The alform welding system

the world's first system for high-strength welded structures

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This paper, delivered at the 2015 IIW International Conference in Helsinki, Finland last year, describes the alform® welding system, a new approach to base material and welding consumable development that aims to optimise the combination for fabricated structures in high-strength and ultra-high-strength material grades. Customer-focused advantages are listed and examples of successfully implemented alform® welding systems are illustrated.

Filler metals and base materials are usually developed separately and offered independently from each other. Base material producer, voestalpine Stahl and welding consumable producer, voestalpine Böhler Welding, have now adopted a different approach. Within a group project, the two companies have developed an entire series of base-material/filler-metal combination for high-strength and ultra-high-strength weld joints with yield strengths ranging between 700 and 1 100 MPa.

This series is being marketed as the alform® welding system. The essential advantages of this fine-tuned solution are the extended welding range for high-strength and ultra-high-strength weld joints as well as lower cold-cracking sensitivity in weld seams and optimised seam properties. The filler metals supplied in the system include stick electrodes, solid wires, metal-cored wires and submerged arc wire/flux combinations. Special emphasis during the development is placed on well-adjusted microstructure while taking into account the dilution of the base material and the resulting property profiles.

The alform® welding system

The selection of a proper combination of filler metals and base materials is usually done by the customer, who, therefore, carries the risk that the combination may not meet the specified and required properties for the application. Sub-optimum weld seam properties often result. (Figure 1).

Figure 1: Conventional weld design. Filler metals and base materials are usually developed separately and offered independently from each other.

This situation is rooted in the different development objectives and design limitations of base material and filler metal manufacturers.

The manufacturer of the base material is bound by normative specifications and the production equipment (Figure 2). This results in varying production routes, especially in the high-strength range of steel grades, such as QT, DIC, DIC+A, etc, which influence weldability to a substantial degree. Characterisation of the weldability of the base materials primarily focuses on the properties in the heat-affected zone (HAZ) and the achievement of properties similar to the required specifications of the base material. Evaluation of the hardening and softening behaviour and the toughness properties is of primary importance (Figure 3). At voestalpine, these evaluations are achieved via welding experiments at the processing centre and by conducting of welding-procedure qualification tests. The filler metals used are usually standard types that often yield sub-optimum property profiles of the weld seam due to dilution with the base material.

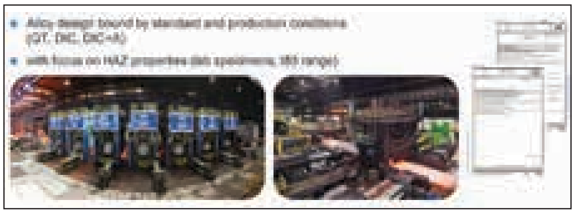

Figure 2: Restrictions in alloy design of the base material manufacturer are bound by production routes, such as QT, DIC, DIC+A, etc.

Figure 3: Characterisation of the base material weldability primarily focuses on the properties in the heat-affected zone (HAZ) – cold-cracking resistance, hardening, softening and toughness.

As mentioned above, material grades originated by various production routes are characterised by different welding behaviours. Examples of cold-cracking sensitivity in several steel grades available on the market with yield strengths between 700 and 1 100 MPa are shown in Figure 4. Special attention is drawn to the low carbon content of voestalpine steel grades alform 700 through to alform 960 x-treme. The carbon content of conventional quenched and tempered steels is generally much higher.

According to a classification by Graville, lower carbon content leads to lower sensitivity to cold cracking. Higher resistance to cold cracking in steel grades with low carbon content is achieved through reduced HAZ hardening, as shown in Figure 5. In comparison to traditional quenched materials, high-strength steel grades made by voestalpine do not show

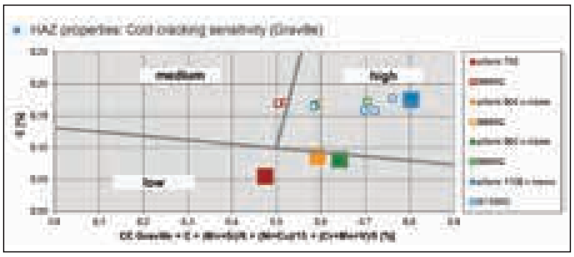

Figure 4: Sensitivity to cold cracking during welding of steels as a function of carbon content and carbon equivalent (Graville [4]).

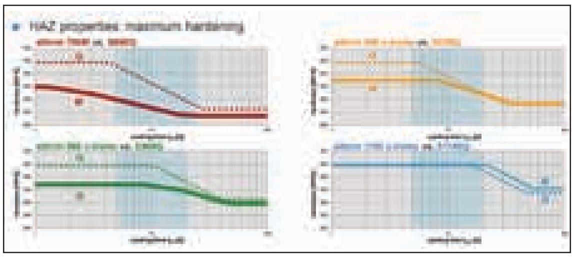

Figure 5: Maximum hardness in the coarse grain HAZ of single pass welded joints.

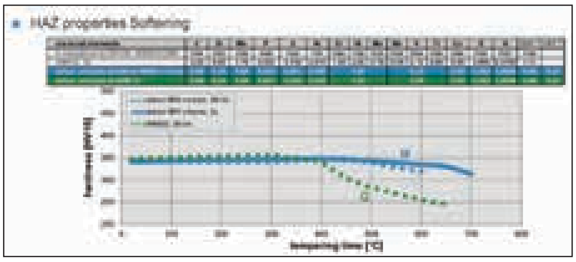

Figure 6: Softening in the tempering zone of HAZ (SCHAZ) of ultra-high-strength base material steels produced using different methods.

any significant temper softening (see Figure 6) in the HAZ. These steel grades are an optimum compromise between the QT and DIC base material production routes [2],[3].

The welding range (in terms of the cooling time between the 800 and 500 °C temperature window, $t_{8/5}$) is limited by applying the results obtained from the thermal welding simulator and the property profiles of the real weld seams created during welding procedure qualification tests. This guarantees that the mechanical/technological properties of the joints meet the specified values of the base material (Figure 7).

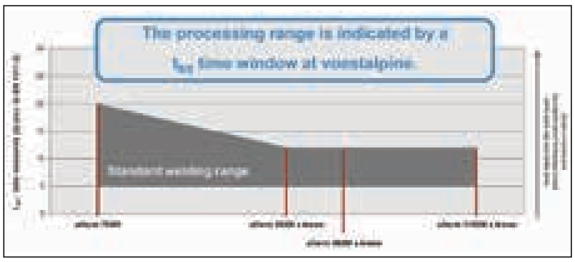

Figure 7: The $t_{8/5}$/heat-input range when welding using standard welding consumables of 'similar' composition.

In many cases the properties are limited by the standard filler materials used rather than the base material itself. This fact can be explained by the development objectives of the filler-metal manufacturers. Filler metals are classified in accordance with standards (such as EN 12534 and EN ISO 18276) that specify guaranteed values (chemical composition, mechani-

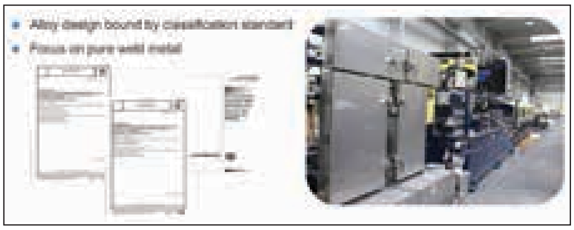

Figure 8: Restrictions in alloy design by filler material manufacturer relate to the standards, which are solely based on the pure and undiluted weld metal for a single welding parameter combination.

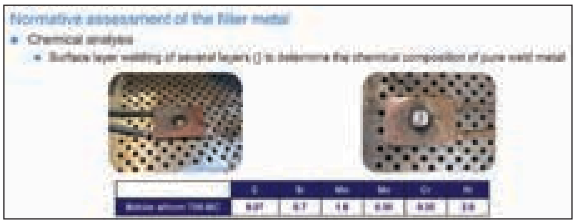

Figure 9: Normative requirement for determining the chemical composition of welding consumables.

Figure 10: Normative specification for determining the mechanical properties of the weld metal.

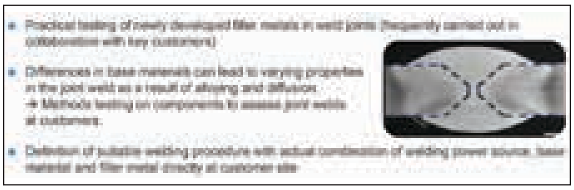

Figure 11: Diluted weld-metal in real welds.

Figure 12: Some of the problems experienced by fabricators in the design of welding procedure qualification tests.

cal/technological properties), which are solely based on the pure and undiluted weld metal for a single welding parameter combination (only one $t_{8/5}$ time) (Figures 8 to 10). A $t_{8/5}$ window is usually not taken into account. Properties of the diluted weld metal within practical joints, however, cannot be determined from these results (Figure 11).

Therefore customers are faced with the following scenario (Figure 12). Differently designed steels and filler metals are employed that do not share the same property profiles and this results in varying properties in weld seams.

As mentioned above, properties of the weld metal cannot be estimated because of dilution between the filler metal and the base material. The extent of dilution depends heavily on


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the shape of the bead and the joint build-up sequence for the seam. These in turn are determined by welding parameter selection.

Consequentially, the properties of joint weld metal for specific welding parameters must often be directly tested via extensive welding procedure qualification tests by the customer. Determination of a suitable welding procedure, along with the respective combination of welding current source, base material and filler metal, results in significant additional expenses.

The selection of optimised welding parameters is always challenging because prescribed $t_{8/5}$ cooling times can only be regarded as reference values for heat input and can be achieved using a variety of different parameter combinations. In designing weld seams, the bead shape and layer sequence must be taken into account along with the $t_{8/5}$ time because all of these factors determine welding properties. The approximate $t_{8/5}$ cooling time can be calculated according to EN 1011-2 or measured with thermocouples.

The calculated $t_{8/5}$ cooling time according to EN 1011-2, however, is also only a reference value because of the large number of variables that cannot be conclusively determined (Figure 13).

In addition, experience has shown that converting prescribed $t_{8/5}$ times into welding parameters is problematic because the displays on welding machines merely indicate mean values, which in the case of the short or pulsed current arc are too low (by 30 to 60%) when compared with the effective values at the torch.

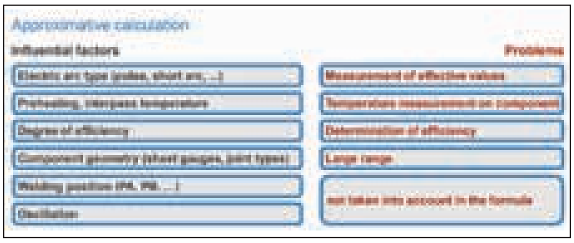


Figure 13: Sources of error in the calculation of the cooling time $t_{8/5}$ according to EN 1011-2.

The interpass temperature also has a substantial influence on the seam properties in thin-walled weld joints with two-dimensional heat flow. According to Figure 14, for example, an increase in the interpass temperature from 20 °C to 100 °C would lead to an inadmissible prolongation of the $t_{8/5}$ cooling time by 50% (from 20 seconds to 30 seconds). The loss in weld seam strength caused by these conditions can only be avoided by reducing heat input.

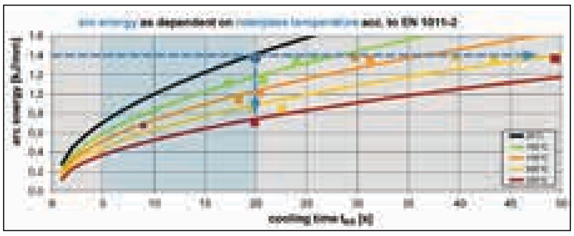


Figure 14: The influence of the interpass-temperature on the $t_{8/5}$ cooling time.

Welding-position-dependent oscillations, which cannot be taken into account by the calculation, have a similar effect in prolonging the $t_{8/5}$ cooling time. The most efficient method of ascertaining the property-determining $t_{8/5}$ cooling time is measurement by means of a thermocouple dipped into the weld pool at the component. This method is especially recommended for sheet thicknesses thinner than 10 mm (in the range of two-dimensional heat conduction).

As shown in Figure 15, the weld metal softens significantly at prolonged $t_{8/5}$ times. The dissolving effect caused by dilution of the base material, therefore, often results in a very narrow processing window for similar standard filler materials.

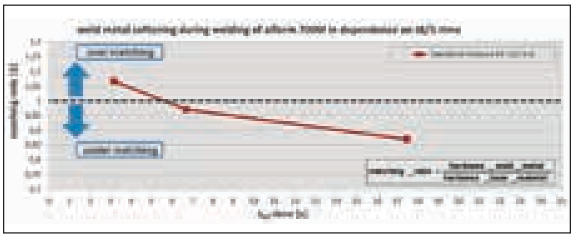


Figure 15: Softening of the weld metal in real welds with increasing $t_{8/5}$ cooling time is due to decreasing alloy content with increasing dilution of low-alloyed base material.

The weak points and difficulties in weld seam design discussed above have been eliminated through a collaboration between base metal producer, voestalpine, and its affiliate, voestalpine Böhler Welding. The two companies have developed an entire series of base-material/filler-metal combinations for high-strength and ultra-high-strength weld joints with yield strengths ranging between 700 and 1 100 MPa.

This series is marketed as the alform® welding system (Figure 16). The essential advantages of this fine-tuned solution are the extended welding range for high-strength and ultra-high-strength weld joints, low cold-cracking resistance in the weld seams and optimised mechanical properties. The filler metals supplied in the system include stick electrodes, solid wires, metal flux cored wires and wire/powder combinations.

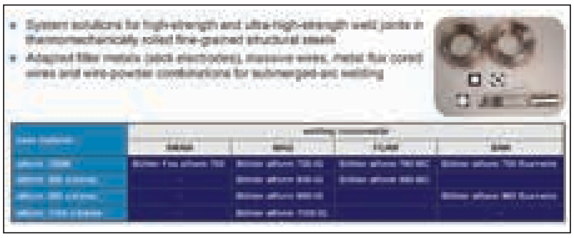


Figure 16: Base metal and welding consumable combinations that make up the alform welding system.

The dilution between the base material and the filler material is taken into consideration in the alloy design of the filler metals. Therefore, a decrease in the carbon equivalent values of the diluted weld metal below the respective values of the base material is overcome. This leads to an increase in weld metal strength at prolonged $t_{8/5}$ times, as shown in Figure 17.

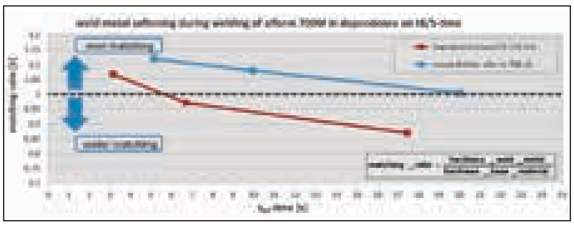
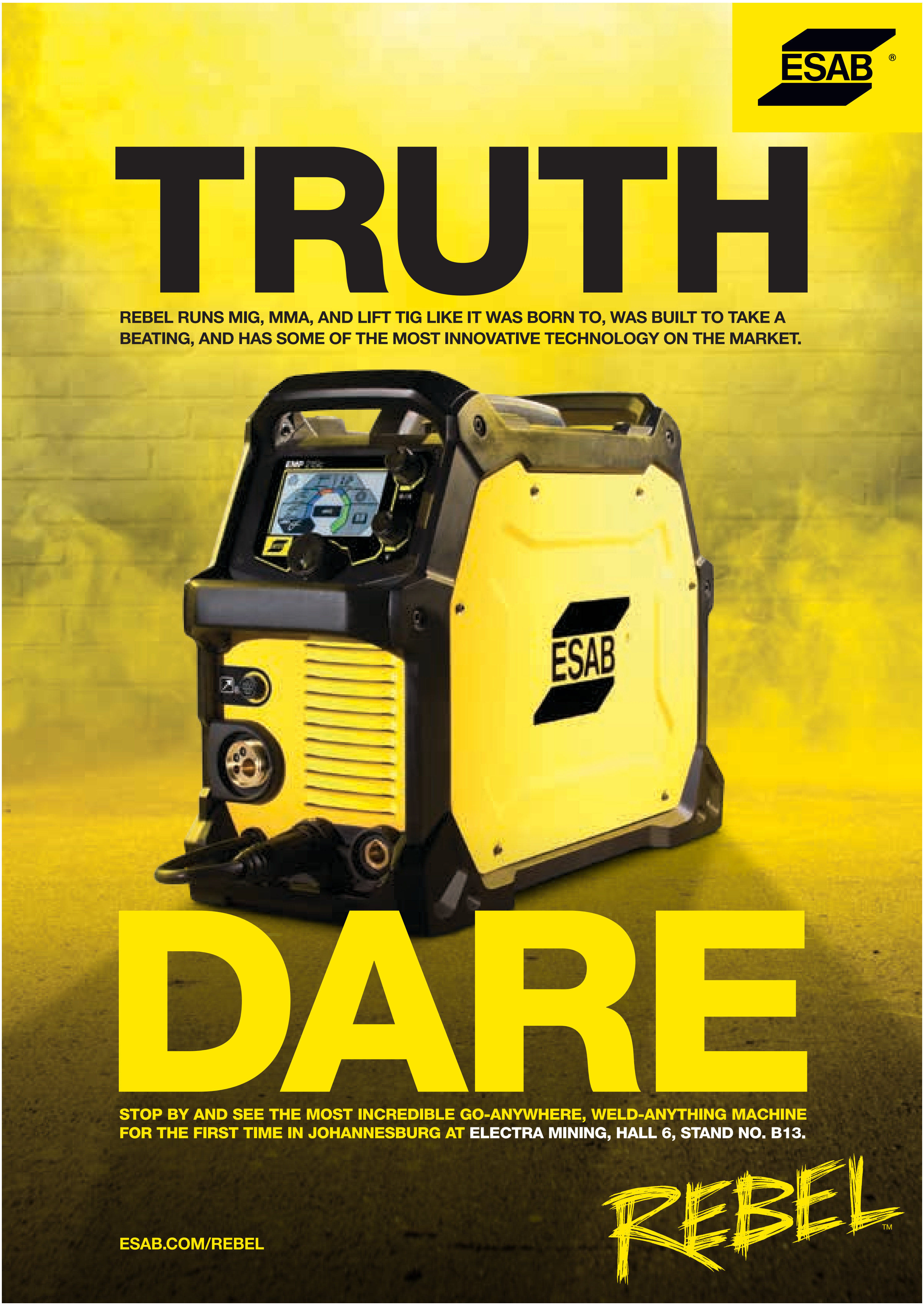


Figure 17: Softening of the weld metal in real welds using the newly developed alform system welding consumables.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The extended welding range has been verified by a wide variety of welding method tests for both X and V seams. Figure 18 provides an overview of the investigated combinations of filler, base materials and seam shapes.

Figure 18: Available system solutions, secured by welding procedure qualification tests according to EN 15614-1.

Welding parameters that have an influence on properties, such as heat input, layer buildup and interpass temperature, were also intentionally varied and taken into account.

Furthermore, the strength of optimised system V-joints meets the required strength values of the base material up to a $t_{8/5}$ time of 20 seconds and higher, e.g. alform welding system 960, Figure 19. The charpy-V-notch toughness values are at high levels, both in the weld metal and the heat-affected zone, even at a testing temperature of -40 °C, and are substantially higher than the guaranteed value (Figure 20).

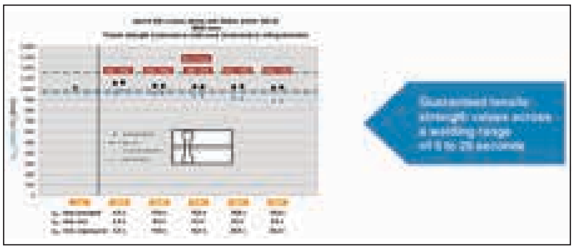

Figure 19: Strength properties transverse to V-seam welds prepared with the alform 960 welding system.

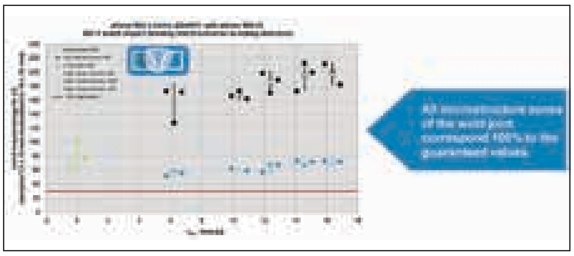

Figure 20: Toughness properties of the weld metal and the HAZ transverse to V-seam welds prepared with the alform 960 welding system.

The system solution also features a balanced hardness (strength) profile across the seam without any significant softening and hardening zones (Figure 21).

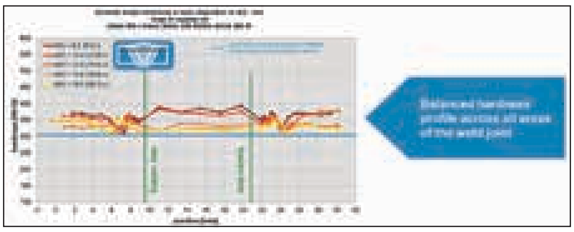

Figure 21: Hardness tracks across a V-seam weld prepared with the alform 960 welding system.

The possible extension of the welding range (up to 70%) with the alform welding system for weld joints ranging in yield strength between 700 and 1100 MPa is shown in Figure 22.

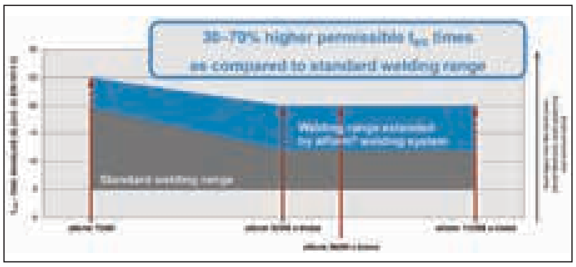

Figure 22: The expanded $t_{8/5}$ heat-input range for welding, made possible by using alform welding system combinations.

Summary and conclusion

As a result of optimising base material and welding consumable combinations, customers benefit from unique advantages, particularly with respect to efficiency and reliability. Aspects such as easier system implementation of existing welding solutions and higher parameter windows in terms of $t_{8/5}$ cooling times lead to higher efficiencies for fabrication customers.

Reliability is assured through proven system solutions, well-matched material partners as well as high quality requirements.

In Figure 23 a successfully implemented alform welding systems is shown. In this case the crane as well as the basic frame was welded with the alform welding systems. Higher weights may lifted and the lower machine weight offers better performance in rough terrain.

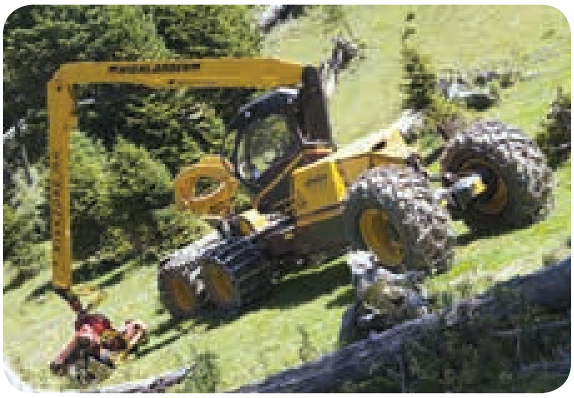

Figure 23: Example of well-implemented alform welding system to manufacture a lighter weight crane with a greater lifting capacity.

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