IMPACT OF NOVEL ARC CONTROL MECHANISMS ON THE PROPERTIES OF GAS METAL ARC (GMA) TANDEM WELDING

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Abstract

Tandem welding has become a well-established joining process in high performance welding over the last two decades. It meets the demand for continuously increasing productivity in modern mechanized welding. The higher deposition rate can be transferred to either high welding speeds or large seam volumes. Tandem welding is superior in terms of gap bridging ability and undercut.

Lately the technological advancements made within the development of the TPS/i generation have been transferred to tandem welding, resulting in the all-new tandem welding system TPS/i TWIN Push. Apart from improvements concerning the connectivity and compactness of the system and it’s peripheral components the Pulse Mix Control (PMC) process variant was established for tandem welding as well as new process functions have been developed. Amongst them PulseSync allows the application specialist to independently choose for strongly differing wire feed speeds for both arcs with the system automatically applying the necessary corrections.

The article addresses a short classification of the TPS/i TWIN within high-performance two-wire welding. This is followed by an introduction to the functionality of PMC as well as to the new welding process functions, especially PulseSync. Results show the impact of these process features on welding speed and penetration on fillet and butt welds on thick plate mild steel.

1 A BRIEF OVERVIEW ON GAS METAL ARC TANDEM WELDING

1.1 Classification of high performance and two-wire welding

High performance gas metal arc welding (GMAW) is most commonly defined as a welding process exhibiting a wire feed speed > 15 m/min (for wire diameters of 1,2 mm) or a deposition rate of > 8 kg/h for wire diameters larger than 1,2 mm [1]. Within this range two-wire processes are used to reach a high deposition rate with less tendency for building undercut and spatter due to the enlarged melt pool and reduced arc intensity.

Two-wire processes are classified depending on whether one common or two separated potentials are applied to the wire:

- Double wire welding: both wires share the same electrical potential
- Tandem welding the wires are applied with independent potentials

Whereas the double wire concept is less complex it has limited application potential: In common standard droplet transfer mode the process is prone to instabilities due to the accidentally appearing droplet transfer is causing irregular blow-out effects between the two arcs. In pulse mode the pulse current appears at the same time for both arcs being disadvantages in a serious number of applications [2].

Considering pulse GMA tandem welding in the following, a further differentiation needs to be done since the arcs can either be synchronized or not.

1.2 Fronius TPS/i TWIN Push – a synchronized tandem welding process

Since the term “TWIN” is used frequently and differently within the welding community it needs to be clarified which process is meant.

The Systems TIME TWIN, CMT TWIN as well as the new TPS/I TWIN Push all provide tandem processes with two distinct potentials on each wire.

CMT TWIN is an unsynchronized yet stable and highly recommended process [3] combining two different processes e.g. pulse/CMT. TIME TWIN and its replacement TPS/i TWIN Push are both synchronized push systems that operate mostly in pulse/pulse mode. The letter are more affordable and offer higher deposition rates whereas the former is superior concerning process stability.

1.3 Benefits of tandem welding

As mentioned earlier crucial to tandem welding compared is that high deposition rates are present at a significantly lower energy density and with a significantly larger melt pool compared to single-wire welding. This affects the maximum reachable welding speed since the process is loss prone to formation of undercuts. Also it is possible to replace multi-layer seams in a single pass therefore saving welding time. Another benefit of the larger weld pool is the higher gap bridging ability allowing for savings in part preparation.

Pogreška! Izvor reference nije pronađen. shows a comparison of single-wire to tandem welding in case of fillet welds with a throat thickness of 8 mm. Welding speed is almost doubled from

35 to 60 cm/min when using a tandem process instead of a single-wire process. Additionally the energy input is reduced by 23 % to 20 kJ/cm.

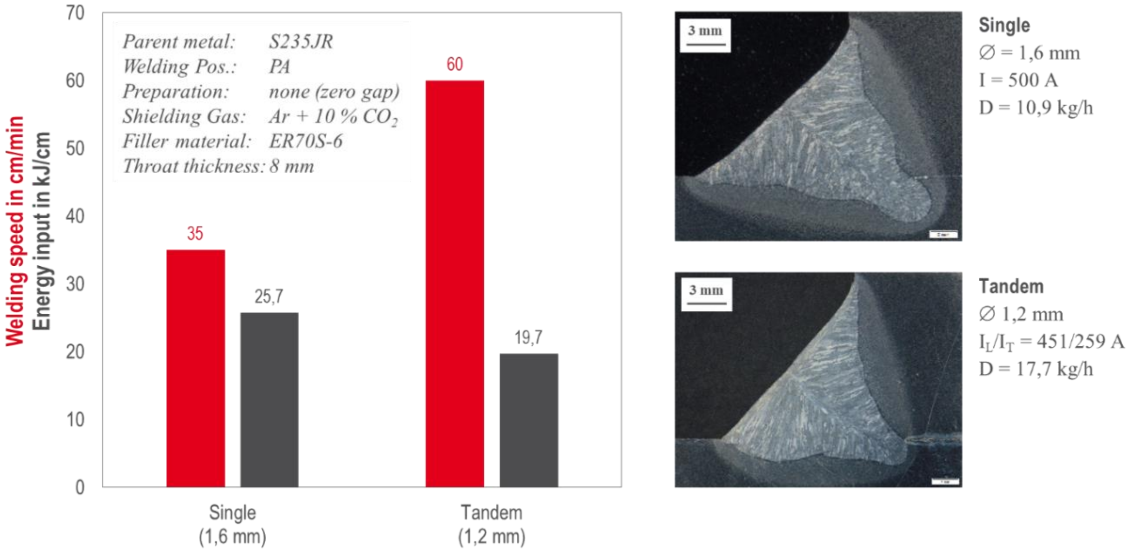


Figure 1. Comparing single wire with tandem welding on a fillet weld with a throat thickness of 8 mm. Both seams where welded with pulse GMAW using the process variant PMC. The tandem weld exhibits an increase of welding speed of almost a factor of two and at the same time reducing the heat input by 23 % (Note: Energy input is electrical energy, no arc efficiency is taken into account.).

2 EXPERIMENTAL SETUP AND WELDING PROCESS

2.1 Welding equipment

The welding tests where done using the TPS/i TWIN Push welding system employing the newly available modified pulse GMAW processes explained in more detail in the following sections.

Pogreška! Izvor reference nije pronađen. gives a brief overview of components: The TWIN Controller connects both power sources. It is responsible for the synchronization of both arcs, manages the flow of information and error handling between both process lines and acts as a single point of access for the integration into a robot system via common fieldbus protocols.

As a power source two TPS 600i where used each suppling up to 500 A at a duty-cycle of 100 %. All periphery parts (hose packs, torch and wire feeder) are designed to handle this total amount of 1 kA at 100 % duty-cycle. The compact two-in-one wire feeder is capable of feeding at a speed of up to 30 m/min at each process line. Tandem processes with total current of more than 800 A and a deposition rate above 20 kg/h are typical process parameters being used with this system. The used torches are water cooled and allow a fast change of the contact tip angle via changing wear parts.

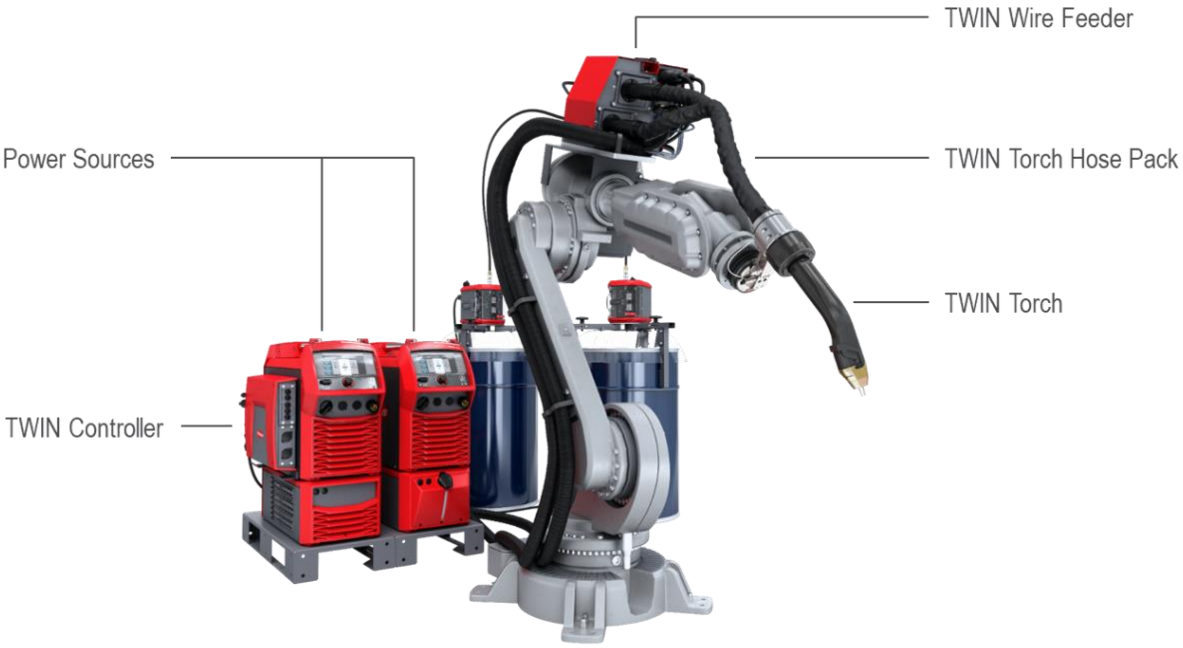


Figure 2. Rendering of the used TPS/i TWIN Push welding system.

2.2 Material and preparation

All tandem welding tests were done on mild steel (S235JR) using a 1,2 mm diameter wire of ER70S-6 as filler material.

Processes where either pulse/pulse or PMC/PMC with activated arc length stabilizer.

Fillet welds where done on T-joints of 8 mm thick plates in either PA or PB position with zero gap and without seam preparation in all cases.

Butt joints where welded in PA position using a Y-preparation with 1 mm bridge and zero gap on plates with a wall thickness of 10 and 15 mm. The preparation angle was around 50 ° depending on wall thickness and a copper backing was applied.

2.3 Employing Pulse Multi Control (PMC) for tandem welding

In the development of the new TPS/i TWIN system the process variant PMC was made available for synchronized tandem welding.

PMC is classified a modified pulse arc [4]. The droplet transition takes place during a controlled short-circuit phase (**Pogreška! Izvor reference nije pronađen.**). As a result the arc is more concentrated and shorter compared to conventional pulse GMAW. Due to this modified arc behavior the process is [5], [6]

- more efficient due to less radiation loss of the short arc,
- deeper penetration due to a more concentrated arc,
- reduced heat input due to a more concentrated arc,
- less prone to build undercuts.

Along with the PMC process variant also the functions arc length stabilizers and penetration stabilizer are made available for tandem welding. The penetration stabilizer function automatically corrects the wire feed speed if the distance between the torch and the work piece changes. In this way a constant penetration depth is reached. Using the arc length stabilizer the arc is always controlled to operate at the shortest possible arc length. Especially in tandem welding this value gives a more reliable base compared to e.g. the welding voltage.

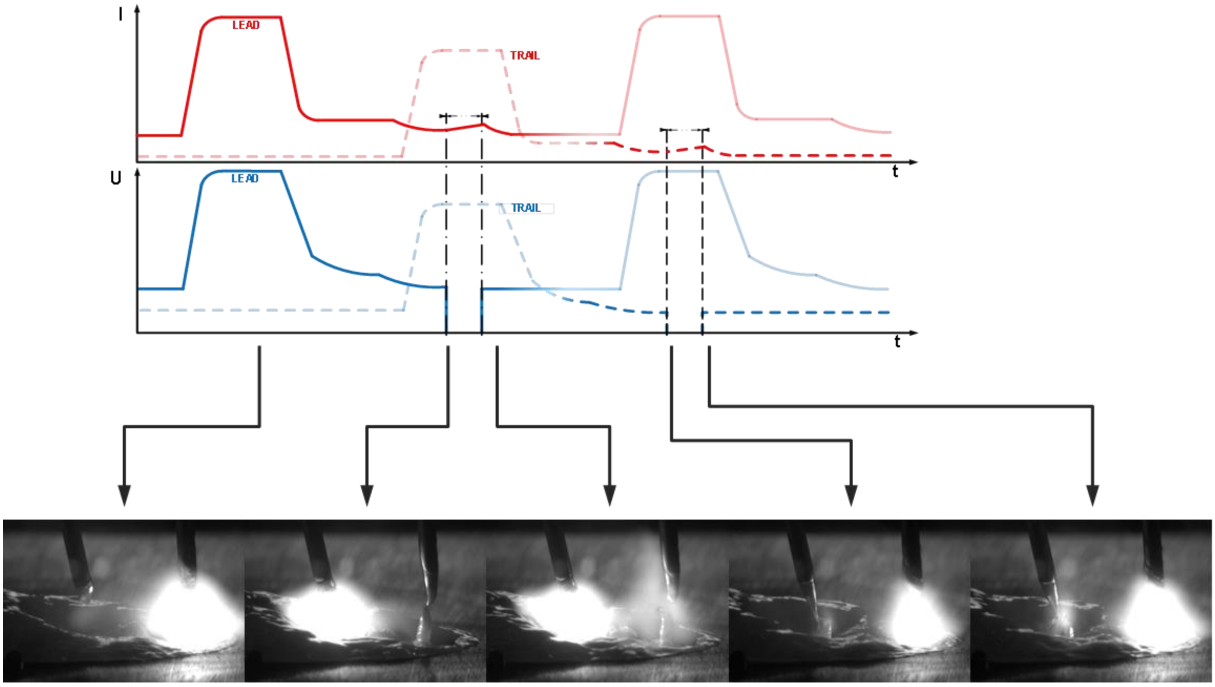


Figure 3. A sketch of the IV dynamics along high-speed camera images showing the principle of the PMC process variant. A short-circuit during the droplet transfers is the basis for this short and concentrated pulse arc with improved penetration depth, reduced spatter and reduced heat input.

2.4 New aspects of TPS/i TWIN Push

In addition to transferring the benefits of PMC welding to the tandem process, much effort has been put into optimizing the interaction between the two arcs. This lead to synergic TWIN lines and to three additional TWIN functions.

Within the concept of synergic TWIN lines two principally identical synergic lines are present on each process line, but different parameter corrections are already applied for the leading and trailing arc in order to optimize welding stability and account for the interaction between the arcs.

The additional functions SyncStart, PulseSync and PulseShift are pre-parameterized within the synergic TWIN line or can be parameterized individually by the application specialist:

- SyncStart optimizes the starting event of the leading to the trailing arc. It synchronizes the starting point of the trailing to the leading arc including a specific amount of delay. Additionally it changes start-parameters of the trailing arc in dependency of the actual situation given by the leading arc. In this way a contactless ignition of the trail arc is possible with clearly reduced spatter. As a result an improved welding start is achieved.
- PulseShift is a well-known function that can shift the pulse position of the trail relative to the leading pulse. This is used to find the optimum trade-off between magnetic blow-

out effects in alternating mode (phase-shift of 180 °) and tendency of spatter formation in common mode (phase-shift of 0).

- PulseSync enables the choice of strongly differing wire feed speeds. Depending on the difference in wire feed speed the power source automatically applies corrections to the welding parameters while keeping the two arcs synchronized. This function increases the process window, makes it easier to find the ideal welding parameters and enables deeper penetration depths at large wire feed speed spreading.

Pogreška! Izvor reference nije pronađen. illustrates the working principle of PulseSync at the example when the wire feed speed of the trailing process line v_w^T is gradually reduced while keeping the wire feed speed of the leading arc constant. The straight forward strategy to gradually reduce pulse frequency and welding current cannot be applied without losing synchronization. Hence, for small deviations in wire feed speed a stable droplet formation is maintained by applying corrections to some welding parameters while keeping the frequency of the trailing arc constant at $f_T = f_L$. This can only be done up to a specific point where a further reduction of power would lead to imperfect droplet formation. At this point the pulse frequency of the trail is abruptly reduced to match the half pulse frequency of the leading arc ($f_T = f_L/2$) including a switch to a parameter set that matches this lower pulse frequency. Again additional corrections are employed and are gradually reduced as the wire feed speed of the trailing arc decreases. Using this strategy the synchronization of both arcs can be maintained in all cases by sparing out every second pulse on the trailing power source. Finally, when wire feed speed of the trailing process line matches half the wire feed speed of the leading arc a parameter set is reached where $f_T = f_L/2$ and no further corrections are applied to the trailing arc. The same principle is repeated if the wire feed speed of the trailing process line is further reduced. The pulse frequency of the trailing arc is reduced abruptly to $f_T = f_L/3$ where trail pulses only appear at every third lead pulse.

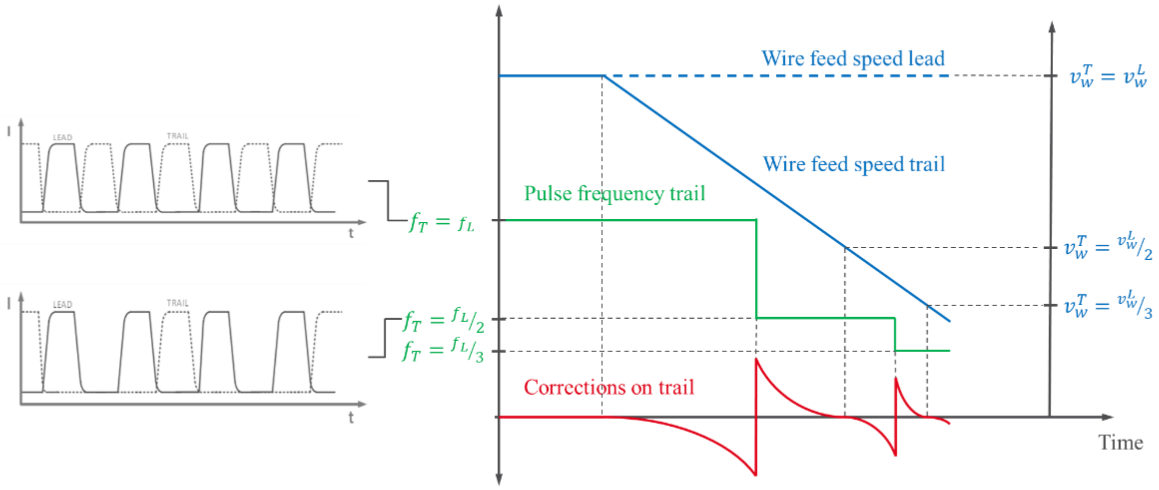


Figure 4. The graph illustrates the principle of the PulseSync function. In this example the wire feed speed of the leading process line v_w^L *is kept constant while gradually reducing the wire feed speed of the trailing arc*v_w^T*. For small deviations in wire feed speed corrections on the welding parameters are applied to compensate for the smaller amount of wire to be melt. At a certain point the corrections reach their maximum and the pulse frequency of the trail is reduced to* $f_t = f_L/2$*. In this way the synchronization of both arcs is always maintained.*

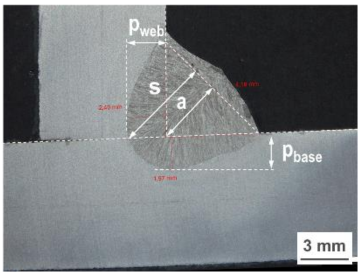
3 RESULTS

3.1 Increasing welding speed for fillet welds

Since the increase in welding speed and penetration depths is a result of several effects it is reasonable to separate these effects in experiments. In order to separate the influence of the short-circuited pulse arc of PMC from the influence of the wire feed spreading and the contact tip angle. By changing the contact tip angle the distance between both wires is changed. Choosing a small contact tip angle brings the wires further apart and reduces disturbances. Following welding tests were carried out:

1. Fillet welds on mild steel have been carried out using TPS (pulse/pulse) and TPS/i technology (PMC/PMC). Both welds where carried out to
   a) meet the same throat thickness of 4 mm
   b) using the same contact tip angle of 11,5 ° for both systems and
   c) with negligible wire feed spreading of $v_W^T/v_W^L > 90$ %
2. The welding performance was further optimized by
   a) changing contact tip angles
   b) increasing wire feed spreading

These tests were carried out in PB position with 1,2 mm diameter filler wire and M21 shielding gas (Ar + 18 % CO_2). The weld seams where analyzed in terms of throat thickness and penetration depth according to **Pogreška! Izvor reference nije pronađen.**. For the sake of simplicity the nominal throat thickness will simply be referred to as throat thickness.



a	nominal throat thickness
s	deep penetration throat thickness
p_{web}	web plate penetration depth
p_{base}	base plate penetration depth

Figure 5. Definition of throat thicknesses and penetration depths.

Pogreška! Izvor reference nije pronađen. shows the result of the direct comparison between pulse/pulse and PMC/PMC carried out in step 1. A significant increase of 23 % in welding speed as well as an increase in web plate penetration depth of 34 % was achieved.

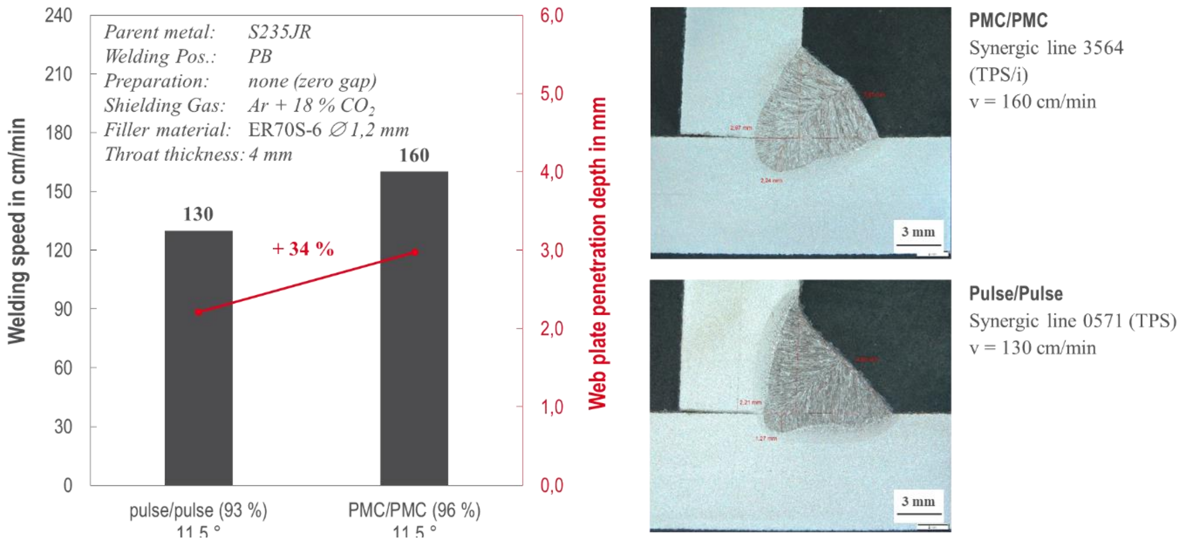


Figure 6. Comparing the pulse/pulse process available on the TIME TWIN system (TPS) with the new PMC/PMC Process available in the TPS/i TWIN Push system: Welding speed and penetration depth are raised.

Further improvements lead to a maximum welding speed at a wire feed speed spreading of $v_W^T / v_W^L = 60$ % and a contact angle of 8 °. As shown in **Pogreška! Izvor reference nije pronađen.** a welding speed of 180 cm/min reached. The further increase in welding speed could only be reached by increasing wire feed spreading and enlarging the distance between the wires. The seam shows a throat thickness of 4,2 mm with a web plate penetration depth of 2,4 mm. The electrical energy input was 7,7 kJ/cm at a deposition rate of 19 kg/h.

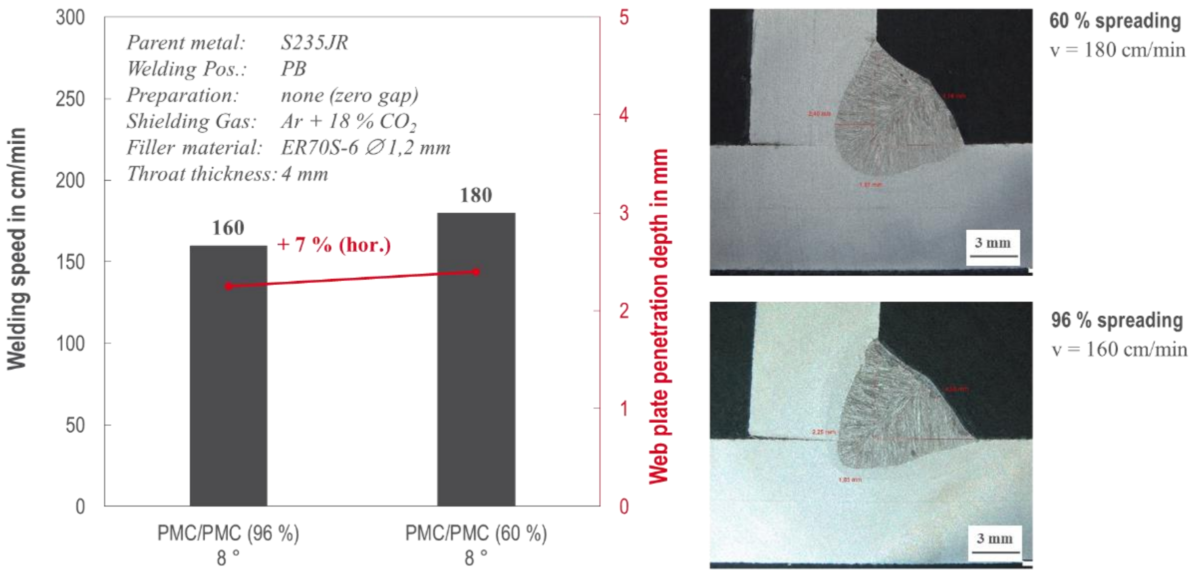


Figure 7. Further improvements in welding speed where reached by increasing wire feed spreading. Note that additionally the contact tip angle had to be changed to reach the maximum welding speed of 180 cm/min.

3.2 Welding speed versus throat thickness for PMC/PMC fillet welds

Welding tests were carried out in order show the maximum reachable welding speed for different throat thicknesses. These comparisons were carried out in PA position with M20 shielding gas (Ar + 10 % CO_2). For throat thicknesses between 4 and 9 mm the maximum achievable welding speed ranged between 180 and 42 cm/min (**Pogreška! Izvor reference nije pronađen.**). The according energy input increased from 6,6 to 21 kJ/cm and deposition rate ranged from 22 to 16 kg/h.

To maintain a deep penetration the wire feed speed of the trail was decreased relative to the lead from 75 to 41 %. In this way deep penetration throat thickness was kept roughly a factor 1,4 larger then nominal throat thickness (**Pogreška! Izvor reference nije pronađen.**).

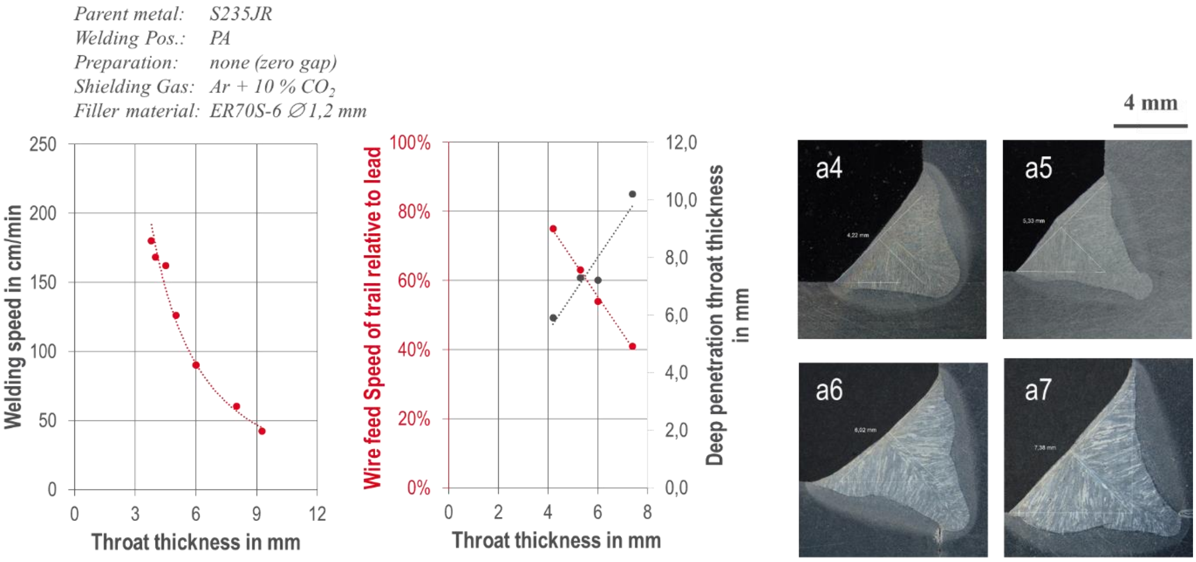
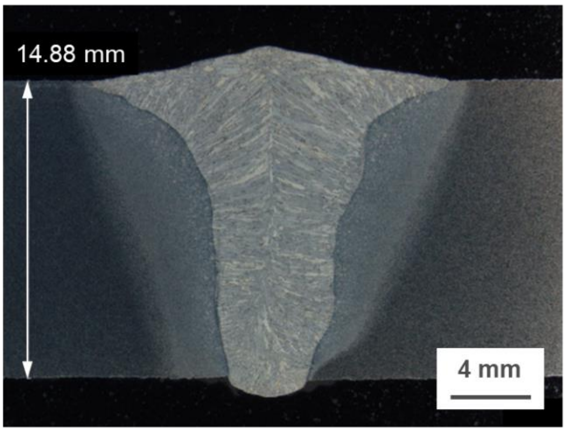


Figure 8. Maximum achievable welding speed for fillet welds welded in PA position with PMC/PMC. The wire feed speed spreading is continuously decreased to maintain a deep penetration.

3.3 Single-pass welding of butt-joints

On butt joints with a wall thickness above 8 mm usually multi-pass welds are employed with tandem welding. Due to the deeper penetration caused by PMC and wire feed speed spreading also joints with wall thicknesses of 10 mm or more can be done within a single-pass for mild steel.

To show the capability 15 mm thick plates of mild steel welded at a welding speed of 60 cm/min (**Pogreška! Izvor reference nije pronađen.**). For this the wire feed speed spreading was further increased to $v_W^T/v_W^L = 50\,\%$. Deposition rate was 20 kg/h and with an electrical energy input of 24 kJ/cm. The material was prepared with an opening angle of ± 25° and 2 mm bridge. It was welded with zero gap and a copper backing.



TPS/i TWIN Push
PMC/PMC
Single-pass
50 % v_W spreading
v = 60 cm/min

Parent metal:	*S235JR*
Welding Pos.:	*PA*
Preparation:	*Y with ± 25 ° and 2 mm bridge (zero gap)*
Shielding Gas:	*Ar + 10 % CO_2*
Filler material:	ER70S-6 *∅1,2 mm*
Wall thickness:	*15 mm*

Figure 9. Butt joint of 15 mm thick mild steel plates welded with PMC/PMC TWIN Push in single-pass at a welding speed of 60 cm/min using a wire feed speed spreading of $v_W^T/v_W^L = 50\,\%$.

4 SUMMARY

We compared welding speed and penetration depth for T-joints and butt-joints on mild steel welded with either conventional pulse/pulse tandem process or the new PMC/PMC tandem process. The main content of the presented comparisons is:

- Welding speed and penetration depth can be significantly increased by applying the new PMC/PMC tandem process available with TPS/i TWIN Push. Welding speed was increased from 130 to 160 cm/min on mild steel fillet-welds with 4 mm throat thickness. Web plate penetration depth was increased from 2,2 to 3,0 mm.
- The influence of different electrode distances in tandem welding and the well-known advantages of spreading the two wire feed speeds are demonstrated in welding a4 fillet-welds and a single pass butt-weld of 15mm. The required spreading can be applied over the entire pulse/pulse process window as process frequencies are automatically changed from 1:1 to 1:2 or 1:3 within the new synergic TWIN lines without losing synchronization.

With latest power source technology both arcs are controlled and synchronization is maintained from ignition till weld end - despite parameter changes or disturbances. This enlarges the process window for tandem welding and offers new strategies for optimizing weld seam properties.

5 REFERENCES

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