to consider.

Keywords

Welding processes, Laser Hybrid MIG Welding, FSW, Magnetic Pulse Welding, Mechanical Joining, Welding in the Shipyard and Automotive Industries

Introduction

There are continuous efforts all over the world trying to improve the productivity, quality and flexibility in joining workpieces of different seizes with minimum environmental impact. There are different means to realise these objectives. In this paper some emerging joining technologies will be briefly described but also drivers dependent of material development, industrial segments and growing workpiece sizes.

Conversion of arc welding processes

Figure 1 illustrates the conversion from manual to semiautomatic and automatic welding with solid and cored wires. MMA-consumption has during the last 25 years decreased annually with 5 % in all three regions while solid wires have increased with 3-5 %/year. The consumption of cored wires differs however much. These were introduced far earlier in USA than in Europe and Japan, while consumption of cored wires grew very fast during the last decade in Japan 12%/year. The consumption of welding consumables in Korea is similar to the Japanese situation.

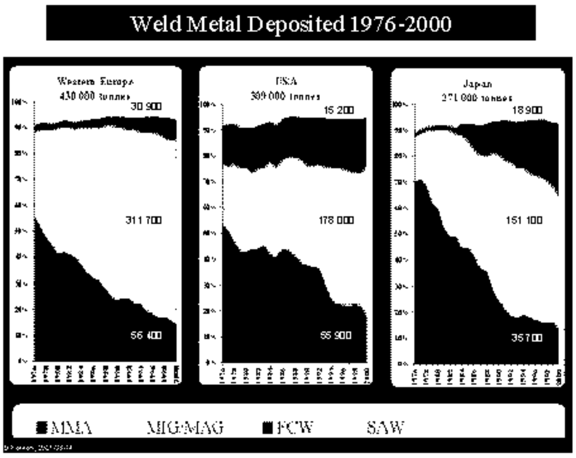


Figure 1

The SAW has decreased annually with 1-2 % due to

- That the shipyard industries have moved to other countries like South Korea, Peoples Republic of China, Poland and Croatia, which are not included in the above given regions

- That high strength steel is used more
- That heavy welding has been moved to low cost countries

The consumption of cored wires in USA hides another drastic change from selfshielded to dualshielded wires out working environmental reasons.

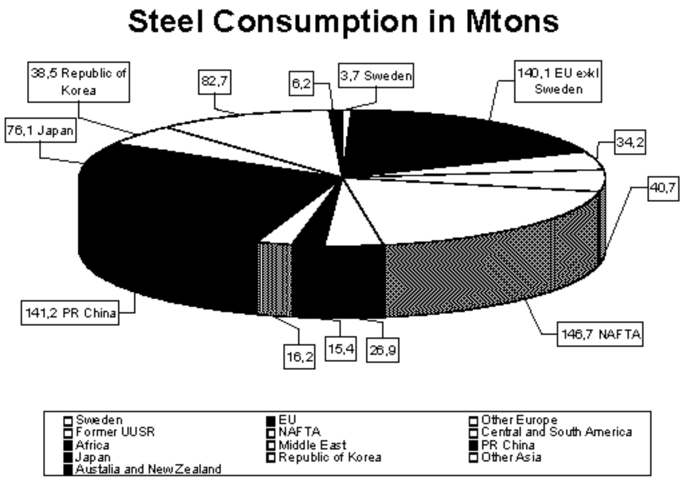
The impressing growth in consumption of cored wires in Japan and South Korea is result of

- Increase in deposition rate
- Better penetration
- Less spatter
- Efficient in positional welding

Cored wires are nowadays replacing solid wires in SAW due to 20-30 % higher deposition rates.

Steel consumption

It is obvious that the steel consumption is strongly correlated to development of the joining processes. We can follow this in most countries with high steel consumption but not in Peoples Republic of China and South Korea probably due to low presence at international conferences.



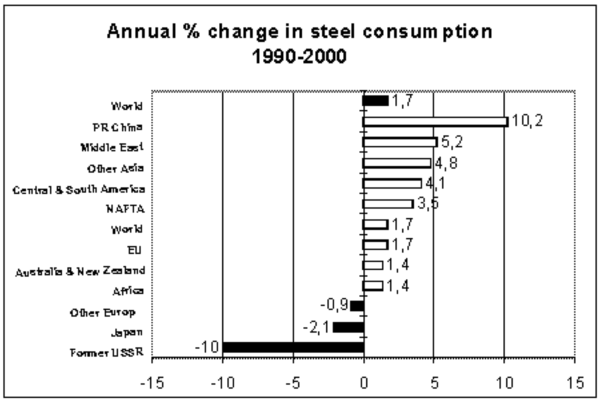


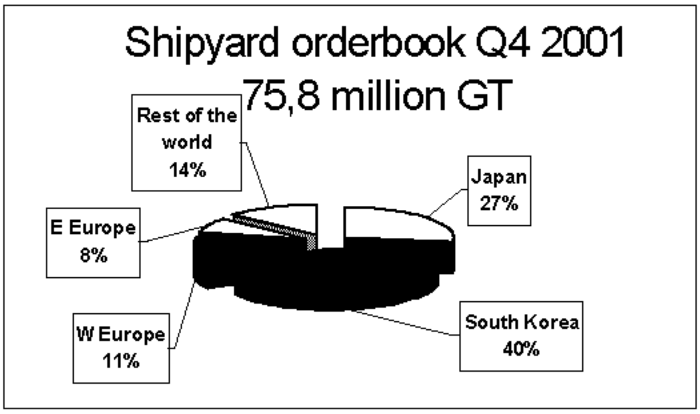
Figure 2 **Figure 3**

Total steel consumption 768,7 Mtons

The figures 2&3 show, that PRC will certainly further strengthen its position as the largest steel consumer in the world. South Korea will also increase its consumption as the country has the largest shipbuilding capacity in the world and the production of cars is growing. These two industrial sectors are the leading users of joining processes. That is the reason for continuous improvement of the joining processes and welding innovations introduced in these sectors.

Welding in the shipyard industry

South Korea is by far the largest producer of ships (Figure 4)



Annual output 28,7 million GT

The market has during the last 15 years annually grown on average with 4,6 %. PRC is expected to increase its market share while in Europe Poland and Croatia is doing the same.
Arc welding will remain to be the dominating joining process but with a higher degree of mechanisation to deposit all the weld metal corresponding (2,2-2,3) % of the steel weight in the ship.
One side SAW is the dominating process for the butt joints in the panel lines. Cored wires are often used and as well iron powder addition to increase the welding speed.
For welding the stiffeners we note more use of MIG/MAG welding robots(Figure 5), which is since years very common in the Japanese shipyards

Robot welding gantry

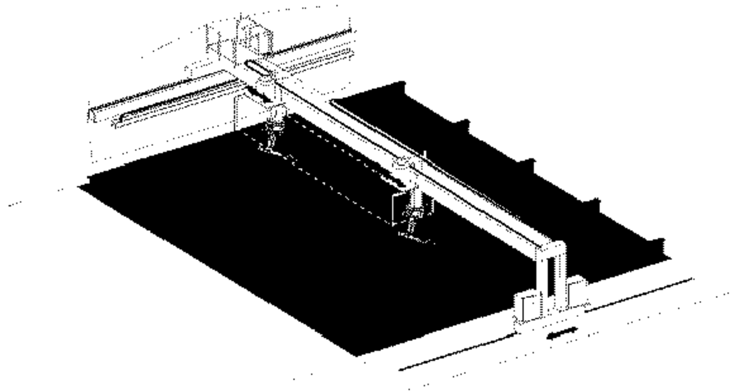
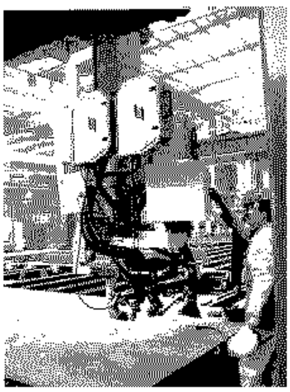


Figure 5

A similar set-up with a gantry and suspended robots is used for curved panel welding stations.
Tandem MAG-welding (2) is becoming a common process in shipyards and construction industry. There are already about 100 installations running in production mostly in Germany (Figure 6).

Tandem MAG welding of Panel Stiffeners



Welding data

Electrodes = 1.2 mm
Throat thickness = 4.5 mm
Stickout = 20 mm

Parameters		Electrode 1	Electrode 2
Welding voltage	V	29.5	30.5
Welding current	A	385	301
Wire feed speed	m/min	18.2	13
Travel speed	m/min	2. 45	

Figure 6

The Tandem solution has inherently greater freedom in varying the welding parameters like using different electrode diameters or mix with cored and solid wires besides the ordinary parameters for voltage, currents and travel speed. In order to reduce the spatter and the interference between the arcs, pulsing with phase shifting is introduced.
There are additional efforts in Europe increasing the degree of mechanisation of welding. The EU-project DockWelder has the objective to demonstrate a flexible modular automation applied in welding ship sections in the dock (Figure 7)

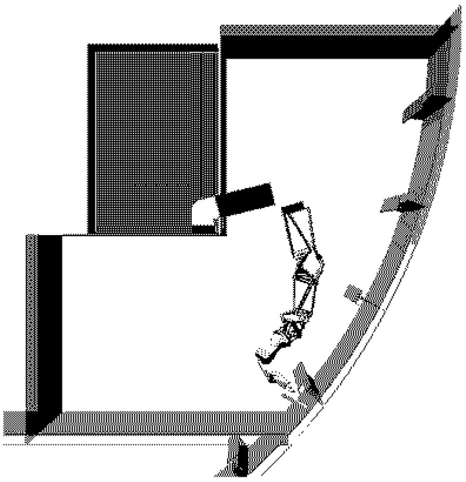


Figure 7
Artistic illustration of the DockWelder

The project has the following participants

- Amrose Denmark
- APS Germany
- Cybenetix France
- Lindö Shipyard Denmark
- Ficantieri Shipyard Italy
- Inst. For Production Technology

An optical sensor for joint tracking is used in this installation

Laser hybrid MIG welding in shipyard

Many European shipyards have jointly investigated the feasibility introducing laser welding of ship panels and classification bodies have been involved for approvals of the welding procedures. Few installations with CO_2-lasers combined with cold wires were made some years ago. The accurate joint preparations with a gap < 0,5 mm required was a major obstacle. The level of impurities of sulphur and phosphor was another hindrance. The latest process development with a combination of arc and laser welding; a hybrid process; is offering a more tolerant process with larger groove gap allowed. The heat input is also reduced. See table 1. (5)

Comparison of hybrid laser MIG welding with laser welding with cold wire

Parameter		Hybrid laser MIG welding	Laser welding with filler wire
Plate thickness	mm	6,0	6,0
Electrode diameter	mm	1,2	1,2
Gap width	mm	1,0	0,5
Travel speed	m/min	2,6	1,0
Wire feed rate	m/min	13,8	2,7
Power source output	kW	7,9	-
Heat input	kJ/m	321	360

Table 1

Such a set-up is requiring a lower investment.
Besides a more tolerant hybrid process the travel speed can be drastically increase, which the figures in table 2 illustrate for butt welding of plate with t = 5 mm.

Process	Travel speed m/min
SAW	0,8
CO_2 laser welding with cold electrode Laser power 12 kW	2,3
Hybrid laser – SAW Laser power 12 kW	3,2

Table 2
Comparison of travel speeds with SAW and two laser welding set-ups

We have now seeing a technical breakthrough for the laser hybrid process at Meyer Shipyard in Germany. Figure 8 illustrates the line covering both butt-welding of the panels and fillet welding of the stiffeners.

Ship panels 20x16 m welded with the hybrid laser MIG process

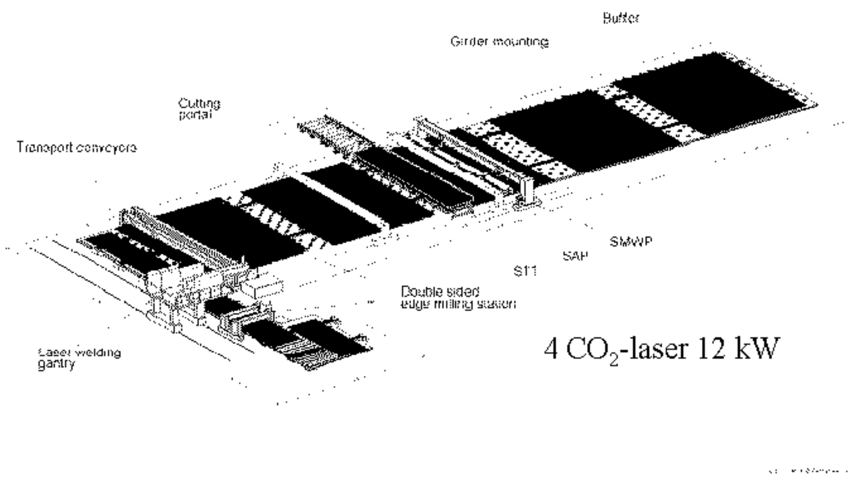


Figure 8

The panels are manufactured with closer tolerances and much less distortion.
There are other European shipyards also working with this process and close to invest in a laser panel line.
The next development phase has already started by developing a YAG-laser station for welding the webs and other structures on the ship (Figure 9 below).

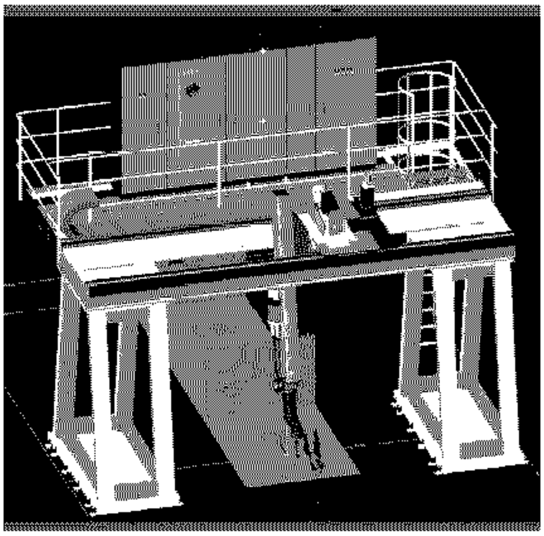
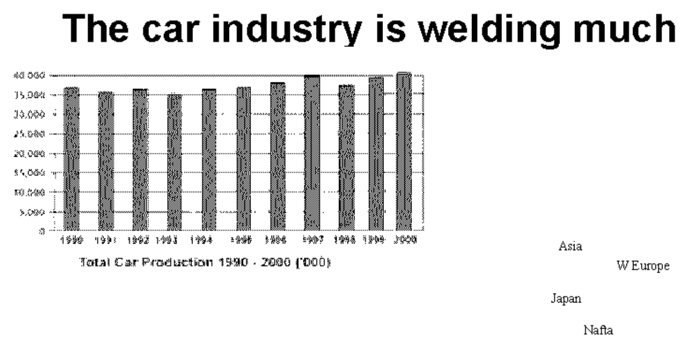


Figure 9
In this case a YAG-laser with the welding head mounted on an articulated robot is used thanks to the higher flexibility allowed by using an optical fibre delivering the light beam to the welding position. The wavelength is 1,06 µm compared with the wavelength for CO_2 light beam 10,6 µm, for which an optical fibre cannot be used.

Welding in automotive industry

In this industry sector an intense development of joining processes is ongoing as a very large volume of cars a produced (Figure 10)



Annual growth 2,1 %

Figure 10

By studying the developments in this sector one can fairly well forecast what new joining processes we can expect to see applied in other sectors. The automotive industry is the most important driver of continuous improvement of and innovations in joining.
MIG-, laser- and plasma-brazing are processes (1) attracting a lot of interest for welding of zinc-coated steel. The corrosion surface remains intact without any evaporation of the zinc next to the seam when brazing (Figure 11).

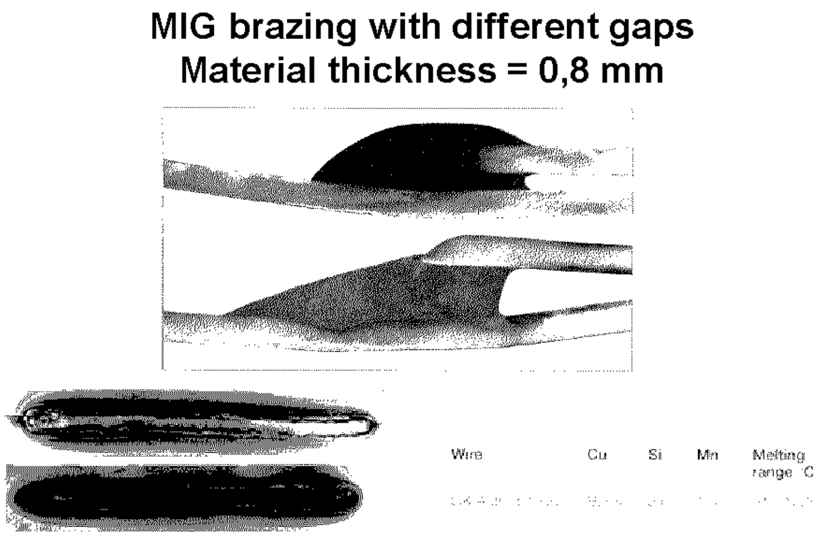


Figure 11

The brass solder overbridge gaps well as a consequence of the capillary action. The joint is produced without any spatter and porosity and the joint appearance is attractive.
We can expect more applications in other fields for MIG-brazing e.g. ventilation, household equipment, fire-resistant doors, roof and facade components in the building industry etc.
The mechanical joining methods; clinching and self-piercing riveting; are increasingly used in this industry especially for Al-cars like Audi A2 (Figure 12) . It contains

- YAG-laser welding 30 m with P = 4 kW, v = 5,5 m/min
- MIG-welding 20 m v = 0,7 m/min
- Self-piercing rivets 1800 pieces

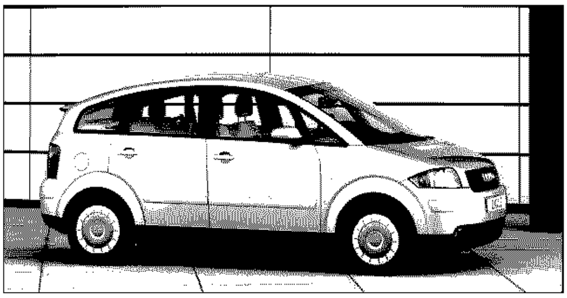


Figure 11
Audi A2 completely in Al

The line has 220 robots and the degree of mechanisation is 80 %.
The countermeasure against the higher use of Al by the steel industry is the introduction of Advanced High Strength Steels (AHSS), which is developed in project Ulsab financed by 33 steel companies. The conceptual design was made by Porsche Engineering ending up with

- Meeting anticipated crash safety requirements for 2004
- Significantly improved fuel efficiency: 3,2 – 4,5 litre/100 km
- Lower CO_2 emission: 86 – 108 g/km
- Low environmental impact – recyclable
- High volume manufacturability at affordable cost
- Demonstrating effective design concepts in AHSS: - 200 kg lighter

Tube structures and tailored blanks (40 % of structures) are used. 85 % of the body is made in AHSS. The traditional manufacturing processes can be applied

- Stamping
- Spotwelding
- Laserwelding
- Hydroforming

It will be interesting to follow how these new options into the automaker´s arsenal will be applied to improve safety, performance of lower fuel consumption without hitting the car buyer in the pocketbook.

MEGA-float structures (4)
A major research and development project for Mega-Float just more than 1000 m long , 121 m in width and 3 m in depth and designed for a lifetime for 100 years has been accomplished in Japan (Figure 12).

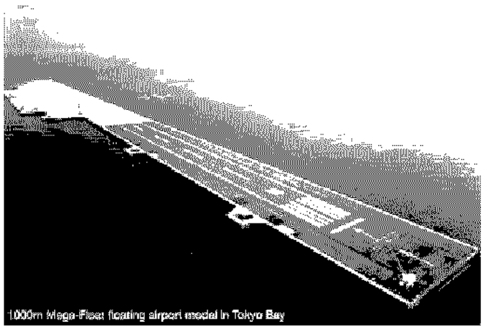


Fig.12 Construction of Floating Airport Model

There were many challenges in this huge project especially covering

- Relative motion between floating units during joining operation
- Geometrical accuracy management on thermal distortion and welding distortion
- Underwater welding, which could be made wet or dry as illustrated in figure 13

Much of the welding (Figure 13) was necessary to perform during dark hours as the deck plate became during sunshine 30° C higher in temperature than the bottom plate. This difference of temperature caused not only geometrical inaccuracy of the floating structure but also wide opening between the bottom plates of floating units.
The value of welding shrinkage and welding distortion was possible to estimate by using FEM.

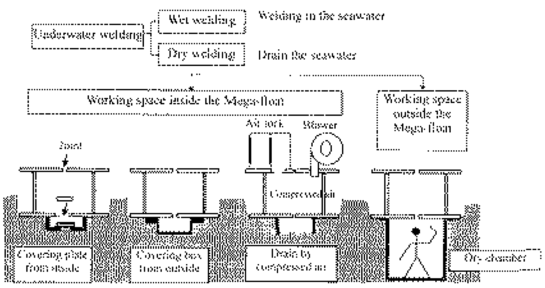


Figure 13
Working space applied to experimental floating models

In March 2001, the "MEGA-float Airport Investigation Committee" put together a detailed evaluation of the verification test on the 1000 m Mega-Float airport with 37.000 tons of steel and 4000 m-class test design, and announced in their final report that a Mega-Float airport with a scale of up to 4000m as being more than feasible. This design is one of the evaluated alternatives for extension of the Kansai Airport outside Osaka.

Welding of wind power stations

The environmental sustainability objectives are among all resulting in an increased number of installed wind power stations, which contains currently a lot of weld metal on average 1500 kg. The SAW process is hence used when possible to get a high deposition rate. Then the welds must be made in downhand position with a root pass from inside and the capping passes from outside, for which two electrodes DC and AC are mostly used. Systems similar to the one shown in figure 14 are often installed. As in other SAW applications metal-cored wires are introduced

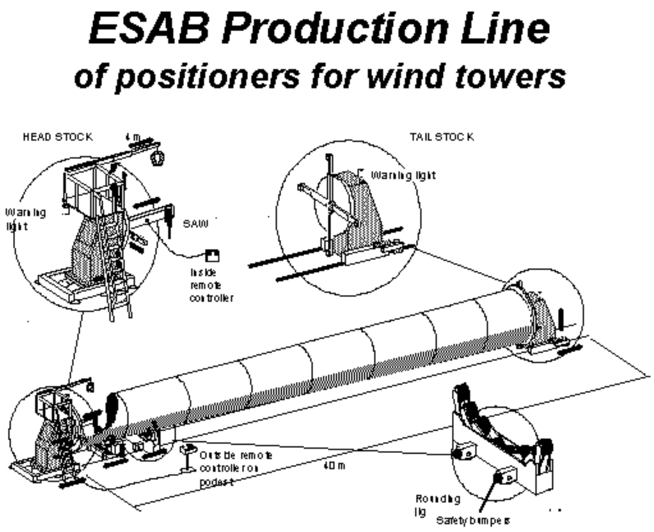


Figure 14

.

Robotized welding of large work pieces

A large and heavy workpiece like an excavator arm contains a lot of welding. To mechanise this manufacturing is asking for an intelligent system. An European group has been formed to realise a concept to fabricate structures with several cubic metres in volume, weight up to ~5 tons and with a steel thickness 3-50 mm.
The planned autonomous robot system (Figure 15) will encompass the following innovative aspects:

- Use of manufacturing simulation for automated process planning and real-time system monitoring
- Autonomous robot transport vehicle (RTV) navigation for high accuracy positioning of a robot arm in an industrial manufacturing environment
- Design and build of an industrially rugged RTV with accuracy and stability required for welding tasks
- Use of specially developed welding consumables, welding procedures and sensor systems designed to allow "all positional" robotic welding with a degree of control and dexterity unmatched by current systems.

A metal-cored wire will certainly be used in this station (Figure 15), which will be equipped with four cameras viewing the whole station, a vision system on the robot wrist, a through-the-arc sensor and a tactile sensor to find the starting point.

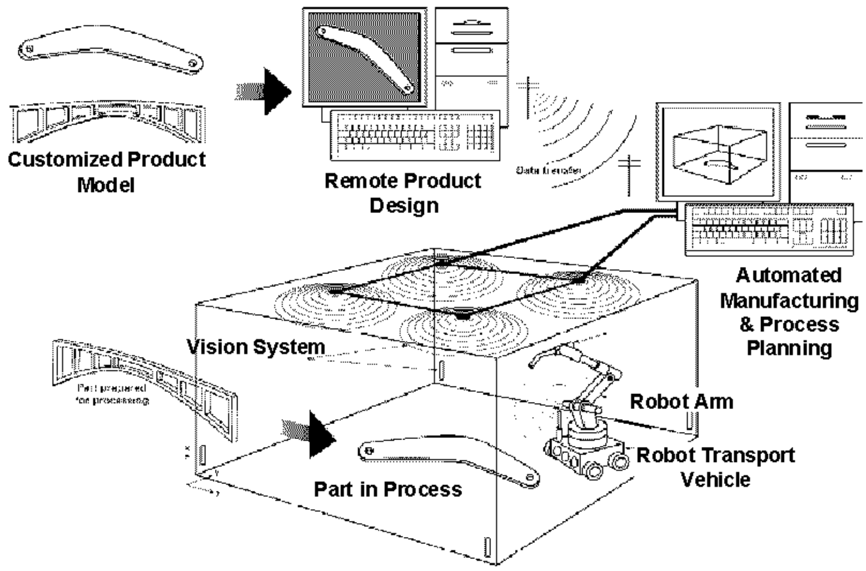


Figure 15
Conceptual design of the station

It is a three and halfyear project with a budget on 4,8 € Million.

Friction Stir Welding (FSW)

The process invented 1991 at TWI Cambridge (UK) (Figure 16 below) is already used in some very demanding applications for joining Al e.g. in

- Aerospace and aircraft
- Shipbuilding
- Automotive

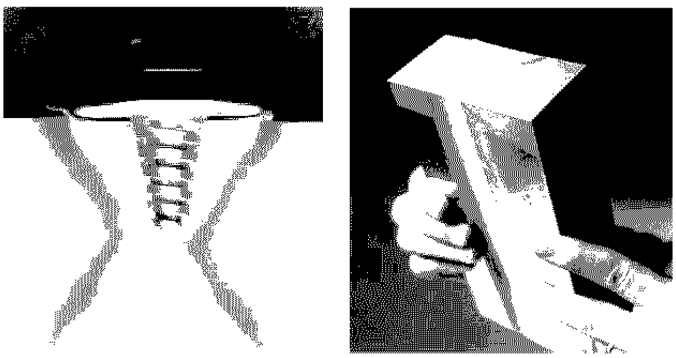


Figure 16
The left photo shows FSW of t=75 mm AA 6082 with a prototype tool Whorl^{TM}

The left photo shows twoside welding of Al with t = 55 mm

The talking points for introducing the FSW are:

- High and consistent weld quality – low defect rate 10 times lower than for arc welding
- High productivity – (50 – 3000) mm/min depending on thickness and Al alloy
- Fatigue properties much better than for arc welding
- Impact values excellent
- No welding consumables
- Possible to weld al Al alloys difficult or impossible to arc weld

The Swedish Nuclear Power and Waste Management Company is carefully evaluating to FSW to be used for encapsulation of spent nuclear fuel in durable canisters in Cu. These canisters will be stored in a deep repository in the Swedish bedrock. The canisters are 1050 mm in diameter and 4830 mm long. Figure 17 shows some test welding photos (6).

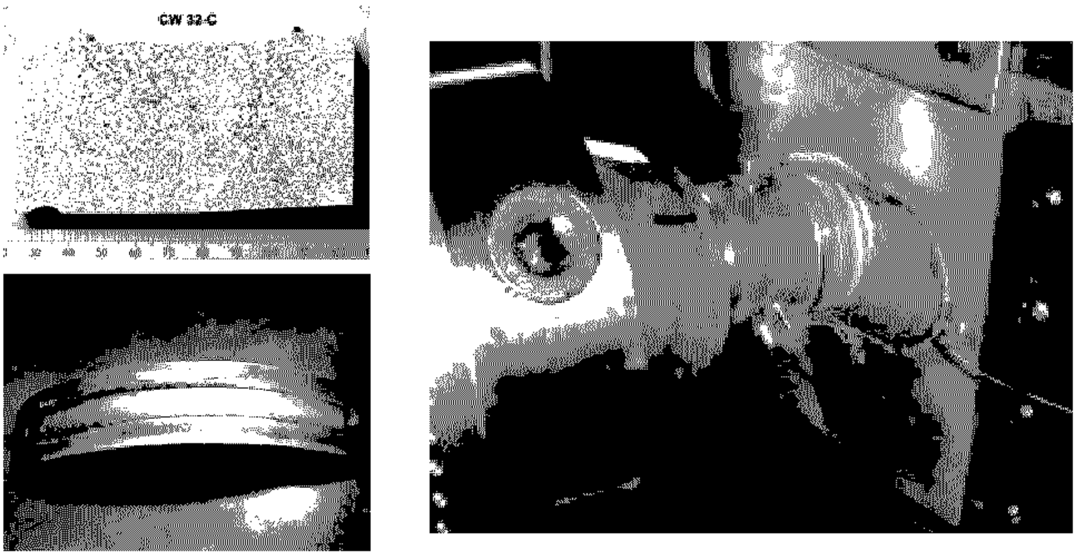


Figure 17
Welding of a lid to Cu-canister for nuclear waste with t = 50 mm

A group of companies (11) have together with TWI started a European project EuroStir with the objectives to

- Improve and develop tools
- Increase the max. material thickness possible to join
- Increase the productivity
- Introduce FSW in 3D applications
- Increase the knowledge about the mechanical properties in the weld metal
- Disseminate the results

It is a 5 year project with a budget on 6,8 € Million

Laser welding

YAG-laser with higher power up to 10 kW is attracting a lot of interest especially by the automotive industry, in which today several 4 kW YAG-lasers are installed. Above some data for laser welding of Audi A2 is given. In one of the latest installations at Seat Spain 1300 chassis for Ibiza are YAG-laser welded each day. The installation encompass 3 YAG lasers each on 4 kW connected to 14 welding heads for welding totally 7 m with a speed of 3,5 m/min.

Laser brazing is growing in application. It is currently running on

- Trunklid on VW Bora (4500 units/day)
- Roof ditch without trim cover , door openings and between body side and floor panel on VW Polo
- C-pillar on Audi TT Coupe

Remote Laser Welding, which is performed with mirrors covering a cube up to 1 x 1 x 0,3 m^3, is another emerging technology, introduced already for the swing door structure on Chrysler Jeep Liberty.

YAG-laser welding of pipes are studied. Figure 18 (7) shows some welding results for t = 15 mm at P = 9 kW

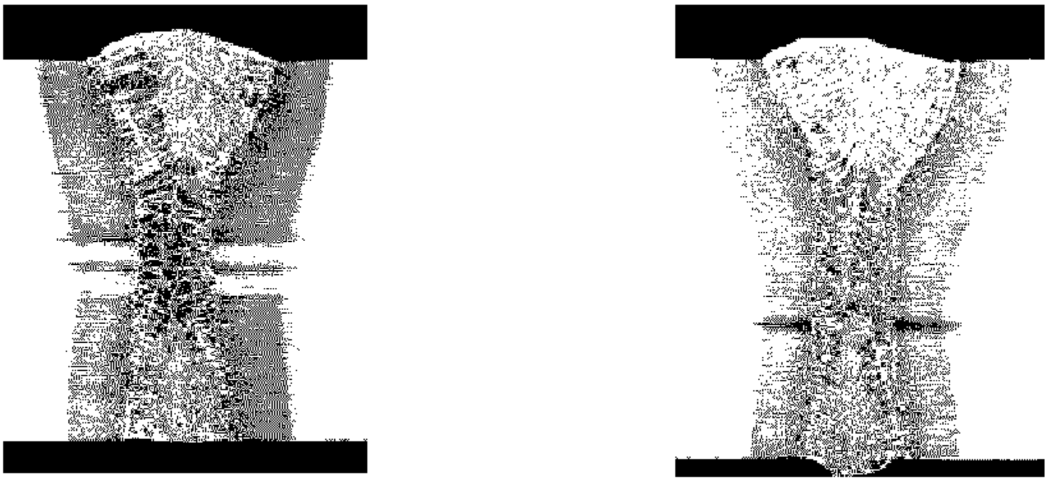


Figure 18

Focus point on surface
Shielding gas Ar 20 l/min
Welding speed 0,30 m/min

Focus point – 3mm
Shielding gas Ar 20 l/min
Welding speed 0,35 m/min

A diode laser consisting of a stack of semiconductor laserdiodes is an alternative to CO_2 and YAG laser. The diode laser delivers the laser beam in a line e.g. 6 mm x 0,5 mm with a power up to 4 kW (Figure 19) (9)
.

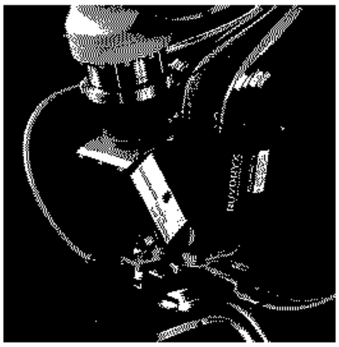


Figure 19
Laser diode with a weight on 6,5 kg and 23 cm x 26 cm x 14 cm in size

The advantages the diode laser offers compared to CO_2- and YAG-lasers can be seen table 3.

Function	Diode laser	CO_2-laser	YAG-laser Lamp-pumped	YAG-laser Diode-pumped
Efficiency %	30	6	1	6
Wavelength µm	0,8	10,6	1,06	1,06
Energy absorption				
- Steel %	40	12	35	35
- Aluminium %	13	2	7	7
Foot-print with cooler m^2	0,8	5	10	6
Maintenance hours	10.000 Exchange laser diodmatris	2.000 Optic 20-30.000 Turbine	1.000 Exchange lamp	10.000 Exchange laser diodematris

Table 3

The diode laser has

- Higher electrical efficiency
- Shorter wavelength suitable for optical fibre
- Higher energy absorption
- Much smaller foot-print and volume
- Much lower weight

This kind of laser can currently only be used for welding due to the energy distribution in the laser beam. There are improvements made at the University of Applied Sciences, Jena, Germany, where a smaller focus was realised and hereby achieving a higher energy intensity $3x10^5$ W/cm^2. With this solution a penetration of 6 mm was achieved with P = 2,5 kW (8).
This laser technology is still in its infancy stage and no industrial application is yet found. Some experts forecast that it will take another 5 years before we will se several diode lasers running in regular manufacturing.

Magnetic Pulse Welding (MPW)

The Magnetic Pulse Technology (3) , which can be applied for

- Welding
- Crimping
- Punching
- Forming
- Calibration

is known for many years but mainly few forming installations have been made. During the last years the Magnetic Pulse Welding has become a joining process evaluated carefully by the automotive, household appliance and electrical industries. This solid state process, in which bonding is produced by an oblique, high-velocity collision between the two bodies that are going to be welded (Figure 20)

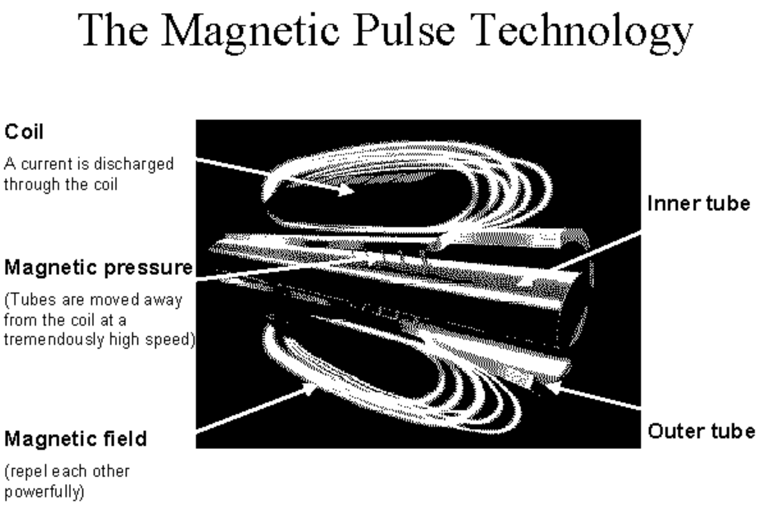


Figure 20

The process is based on a high current in short time less than 0,1 second passing through a coil creating and eddy current in the conductive workpiece. Repulsion between the two magnetic forces creates a pressure and accelerates the workpiece into a new configuration. The energy charged in highvoltage (up to 10 kV) capacitors is discharged through the coil with low self-inductance and resistance. The peak current can reach several million amps.
The bond, that is produced, is a true metallurgical bond, usually stronger than the weaker of the two materials that are being welded.
The process is precisely controllable and repeatable and best used for high volume manufacturing, as the coil must optimised for each workpiece.
Figure 21 shows geometry used in MPW. They are typically lap joints. The workpiece shape can also be elliptical or rectangular to produce tube-to tube or tube-to-bar welds. The MPW process is as well suitable for flat welding areas.

Different lapjoint configurations for Magnetic Pulse Welding

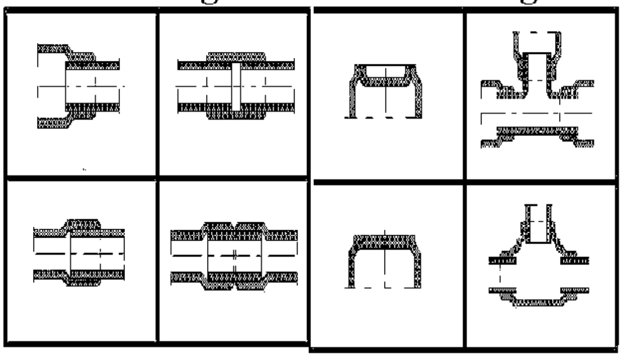


Figure 21

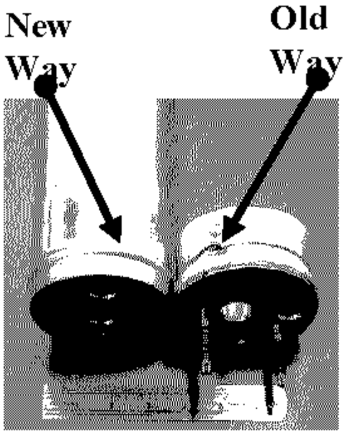
The MPW has been developed for a number of material dimensions and combinations. The ranges of these combinations welded to date are shown in table 4.

	Magnesium	Stainless Steel	Nickel	Titanium	Steel	Zirconium	Molybdenum	Brass	Copper	Aluminium
Aluminium	√	√	√	√	√	√	√	√	√	√
Copper	√	√	√	√	√	√	√	√	√	
Steel		√	√		√					
Stainless Steel		√	√	√						
Nickel		√	√	√						
Magnesium	√									

Table 4

The manufacturing cost is much lower for MPW than for the other process as shown in figure 22.
So far there are very few equipment put in production. There are, however; currently about 15 installations for test welding, demonstrations and development of the process, which is protected by several patents. One can foresee the coming years a fast growing number of installations.

Cost comparison for welding of small accumulator (USD)



Diameter = 4”

Material thickness: 1,6 mm

• **TIG**	**0,338**
• **MIG**	**0,454**
• **Laser**	**0,478**
• **MPW**	**0,165**

Figure 22

Summary

In summary we have noted that

- Steel and Al are competing
- We ought to monitor the joining technologies applied by the car industry
- Laser welding is growing fast in many different applications
- Welding of large workpieces are robotized
- Mechanical joining processes must not be forgotten when looking for appropriate joining options
- Magnetic Pulse Welding can be something for you

In this survey nothing is said about structural adhesive, which process is definitely used more often combined with other joining processes e.g. resistance spot welding.

References

(1) H. Rohde, J. Katic, R. Paschold*ESAB pulsed gas-shielded metal arc brazing of surface-coated sheets* Svetsaren, No 3 (2000), page 20

(2) S. Goeke, J. Hedegård, M. Lundin, H. Kaufmann:*Tandem MIG/MAG,* Svetsaren No 2-3, (2001), page 24

(3) V. Shribman: *Take advantage of the new magnetic pulse welding process,* Svetsaren No 2-3 (2001), page 14

(4) Y. Yamashita, S. Kawachi, S. Okada, M. Yoshikawa, T. Sasaki,, Y Kinosheta, Y. Ogawa:*Proceedings Seventh International Welding Symposium (Nov. 20-22, 2001)*

(5) U. Dilthey:*Prospects by Combining and Coupling Laser Beam and Arc Welding Processes,* IIW Document XII-1565-99

(6) C-G Andersson, R.E. Andrews, B G I Dance, M J Russel, E J Olden and R M Sanderson: *A comparison of Copper Canister Fabrication by the Electron Beam and Friction Stir Welding* (FSW International Symposium 2001 in Sweden) Available on CD from TWI

(7) C H J Gerritsen and C A Olivier: *Optimisation of plasma/plume control for high power Nd:YAG laser welding of 15 mm thickness C-Mn Steels.* Presented at 6th International Conference on Trends in Welding Research, 15 – 19 April, 2002, Callaway Gardens Resort, Pine Mountain, Georgia, USA

(8) J Bliedtner, Th Heyse, D Jahn, G Michel, H Müller and D Wolff:*Advances diode lasers increase weld penetration,* Welding Journal, June 2001, page 47

(9) T Nacey: *Diode lasers offer welding advantages,* Welding Journal, June 2001, page 27