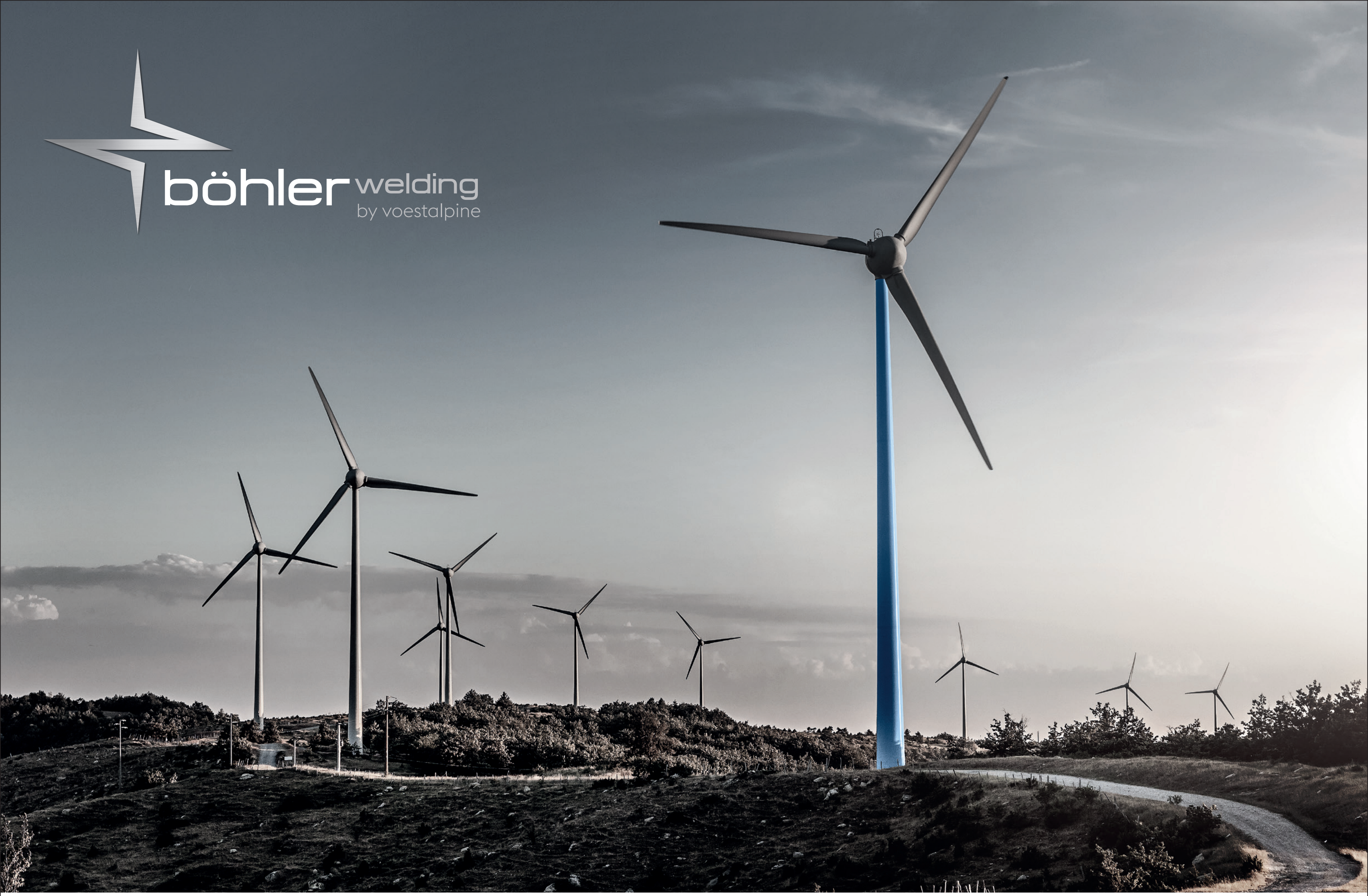


FOUR SUCCESS FACTORS FOR A RELIABLE WELDING PROCESS IN THE MANUFACTURING OF WIND TOWERS AND FOUNDATIONS

BY ERWIN GERING, GLOBAL KEY ACCOUNT MANAGER WIND ENERGY, PIPEMILLS AND STEEL CONSTRUCTION

To create a total solution for the three related problems of energy security, climate change, and affordability the key lies clearly within **power generation from renewables**. To achieve the net-zero emission targets by 2050, **wind energy** will and shall bring a major contribution. Strong growth in wind power capacity will require **large-scale manufacturing** of wind towers and foundations, where **standardization** and **automated welding** is key.

The most applied welding activities concern the circumferential and longitudinal welding of the large diameter sections for towers and in the components for the offshore foundations, like monopolies jackets and pin piles. These welding joints are mostly welded with the **Submerged Arc Welding process** (SAW).

For these welding procedures, it is imperative to have a **highly performing welding flux and wire** with constant product quality. voestalpine Böhler Welding is continuously **optimizing welding consumables** for the different applications in wind energy to fulfill new challenges due to **increased dimensions, weights, and thicknesses,** and the growing application of **steel grades with higher strength**.

GENERAL REQUIREMENTS FOR THE WELDING PROCESS IN WIND ENERGY:

1. Minimal welding defects
2. Stable and high level of mechanical properties of the weld
3. Minimal welding time (arc time) per component
4. Minimal down time (product handling, preheating)

1. MINIMAL WELDING DEFECTS

For serial manufacturing of these large components, it is essential to have a constant predictable throughput. The occurrence of welding defects that need to be repaired (before the next production step) shall be limited to the minimum.

Possible weld defects are:

» Slag inclusions
» Gas inclusions/porosity
» Lack of fusion
» Poor bead aspect
» Gas prints on the weld surface
» Solidification cracks
» Hydrogen induced cracks

In general, the majority of weld defects are **related to factors like:**

» Parameter settings
» Manipulation, wire positioning, seam tracking
» Weld preparation (geometry, pollution)
» Flux characteristics and properties (quality)
» Equipment (imperfections, defects), etc.

Often we intend to identify one single aspect as the root cause for a certain problem/weld defect. A more holistic approach is recommended due to the **interaction of all above mentioned factors**.

When we limit our focus toward the influence of welding flux, it is clear that the operative characteristics of the SAW flux are of great importance to minimize welding defects.

Depending on the required mechanical properties it might be needed to select a Fluoride-basic flux with high basicity index for high toughness in the weld metal. An Aluminate-basic flux (lower basicity) could be preferred (in general) for its nicer welding characteristics, however, might not bring the required toughness level. Both flux types are designed to compromise different requirements.

The flux characteristics are depending on the exact formulation and selection of raw materials and the flux manufacturing process.

Relevant flux characteristics to minimize weld defects are:

» Good arc stability
» Nice wetting and bead aspect
» Nice bead appearance
» Good slag release (no slag residuals)
» Proper grain size distribution (small and large grains)
» Grain shape and grain strength. During welding operation, not all flux is molten (slag). There is a large part of not molten flux that can be re-used. Important is to avoid too much mechanic load (abrasion) on the flux during the flux feeding and recycling since the flux is relatively soft and sensitive to being damaged (dust forming). When flux is damaged during flux feeding or recycling the grain size distribution is changed; different grain size distribution can change the operative characteristics of the flux (wetting, bead appearance, gas prints). To ensure a constant grain size distribution during recycling it is important to have :
  » A good grain shape and good grain strength (abrasion resistance) for minimal dust forming during flux recycling.
  » A constant ratio in mixing recycled flux with fresh flux on which the welding parameters might be adjusted

» Dry flux to avoid moisture-related issues (gas inclusions, gas prints, hydrogen cracks)
» A low(est) level of diffusible hydrogen is essential to reduce the risk of hydrogen-induced cracks. Fluxes with a higher level of diffusible hydrogen normally will require higher preheat temperature, especially in case of base metals with higher C-equivalents (flanges and higher strength grades S420/S460). Robust moisture-proof flux packaging (aluminum composite foil) is key to ensuring low hydrogen levels without prior re-drying of the SAW flux.

2. STABLE AND HIGH LEVEL OF MECHANICAL PROPERTIES OF THE WELD

Mechanical properties of the weld metal are depending of

» Welding wire (chemical composition) and chemical activity of the flux
» Base metal composition and dilution rate with the base metal
» Welding parameters, current type, interpass temperature, and wall thickness
» Weld bead thickness, grain refining (multipass or monopass)

Clearly, the SAW wire-flux combination has a major influence on the mechanical properties of the weld metal. Following wire-flux combinations have been optimized for different requirements:

SAW wire name	Flux name	Flux type BI	Min YS (Mpa)	Min TS (Mpa)	CVN M-Run	CVN 2-Run	Main application Steel grade	Classification EN ISO AWS
Union S 2 Si	UV 408 TT	AB 1,7	420 Mpa 58 ksi	500 Mpa 70 ksi	70 J @ -50°C 52 ft.lb@-60°F	-30/ -50°C -20/ -60°F	Multi- /2 run Onshore, **S355-S420**	S 42 5 AB S2Si H5 F7A8-EM12K-H4
Union S 3 Si	UV 418 TT	**FB 2,7**	**460 Mpa 67 ksi**	**530 Mpa 77 ksi**	**> 100 J @ -60°C > 75 ft.lb@-80°F**	-30/ -50°C -20/ -60°F	Esp. multi-run **Offshore, S355-S460**	S **46 6** AB **S3Si** H5 F7A8-**EH12K**-H4
diamondspark S 55 HP	UV 418 TT	**FB 2,7**	**460 Mpa 67 ksi**	**530 Mpa 77 ksi**	**> 100 J @ -60°C > 75 ft.lb@-80°F**	-30/ -50°C -20/ -60°F	Esp. multi-run **High deposit rate**	S **46 6** FB **T3 H5** F7A8-EC1
diamondspark S 56 HP	UV 400	AB 1,9	**460 Mpa 67 ksi**	**530 Mpa 77 ksi**	**> 80 J @ -60°C > 60 ft.lb@-80°F**	**-50/ -60°C -60/ -80°F**	2 run / multi-run **High deposit rate**	S **46 6** FB **TZ3 H5** F7A8-ECG

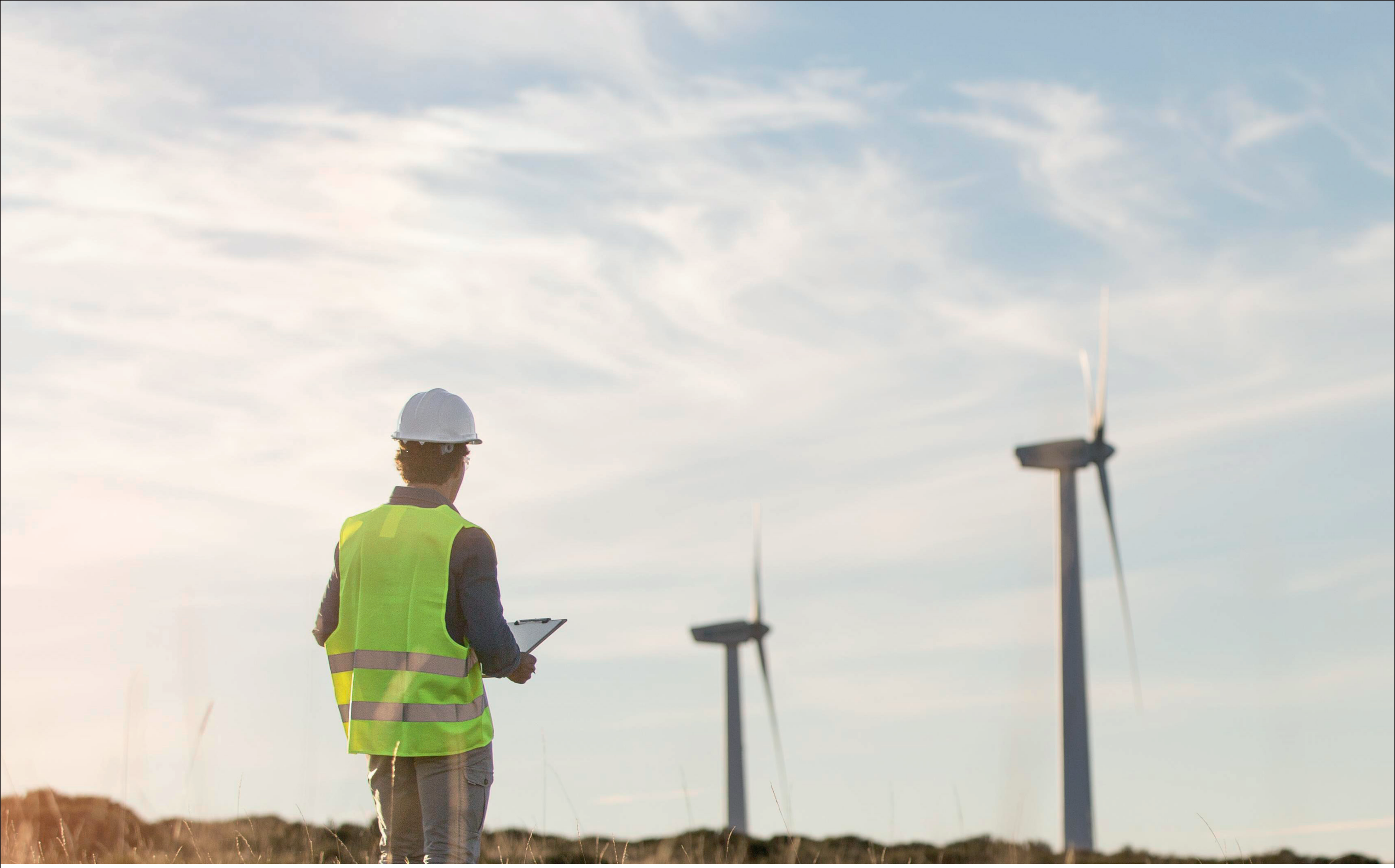
For onshore wind towers, mostly mild steel grades are applied with a minimum specified yield strength of 355 MPa. Some parts of the wind tower might be constructed with a **higher strength level** (e.g. S420 grade). Charpy-V toughness requirements are varying from 27-50 Joules at test temperatures between 0 and -51°C.

In general, there is a **preference to use only one flux and wire type** in a welding shop for wind towers for all projects with different requirements. This is not only for logistical reasons but also to exclude mixing-up (improper weld metal properties). Union S 2 Si – UV 408 TT has been developed specifically for onshore wind towers to cover this wide application range.

For offshore wind towers and foundations, the manufacturing requirements are on a higher level. Base metals vary from S355-S460 and Charpy toughness requirements vary from 27-50 J at -40°-60°C, however, the industry is normally demanding **wire-flux combinations that provide Charpy-V toughness levels > 100J @-60°C**. For this toughness level, a Fluoride-basic flux with a relatively high basicity index is frequently used (mostly with a neutral chemical activity concerning Mn and Si). To ensure also the higher strength level the combined SAW wire has the higher alloyed S3Si-composition.

Union S 3 Si – UV 418 TT has been optimized for these offshore requirements. A very **low level of diffusible hydrogen** for these (higher) strength levels (and higher CE-equivalent) in large components with high wall thickness is very important to avoid cold cracking issues. Fluxes with a higher level of diffusible hydrogen normally will require a higher preheat temperature.

The latest improvements of UV 418 TT has resulted in a very low level of diffusible hydrogen for DCEP and for AC polarity (sinus- and square wave shape).



3. MINIMAL WELDING TIME (ARC TIME) PER COMPONENT

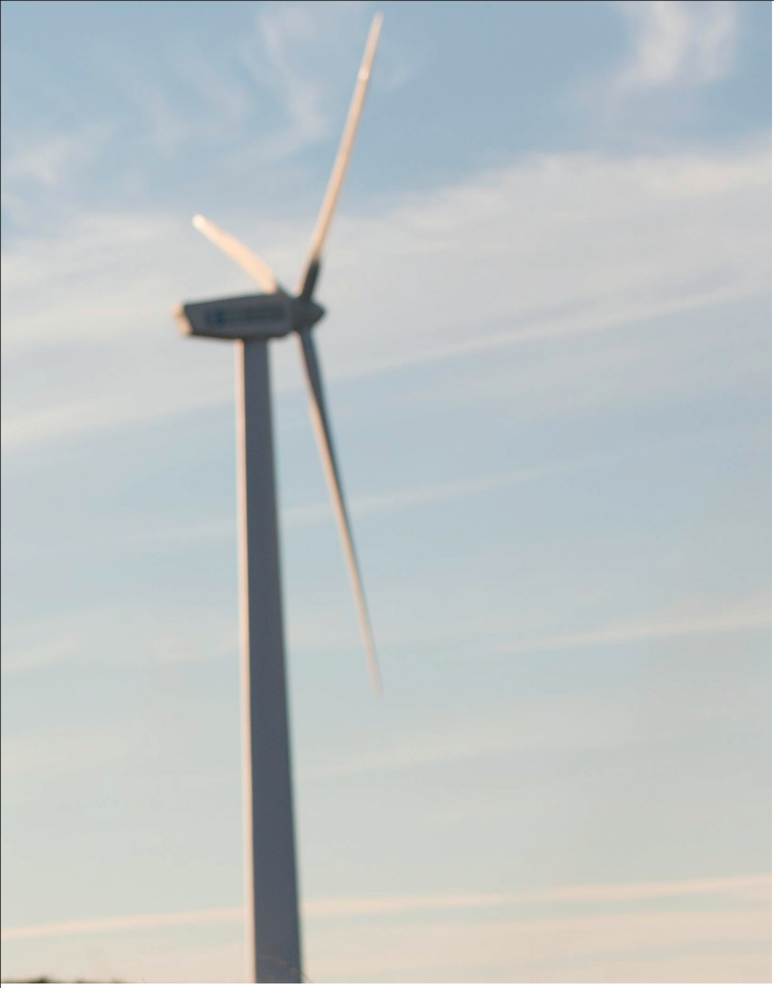
Tact time, the time between starting units, is a critical number because it decides the total output of a production line. Depending on the situation it might happen that a SAW welding station could be decisive for the tact time (bottleneck). Every subdivided action/element inside the welding station might be evaluated to create a reliable time-saving. Welding time (**arc time**) is one of them. Additionally, the increasing dimensions (diameter, length, and wall thickness) of the components will have an increasing effect on :

» the number of cans/circumferential welds
» the number of longitudinal welds (and maybe 2 or 3 longitudinal welds per can),
» the weld lengths (especially circumferential)
» the total weld volume
» the total arc time

A very efficient solution could be to complete **several SAW weld seams in parallel/simultaneously**. Another possibility might be to **reduce the weld volume.** Attention must be paid to avoiding too narrow weld preparations that would increase the failure rate (weld defects). A good example of an efficient "narrow gap" weld preparation for SAW process would be 7-8° bevel angles with a radius of 7-8 mm.
Such a weld preparation can be made by dedicated machining equipment. An alternative to reduce arc time could be applied by **increasing the deposition rate**. Welding procedures with very large bead cross-sections are more sensitive to different penetration profiles/less penetration/lack of fusion. To avoid too large weld beads it might be necessary to **increase also the welding speed**, this should not result in a poor weld bead appearance/aspect. Increasing the **welding speed is depending on:**

» actual process variant and actual deposition rate and welding speed
» weld preparation geometry and consistency
» operative characteristics of the wire - flux combination
» capabilities of the equipment (roller bed/ seam tracking)
» operator's acceptance

In multi-run applications, the underlying runs are partly refined by the subsequent run(s). With large weld bead cross sections, the share of reheated area decreases and this might have a negative effect on the mechanical properties (also depending on the exact chemistry of the weld metal and the cooling rate (t8/5)).
UV 418 TT has been optimized to reduce the scattering in Charpy-V toughness properties in welds with large bead cross-sections. Also the composition of the **seamless SAW wire diamondspark S 56 HP** has been optimized to ensure very high toughness in large weld beads, including single-pass welds and two-run procedures.



An increase in the deposition rate is possible by :

- increase current
- larger diameter SAW wire will give only a higher deposition rate when also the welding current is significantly increased. At the same current the wire with a smaller diameter will have a higher deposition rate.
- Increase the number of SAW wires in the weld pool (each with its own power source). Tandem, Triple, of 4 wires. Lead wire often DCEP, other wires AC current to reduce magnetic interference. The advantage of AC is ~15% higher deposition rate vs DCEP.
- Twin-arc: 2 relatively thin SAW wires are close to each other and are fed by 1 power source, and 1 contact tip (2 holes). TWIN-arc with 2 wires with a diameter of 2,4 mm will result in a similar deposition rate curve of a single 3,2 mm wire, however, due to the double arc, it is possible to increase the current further up with still good operative performance. With 1 single wire 3,2 mm the weld bead appearance/aspect would become unacceptable at the same (high) current level.
- Special process variants :
  - Additional cold wire
  - Metal powder addition
  - Increased stick-out length
  - AC current (sinus)
  - AC current (square wave; increased negative polarity effect)

These variants have in common to create a higher ratio of deposited weld metal per kW power (V x I). The disadvantage is that these listed variants

- require investment in special equipment
- generate increased complexity

An alternative without investment in equipment is applying seamless SAW wire **diamondspark S 56 HP**. At same current the wire provides automatically an **increased deposition rate (+20% - 35%)** compared with a solid SAW wire with same diameter. Additional advantage is that the better operational characteristics and better bead aspect allow to increase the welding current (=additional increase of deposition rate). Depending on the applied welding procedure it is often possible **to safe 40% in welding arc time**.

4. MINIMAL DOWNTIME (PRODUCT HANDLING, PREHEATING)

Good operative characteristics with nice wetting and slag release will certainly help to weld without unscheduled process interruptions. And also optimized packaging formats, for example: Bulk packaging formats for SAW welding wire up to 1000 kg / 2200 lbs weightresults in **minimum downtime for exchanging**.

For flux, we apply **DRY SYSTEM**, which means that the flux is protected against moisture pick up during transportation and storage. This is done by sealed aluminum composite foil or aluminum liner. The DRY SYSTEM makes it possible that the flux can be used for most applications without prior re-baking (350°C x 2-4 hrs). Besides the standard 25 kg bags, we also provide big bags with 500 or 1000 kg with DRY SYSTEM.

Properly controlled welding flux is also required to **minimize the hydrogen level in the weld metal.**
An increased level of diffusible hydrogen might require a higher preheat and minimum interpass temperature, especially in case of base metals with higher C-equivalents (flanges and higher strength grades S420/S460).
A higher preheat temperature results in higher energy cost and takes more time to bring the large components on temperature.

Reliable supply and high quality and performance level of welding consumables is key, as well as technical support with our know-how.

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Working within voestalpine Böhler Welding for 13 years. My job title is "Global Key Account Manager Wind Energy, Pipemills and Steel Construction" with focus on the "Submerged Arc Welding Process", previously I was active as "Global Product Manager for SAW Wire and Flux" , which is a great advantage in the technical support to our customers

My job is focused to understand the needs of our customers in wind energy, especially concerning the SAW welding process for the manufacturing of wind towers onshore and offshore, as well as the offshore foundations. From a good understanding we can develop optimized welding solutions and support the manufacturers towards highly efficient welding processes.