EFFICIENCY IMPROVEMENT OF HIGH-ALLOYED THIN SHEET GAS METAL ARC WELDING

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Key words*: Gas Metal Arc Welding, CMT, LSC, PMC, high alloyed thin sheet welding, exhaust systems, metal cored wire*

Abstract:

Welding of high alloyed thin sheet metals is challenging. Due to the 2 - dimensional heat flow the risk for overheating and burn - through increases rapidly with decreasing sheet thicknesses. At the same time heat distortion effects visible as a remarkable sheet deformation, often in combination with a gap build-up have to be considered. To overcome these problems, the heat input of the welding process has to be decreased – either by reducing the arc energy or by increasing the welding speed. But both options have their limits: a minimum arc energy is necessary to guarantee a stable welding behavior and the welding speed is often limited by the gap bridgeability of the welding process.

This paper discusses various „low heat input“ gas metal arc welding (GMAW) processes as short arc, pulse arc, CMT, CMT pulse and new developed short arc processes like PMC and LSC. Thereby the achievable maximum welding speed related to their gap bridging ability depending on sheet thickness and the used wire electrode – solid wire and metal cored wire – is the focus of this investigation.

As base metals high alloyed sheets typically used for exhaust systems in the automotive, austenitic 304L and ferritic 441 stainless steel, in the thickness range of 0,8 – 1,2 mm are used. The basic evaluation will be done on a huge set of plain sheet robotic welding trials which are cross - checked by real component welding. A short economic discussion will complete this comparison.

1. INTRODUCTION

Welding of exhaust components is a striking application of Gas Metal Arc Welding (GMAW) and in manufacturing of almost every exhaust system a remarkable part of the production time is related to welding. That`s why the optimization of this joining process is a powerful tool in cost savings. But the challenge is also to join high - sophisticated materials. As the exhaust is the „link“ of the exhaust gases between the engine and the surrounding, the used materials have to undergo different temperature profiles and often high alloyed steels have to be used.

Ecological reasons like reducing the fleet emissions till 2020. in Europe to 95 g CO_2/km (58 mpg), lead now to much tougher material requirements as this limit can be reached only with remarkable higher exhaust gas temperatures.

Additionally economic reasons in weigth - and cost savings strongly increase the demands for welding of exhaust components: high - alloyed thin sheet welding at increased welding speeds with highest arc stability, gap bridging capabilities and reproducibility are thereby the key issues .

2. MATERIALS USED FOR AUTOMOTIVE EXHAUST SYSTEMS

An exhaust system consists in general of the manifold (1), the hot end pipe (2), the catalytic converter (3), the connection pipe (4), the resonator (5), the connection pipe (6), the muffler (7) and the tail pipe (8) as shown in Figure 1.

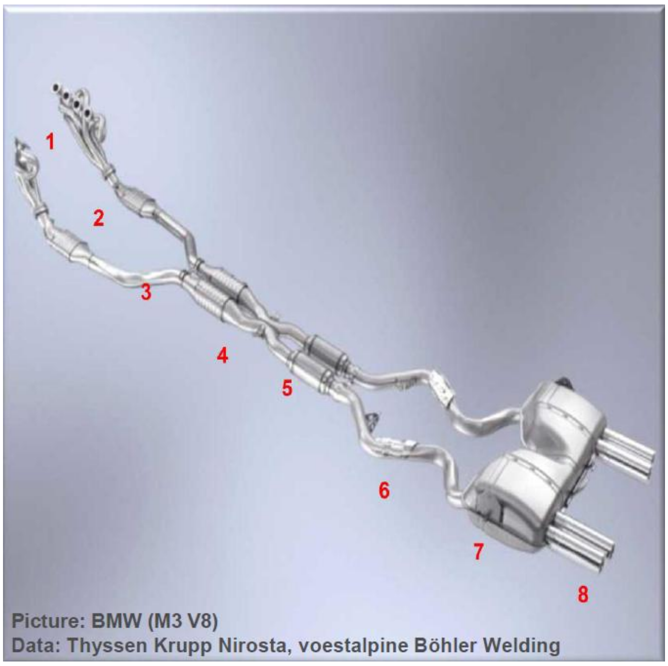

Figure 1. *Components of an automotive exhaust system*

A rough classification of the exhaust system (figure. 2) is defined by the temperature range, in which the parts have to perform so called "hot end" (1, 2, 3) near the engine, the "middle section" (4, 5, 6) and the cold end (7, 8). Depending on the temperature also different materials have to be used, which is shown in figure 2.

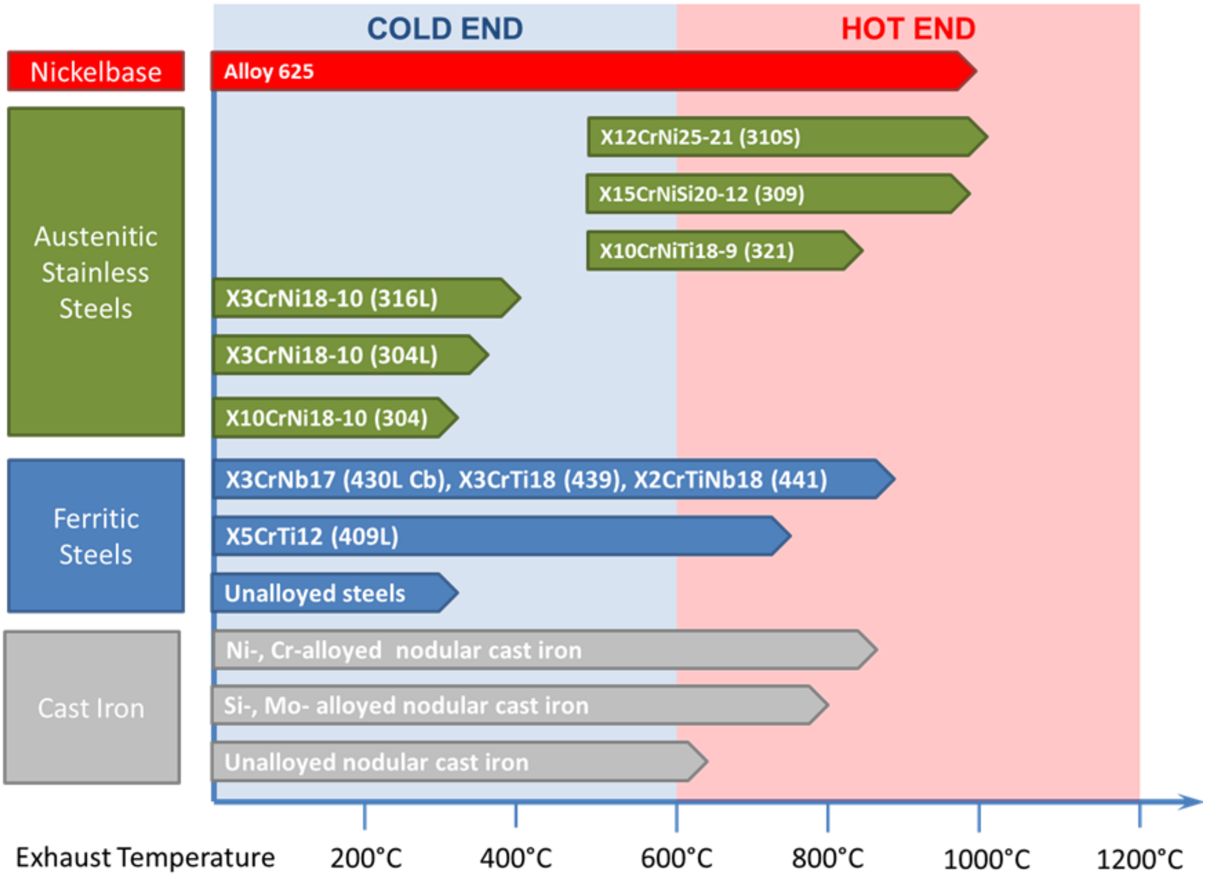

Figure 2. *Applicable temperature range of materials used for exhaust components [1]*

In practical automotive application an austenitic stainless steel and a ferritic steel concept is used. But due to the big difference in the thermal coefficient between austenitic and ferrtic steels, combination between austenitic and ferritic material in the same exhaust system is very seldom. Taking a look on the demands in each range, the following needs have to be fulfilled.

In the hot end the materials used have to fulfill high resistance to scaling and low tendency to high temperature embrittlement where as in the middle end section a high temperature - and corrosion resistance is mandatory. In contrary the cold end section has manly to deal with corrosion resistance.

In the last several years there has been a strong change from the use of austenitic to ferritic steel grades. Looking only at the high temperature tensile strength of austenitic stainless steel, they show up with a perfect characteristic but due to their tendency to material embrittlement in the termparture range between 400°- 800°C austenitic stainless steel cannot be used in the middle section. Taking also thermal fatigue properties into account, ferritic stainless steels are in overall the better solution also to be used for components in the hot end [2].

3. WELDING PROCESSES FOR AUTOMOTIVE EXHAUST SYSTEMS

Main demands in welding exhaust components are thin sheet joinability (down to 0,8 mm thickness), high joining speeds on automated robotic applications, good gap bridging ability, low heat input and at least as less spatter as possible.

The preferred process for fulfilling all these demands is the Gas Metal Arc Welding process (GMAW) in its various versions, starting with the standard short arc process up to spatter free and low heat input processes like Cold Metal Transfer (CMT). Nevertheless the process has to run at low amperage and voltage and increased welding speed to minimize the heat input, otherwise a burn-through of the thin sheet material would occur.

The CMT process, a dip transfer process (figure 3), is characterised by a mechanical droplet detachment, which leads to lower heat input and less spatters. This will be achieved by up to 70 Hz high-frequent mechanical forward and backward movement of the wire during welding. Each movement is thereby exact one droplet detachment.

As the droplet detachment is done more or less „mechanically“, the amperage could be reduced to a minimum during the detachment phase and the heat input can further remarkably reduced compared to the standard short arc process. Additionally the molten metal at the tip of the wire runs smoothly into the weld pool. Due to this functionalities, the process has perfect characteristics for joining thin materials without burning troughs and with almost no spattering.

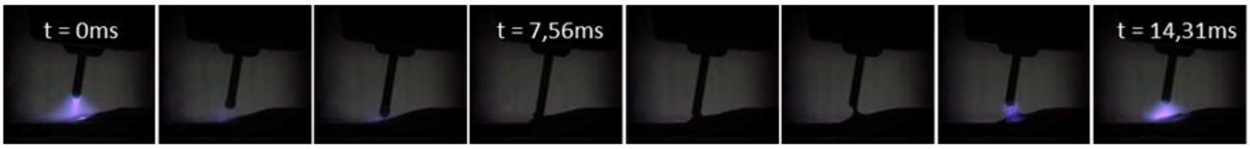

Figure 3*. Method of droplet detachment CMT process*

Based on the CMT process, some variants have been developed to open the enlarge the working window. The first variation is the CMT- Pulse process, which is a combination of pulsed cycles with CMT cycles. This modification allows to to weld materials thicker than 2,5 mm by gaining the positive effects of arc stability and reduced heat input.

The second variation is called „CMT Dynamic“. This one is working with higher frequencies (up to 120 Hz) of the forward or backward wire movement, which allows to weld sheets up to 2,5 mm thickness by gaining more penetration then the common CMT process. In figure 4 the typical parameter window (power versus wire feed speed) for the CMT process and its variants can be seen.

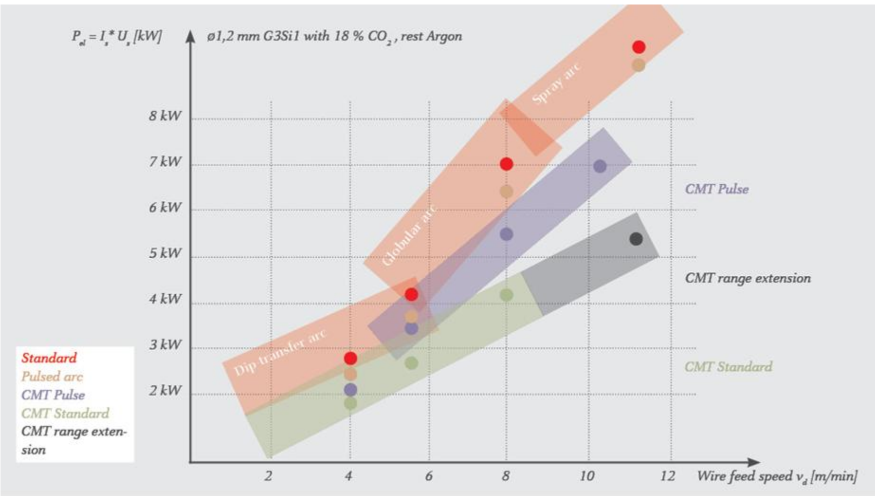

***Figure 4**. Parameter window for various GMAW processes*

Beside a low heat input the gap bridging ability at high welding speeds is by far the most interesting point for exhaust components. Therefore two new process technologies were recently developed by Fronius: Pulse Multi Control (PMC) and LSC (Low Spatter Control) [3].

3.1 Pulse Multi Control (PMC)

The PMC process is a pulsed process with a totally new synergic line algorithm. Therefore a new hardware communication technology had to be established which enables now compared to conventional welding systems a more than 200 times faster communication between „the arc“ and the operating system of the power source.

That`s why this new technology allows to increase the welding speed of the pulsed process due to a high arc stability without any restrictions to the seam quality and the build up of undercuts. Also, spattering is very limited. Additionally, two new functionalities have been implemented in the PMC process:

3.1.1. Penetration Control

Due to a new, very fast comprehensive power source - internal communication, it is possible to keep the welding current constant to guarantee a constant penetration although the „contact to the work piece distance“ (CTWD) varies. Therefore the wire feeding rate has to be adjusted automatically during welding depending on the variation of stick out as shown in figure 5 on the right side.

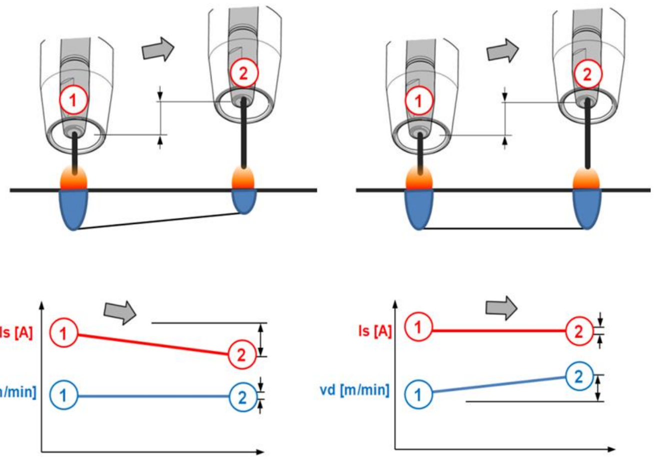

***Figure 5**. Characteristic of penetration stabilizer (left: without penetration stabilizer; right: with penetration stabilizer); v_d: wire feeding rate*

3.1.2. Arc Length Stabilizer

The arc length stabilizer is automatically reducing the arc length, for assuring, that the droplet detachment of the pulsed process takes place in a short circuit transfer mode. This effect leads to a very stable droplet detachment in pulsed process at high welding speeds without getting notches. In Figure6 the principle is shown.

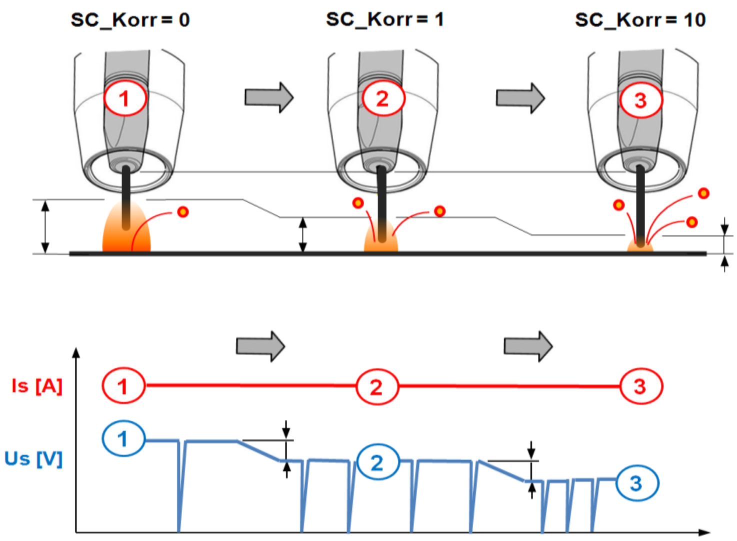

Figure 6. *Principle of the arc length stabilizer*

3.2 Low Spatter Control (LSC)

The LSC process is a short arc process. The differences to the standard short circuit transfer are also based on the fast communication via Speed Net and a new algorithm. The LSC process was especially developed to increase the deposition rate, maintaining a constant penetration, minimizing spattering and increasing arc stability compared to the standard short arc process.

The difference how the process is controlled in contrast to the standard short arc process can be seen in figure 7 and 8.

The difference is during the short circuit phase: in the standard process the current is rising and the droplet detachment occurs stochastically. In contrary by LSC the current will be immediately reduced when short circuiting occurs, followed by a “current peak” for controlled droplet build up, followed by a break down. Then a second current peak will provide a controlled droplet transfer. Out of this algorithm the LSC process is an interesting process regarding welding of exhaust components, above all when it comes to gap bridging.

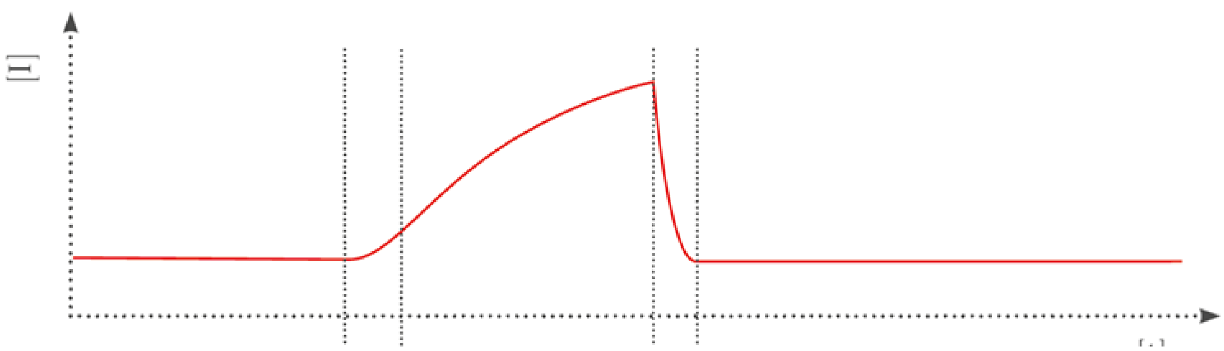

Figure 7. *Current over time short arc circuit*

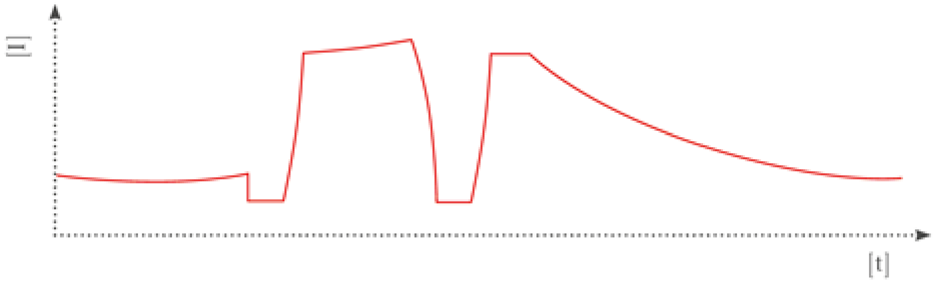

Figure 8. *Current over time LSC*

4. INVESTIGATION PROGRAM

The main topic of this work is comparing the different welding technologies mentioned above under consideration of different filler metals under „laboratory“ contitions on steel sheets. Additionally, two differnet filler metal types, solid and metal cored wires, are also considered. The results are afterwards proven on a real part, an exhaust manifold.

4.1 Laboratory welds on sheet metal

For the basic analysis it has been decided to weld sheets of different base metals in Position PG at declining 30°. Thereby, different gaps from zero up to the size of the sheet thickness were considered. The objective was always to reach the maximum welding speed under the condition of getting at least a penetration ratio of 20%. The materials and processes used can be seen in Table 1.

Table 1. *Materials and processes used*

Base materials	Solid wire (ø 1,0mm)	Metal cored wire (ø 1,2mm)	Process
304L thickness: 0,8; 1,2 mm	ER 307 Böhler A7-IG	EC 307 Böhler A7 – MC	Short arc, Pulse,CMT, PMC, LSC
309 thickness: 1,2 mm	ER 307 Böhler A7-IG	EC 307 Böhler A7 – MC	Short arc, Pulse,CMT, PMC, LSC
441 thickness: 1,2 mm	ER 439 Nb Böhler CAT 430 LCbTi-IG	EC 439 Nb Böhler CAT 430 LCbTi-MC	Short arc, Pulse,CMT, PMC, LSC

Out of table 1, more than 32 test series and 215 welded specimen have been done and evaluated regarding to the maximum reachable welding speed and gap bridging ability. On sheet metal type 304L, the gap bridging capabilities in respect to the achievable welding speed in laboratory welds were investigated. The results are shown in figure 9 for solid wire GMAW and in figure 10 for metal cored wire GMAW.

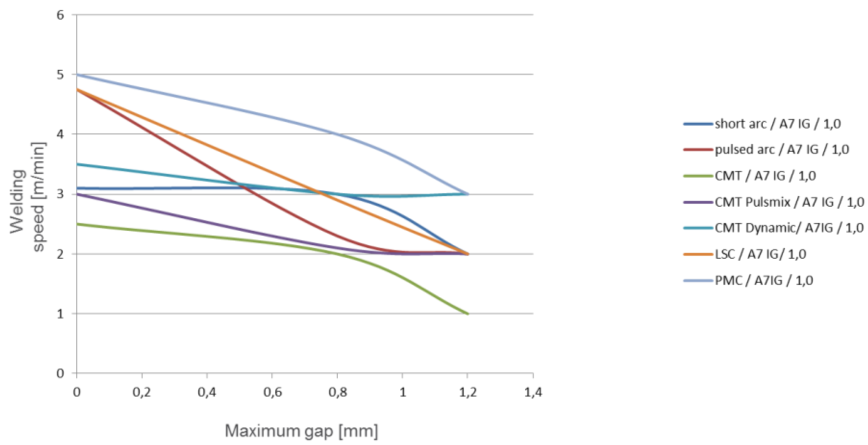

Figure 9. *Gap bridging ability with solid welding wire (A7-IG)*

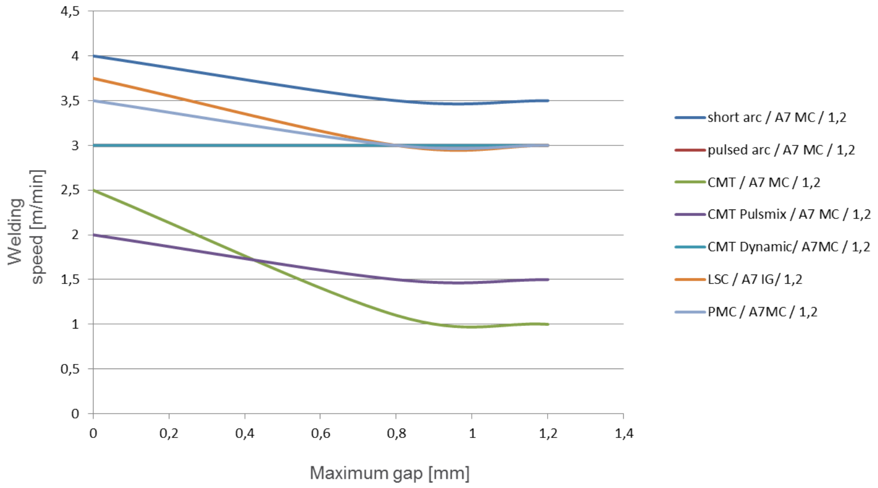

Figure 10. *Gap bridging ability with metal core wire (A7 – MC)*

4.2 Welding of exhaust manifolds

Driving idea behind all these analysis is creating concept, which can estimate the costs, including the invest, for producing welded parts for exhaust components out of simple tests on plain sheets. Depending on the production volume, the weld quality, geometry and the length of the seams the most economic solution (welding process and filler metal) should be found based only at very less welding trials.

Therefore, it has to be proven that the results achieved on plain sheets can be transferred to the real parts. The first component was a manifold as shown in figure 11. The base metal is type 441, in thickness of 0,8 – 3,2 mm.

Figure 11. *Exhaust manifold for evaluation*

As welding processes PMC, short arc and pulse arc were considered. The filler metals have been a solid wire type ER 439Nb (Böhler CAT 430LCbTi-IG) in diameter 1,0 mm and a metal cored wire type EC 439Nb (Böhler CAT 430LCbTi-MC) in diameter 1,2 mm. The investigation has shown, that for solid wire welding similar tendencies compared to sheet metal welding can be seen: Also for this part the PMC process seems to be the perfect process to use.

The overall welding time in comparison to pulsed arc can be reduced from 230 sec. down to 195 sec. for each part, which means a reduction of welding time by nearly almost 15%.

The conclusion we could find out of this ongoing work is achievable welding speeds reached on the "theoretical" analysis are in rather good correlation with comparable gap sizes.

Nevertheless, the seam length and geometries with tight joint radiuses have a great impact on the real achieved welding speeds. But this is also triggered by the used robot system.

5. CONCLUSION

Out of this work which is part of a very comprehensive internal research program, various conclusions could already be derived [1]:

- The sheet metal thickness has only a minor influence on the achievable welding speed in case of zero gap for solid wire and metal cored wire GMAW
- The clamping method has a strong influence on the achievable welding speed - the better the clamping, the less the gaps, the higher the welding speed
- Welding speed is only one part of the economic evaluation - the manipulation time of the part and the torch between welding play also an important rule
- Metal cored wire can improve gap bridging, welding speed and spatter ejection in case of standard processes
- New welding processes (CMT Dynamic, PMC, LSC) improve the gap briding ability significantly and higher welding speeds with very low spatter formation can be achieved

6. REFERENCES

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