HIGH-SPEED WELDING WITH INFOCUS

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Abstract:

The paper explains a novel TIG process and torch, named InFocus. InFocus welding enables an enormous increase of welding speed and the welding of thick metal sheets up to 12 mm in InFocus keyhole welding.

Using InFocus, the electron emitting cathode surface is limited to a very small area at the electrode tip. Thus, the arc is highly focussed at the cathode and the high arc constriction increases the arc stability and the energy density at the work piece. The increase of arc pressure and energy density enables welding with high speed and high quality.

The first part of the paper presents application tests in automotive industry, where welding and brazing speeds of about 4 m/min were achieved. Secondly, results for keyhole welding of stainless steel 1.4301 and mild steel 1.0117 are presented. We explain the treatment of plates with a thickness from 6 to 10 mm for stainless steels and 6 to 12 mm for mild steels. The welding speeds were in the range of 20 to 115 cm/min at currents from 400 to 800 A. Furthermore, results for welding root passes of S355J2 with a thickness of 25 mm are shown, together with cross sections of the root pass and the subsequent submerged arc welding. In the third part of the paper we present results of high speed welding of 2mm thick mild steel square profiles. In this application welding speeds up to 15 m/min were achieved.

1. INTRODUCTION

TIG welding enables high quality weld joints, without spatters and in a wide range of tolerances. The equipment is highly available, easy to use, and inexpensive. Thus TIG welding is licenced for welding of safety-relevant components and is used in many welding applications. However, the limitations in welding speed and penetration depths were the main drawbacks of the TIG process so far.

The new developed InFocus torch enables a multiplication of welding speed and the massive increase of penetration depth. Furthermore a keyhole can be established using InFocus at current loads of 400 A and more. The single pass (keyhole) welding of thick metal sheets provides a high productivity. A small penetration width and heat affected zone can be achieved.

2. THEORETICAL BASICS

In TIG, the arc is established between a non-consumable (tungsten) cathode and the work piece. The emission of electrons at the cathode surface is mainly caused by thermal emission. Using a very efficient cooling of the cathode, the electron emitting surface of the cathode can be limited to a small region at the cathode tip, where the arc is forced to attach. Thereby the arc is highly constricted at the cathode and an increased current density is caused below. Thus, higher arc temperatures as well as an increased arc pressure and a multiplied plasma flow velocity are caused, which all stabilise the arc behaviour and the anodic attachment, see figure 1.

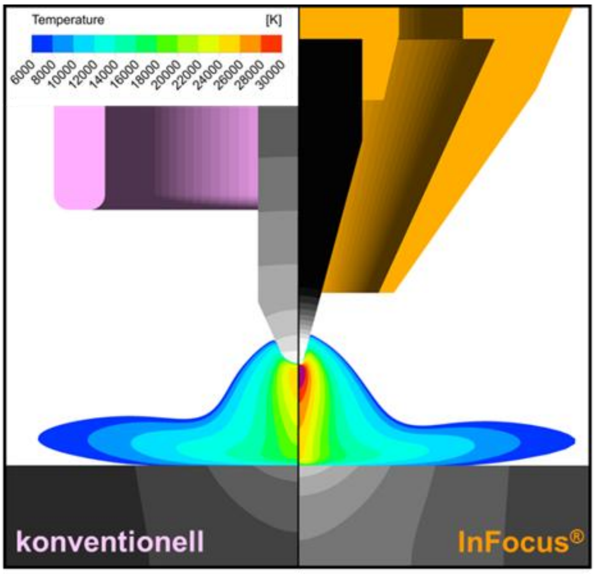

Figure 1. *Principle of cathode focussed TIG-welding*

The new InFocus arc and InFocus process behaviour are based on a new torch design that is shown in figure 2 and described in the following.

The most important design feature of the torch is the cooling of the cathode. The cooling is improved due to an increased thermal conduction between the cathode tip and the water cooling, due to a flow optimised cooling element and due to a reduction of the electric resistivity in particular of all electric contact resistances. Thus the tungsten electrode has a diameter of 6.4 mm and is press fitted in a copper fastener. This cathode unit is a consumable, which is very easy to change. However, it always guaranties the same tool centre point (TCP) of the cathode tip. The cathode unit is screwed into the cooling unit, the heat and current flux is realised through the front faces of the cathode and cooling unit. The cooling system is closed in order to avoid any loss of water, for example during the change of the cathode unit. The design of the cooling system and the cathode was improved by numerical simulations [1].

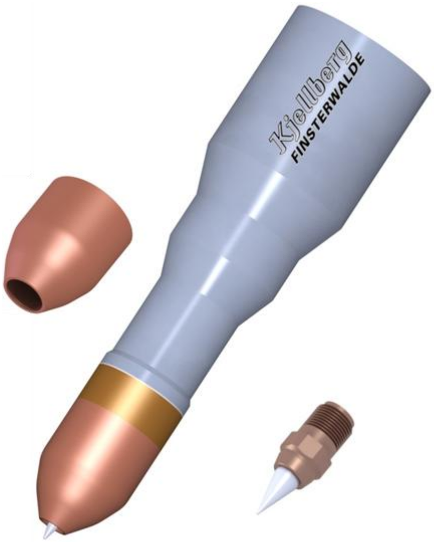

Figure 2. *Design of the InFocus 1000 welding torch and its consumables*

The arc properties, especially the arc pressure, heat flux density and the arc voltage drop were numerically and experimentally investigated and compared with conventional welding torches. The results for arc pressure are shown in figure 3. The measurements of heat flux distribution were published previously [1]. In comparison to a conventional TIG process the arc pressure is doubled and the arc voltage is increased by 20 % or 3 V. The effects increase with an increasing current.

An increase of electric current and heat flux density was especially found for short arcs length. For a 200 A arc with 2 mm arc lengths an increase of 70 % was observed. However, the effect could not be observed any more or an arc length of 5 mm. Thus, we recommend arc length below 1.5 mm for InFocus applications.

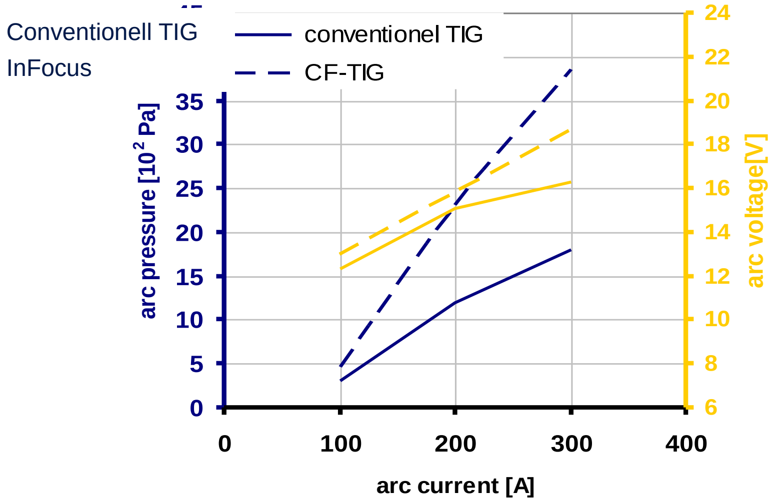

Figure 3. *Comparison of arc pressure and voltage drop of conventional TIG and InFocus demonstrating strong arc constriction*

This new InFocus process provides very stable and high productive welding and brazing applications even when using very high current loads. Tests with a load of 1000 A have demonstrated that the arc is still very constricted at the cathode tip and the erosion of the cathode is still very low.

Thus the InFocus technology enables an access to the high power and high performance TIG welding with applications very similar to Plasma Arc Welding (PAW). However, in comparison to PAW, InFocus is characterized by much less process parameters. Ensuring a short arc length, the electric current and welding speed are the only parameters that have to be harmonized. Thus InFocus is as easy to apply as TIG processes are generally.

3. AUTOMOTIVE APPLICATIONS

The automotive industry is a key industry in which new requirements are defined and critical technology developments are spawned. Technologies that were prevailed here are prevailed in other industries a few years later. The InFocus technology is already tested successfully in automotive welding and brazing applications. Several systems are already running for welding of exhaust manifolds. Currently high-strength and reinforced high-strength steels are used in the car body production. However by welding this steel, the high strength properties are lost due to the high welding temperatures. Otherwise, brazing enables a significant decrease of joining temperature and high speed brazing enables small temperature influenced areas and additionally a significantly improve of the economic efficiency.

The brazing of zinc coated steel sheets is currently mainly realised by laser or dip transfer GMAW processes. Laser applications enable high brazing velocities up to 3.5 m/min but cause high affords for clamping and positioning as well as high costs for laser safety. Alternatively arc processes can be used but they offer much lower brazing speed of less than 1 m/min so far. Furthermore sporadic seam defects, e.g. wetting defects and pores occur and cause cost intensive repair and restoring work. Thus arc processes are seldom used in the sight areas. Using the InFocus, laser-like brazing seams can be produced, see figure 4. Furthermore, the brazing speed can be increased in comparison to laser processes. For a lap joint a brazing speed of 4 m/min can be achieved even without preparations of the work piece surfaces. The maximum speed of 7 m/min was achieved with surface cleaning by acetone and an arc length below 1.5 mm. Due to high arc constriction and high brazing speed, the defects of the zinc coating are negligible and root shortness is avoidable. Compared to laser applications the invest costs of welding plants and clamping are much lower and risk due to laser radiation does not occur.

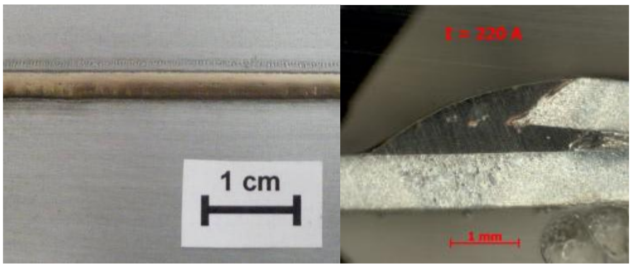

Figure 4. *Surface and cross section of copper bracing joint (I = 200 A, v = 4 m/min, filler: CuSi3)*

The welding of brake pedals was one of the first welding application tests for InFocus. In comparison to the conventional TIG-process, it provides the double welding speed, which is now limited due to the handling system and not any longer due to the arc welding process. In detail, 3.9 m/min welding speed is achieved. Furthermore, the penetration is increased and the formation of slag and oxides on the weld seam were prevented due to a better gas shield. A superior weld seam appearance is achieved, figure 5. Thus it is possible to save an additional procedure, the surface treatment before anti-oxidation-coating.

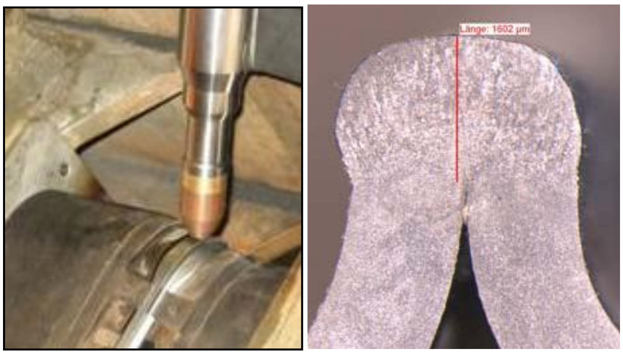

Figure 5. *Welding of brake pedals, welding plant (left) and cross section right (I = 480 A, v = 3.9 m/min)*

4. THICK PLATES INFOCUS KEYHOLE WELDING

In [2] is described, that an energy density above 106 W/cm2 provides vaporisation pressure induced deformation of the weld pool and the forming of hole right through the molten pool to the rear surface (keyhole). The keyhole works along the weld; the material is melting mainly at the front of the keyhole, is moving around the sides and is forming a weld bead behind.

In arc welding (TIG, GMAW or PAW) the energy density is not sufficiently high to form a keyhole due to vaporisation effects. Thus and in contrast to Laser and Electron Beam, the keyhole is formed due to the stagnation pressure of the plasma jet. The new InFocus-process can ensure this high arc pressure and can therefore be used for keyhole welding as the well-known plasma process.

In experiments, the formation of a keyhole was observed for mild steel and stainless steel at current loads of 400 A at least.

The best results were achieved for 6 mm thick stainless steel plates (EN 1.4301), figure 6. Therefore the process is very stable and is characterised by a wide range of parameters, from 400 - 950 A and 20 – 120 cm/min. The process enables stable root forming for gaps between 0 and 2.5 mm without changing the parameters. The maximum plate thickness of stainless steel plates is 12 mm so far.

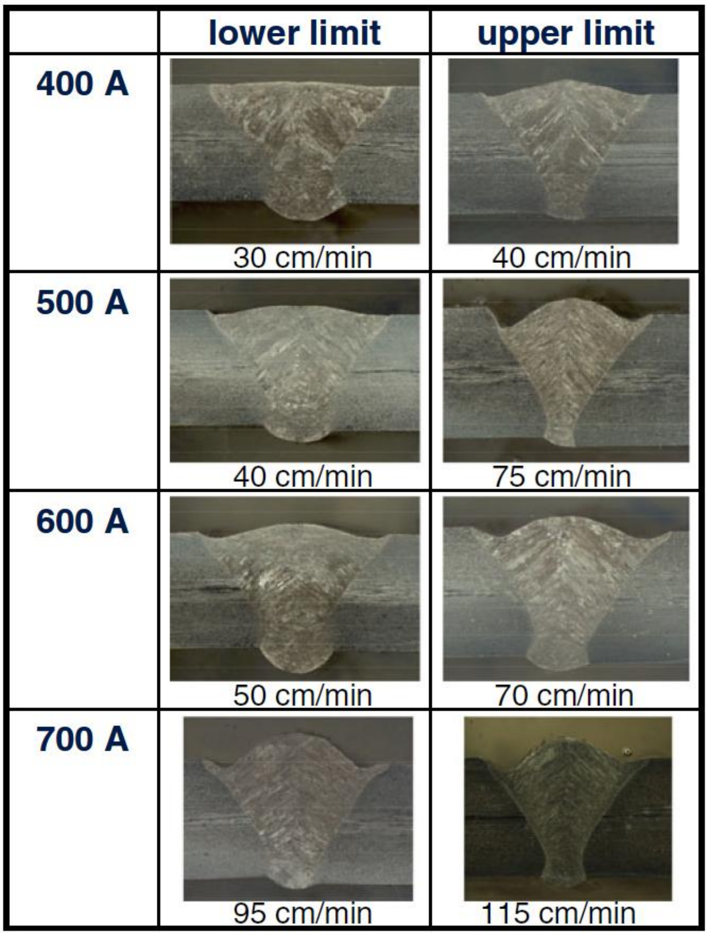

Figure 6. *Cross sections of InFocus keyhole welding of stainless steel; 6-mm-thick specimens with a CWD of 0.5 mm*

Mild steel S235J2G2+C (EN 1.0117) was welded up to a thickness of 11 mm. The range of parameters is not as wide as it is for stainless steel, figure 7. The welding speed is according to the current in a range of 20 - 60 cm/min for 6 mm thick plates. An inductive preheating setup was developed in order to avoid lack of fusion especially for thick plates or welding of the root pass of V or Double-V weld preparations. In figure 7 results for stainless steel and mild steel are shown.

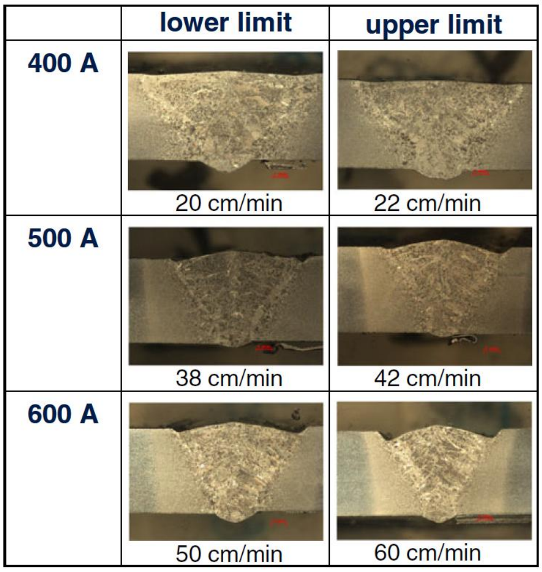

Figure 7. *Cross sections of InFocus keyhole welding of mild steel; 6-mm-thick specimens with a CWD of 0.5 mm*

We got perfect weld seam appearances with very small undercuts for welding speed up to 50 cm/min. Therefore the combination with an additional dressing TIG torch at the very same tractor was tested. The additional use of a filler wire prevents under fill. Otherwise even small undercuts were circumvented.

The results demonstrate the usability of the InFocus technology for welding of pipes, container and apparatus constructions with material thickness up to 10 mm preferably and up 12 mm at maximum.

In order to weld material up to several 10 mm, the V or Double-V weld preparations were used. Here, the increase of the root pass height is one of the main goals in order to reduce the weld seam cross section, energy input, filler material consumption and distortions. The InFocus keyhole welding enables the weld of a 6-8 mm thick root pass. Therefor and in contrast to PAW, the torch can be positioned deep inside the weld preparation. For that case, a maximum weld speed of approximately 1 m/min can be used, since possibly occurring undercuts will be remolded be the subsequent Submerged Arc Welding (SAW) process.

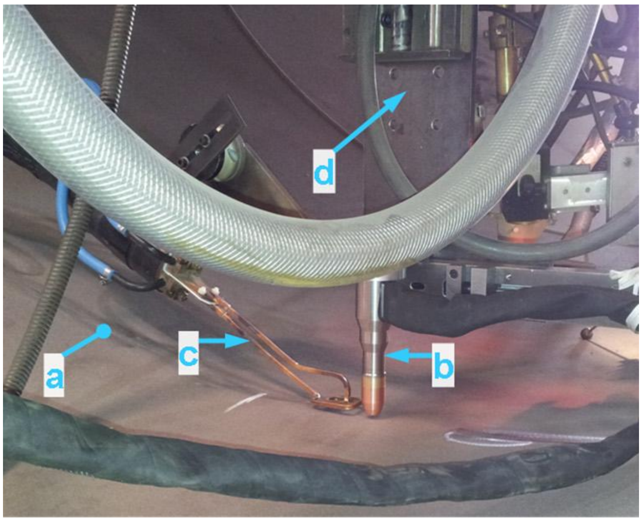

Figure 8. *New test setup with the InFocus torch (b), an inductor (c) for preheating the tube (a) and the support arm (d) of a SAW welding machine*

The figure 8 shows the application setup used for welding of windmill sections. The InFocus torch and our additional inductive preheating advice have been adapted at one tractor. The cross section after InFocus keyhole welding and a subsequent SAW process is shown in figure 9. The SAW passes have been laid with the same welding speed as for the keyhole root pass. Thus for future applications a simultaneous process with the SAW process trailing the InFocus process is possible. Furthermore the welding parameters for the SAW passes were the same as for the conventional process. Therefore it can be assumed that the investigated process gives the same weld quality while requiring a much lower process time.

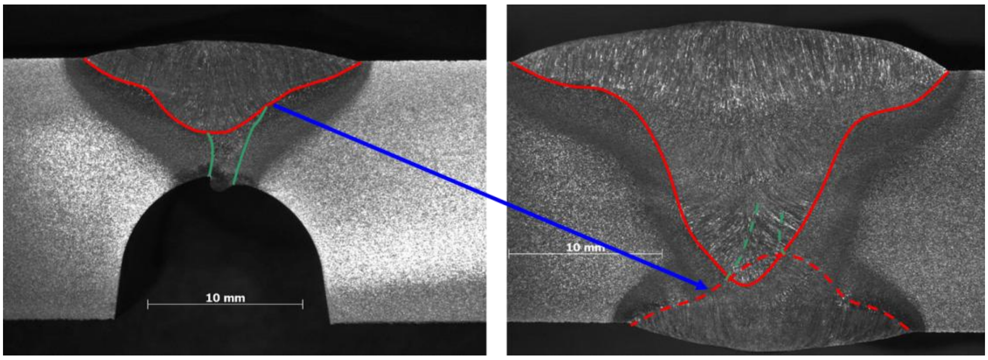

Figure 9. *Cross sections of InFocus Keyhole welding and subsequent SAW of 18 mm thick mild steel plate; U-weld preparation, root face grinded manually, 8 mm depth of root face, 1 – 1.5 mm root gap*

5. INFOCUS HIGH SPEED WELDING

Welding speeds of 5 m/min and more can be reached by welding of long work pieces. Conveyor speeds of up to 50 m/min are achieved in the profiling production of square profiles. If the profiles are welded longitudinal, then the Magnetic Pulse Welding (MPW) is used and allows welding speeds over 30 m/min. However, this welding technique needs long run up and causes waste materials. Thus, this process is not appropriate for short runs of several 10 – 100 meters, but InFocus.

Tests were done for the longitudinal weld of 40 x 40 x 2 mm square profiles. The profiles are made of mild steel (S235). The gap is determined by the forming process and in the range of 0.2 – 0.3 mm with a lateral offset of ±0.03 mm. The profiles were (automatically) deoiled before welding. A welding speed of 7 m/min was the expected goal for InFocus welding.

In application tests, welding speeds up to 15 m/min were reached with InFocus welding of the profiles in production environment. A cross section of the weld seam (12.8 m/min; 630 A) is shown in figure 9. The cross section demonstrates a high quality weld root but under filling, which results by the gap and the lack of filler wire. However, the joint meet the expectations of profiles producer and customers.

The cathode life was tested with 500 to 800 m. It strongly depends on the removing of oil before welding. Furthermore, the arc length is most important once again in order to enable process reliability at the high welding speeds. Thus a height control is used and enables a cathode work piece distance (CWD) of less than 1 mm.

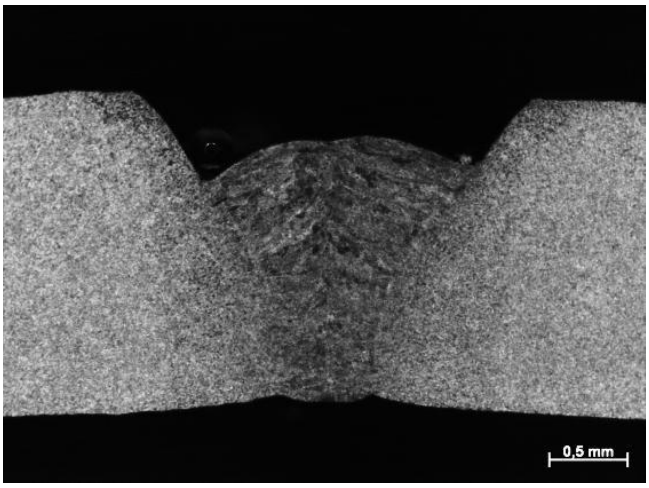

Figure 10. *Cross sections of InFocus high speed weld of mild steel 40 x 40 x 2 mm profiles; 12.8 m/min and 630 A*

6. SUMMARY AND CONCLUSIONS

During the last decades the main focus of arc welding and arc bracing processes was the development of new arc welding machines, current profiles, and control systems. The design of the welding torches has not been changed significantly in this time. The paper presented a new InFocus welding torch that enables a significant increase of process reliability, welding speed, and penetration depths. For this the paper gives several examples:

Brazing of car body structures with 3-7 m/min
Welding of brake pedals with 3.9 m/min
Keyhole welding of 6 -12 mm thick plate of mild steel and stainless steel
High speed welding of 40 x 40 x 2 mm mild steel profiles with up to 15 m/min

7. ACKNOWLEDGEMENT

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8. REFERENCES

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