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Narrow Gap Welding, 
Electrogas - and 
Electroslag Welding
Up to this day, there is no universal agreement about the **definition** of the term **“Narrow Gap Welding”** although the term is actually self-explanatory. In the international technical literature, the process characteristics mentioned in the upper part of Figure 6.1 are frequently connected with the definition for narrow gap welding. In spite of these “definition difficulties” all questions about the universally valid advantages and disadvantages of the narrow gap welding method can be clearly answered.

The numerous variations of narrow gap welding are, in general, a further development of the conventional welding technologies. Figure 6.2 shows a classification with emphasis on several **important process characteristics**. Narrow gap TIG welding with cold or hot wire addition is mainly applied as an orbital process method or for the joining of high-alloy as well as non-ferrous metals. This method is, however, hardly applied in the practice. The other processes are more widely spread and are explained in detail in the following.
In Figure 6.3, a systematic subdivision of the various GMA narrow gap technologies is shown. In accordance with this, the fundamental distinguishing feature of the methods is whether the process is carried out with or without wire deformation. Overlaps in the structure result from the application of methods where a single or several additional wires are used. While most methods are suitable for single pass per layer welding, other methods require a weld build-up with at least two passes per layer. A further subdivision is made in accordance with the different types of arc movement.

In the following, some of the GMA narrow gap technologies are explained:

Using the turning tube method, Figure 6.4, side wall fusion is achieved by the turning of the contact tube; the contact tip angles are set in degrees of between 3° and 15° towards the torch axis. With an electronic stepper motor control, arbitrary transverse-arc oscillating motions with defined dwell periods of oscillation and oscillation frequencies can be realised - independent of the filler wire properties. In contrast, when the corrugated wire method with mechanical oscillator is applied, arc oscillation is produced by the plastic, wavy deformation of the wire electrode. The deformation is obtained by a continuously swinging oscillator which is fixed above the wire feed rollers. Amplitude and frequency of the wave motion...
can be varied over the total amplitude of oscillation and the speed of the mechanical oscillator or, also, over the wire feed speed. As the contact tube remains stationary, very narrow gaps with widths from 9 to 12 mm with plate thicknesses of up to 300 mm can be welded.

Figure 6.5 shows the macro section of a GMA narrow gap welded joint with plates (thickness: 300 mm) which has been produced by the mechanical oscillator method in approx. 70 passes. A highly regular weld build-up and an almost straight fusion line with an extremely narrow heat affected zone can be noticed. Thanks to the correct setting of the oscillation parameters and the precise, centred torch manipulation no sidewall fusion defects occurred, in spite of the low sidewall penetration depth. A further advantage of the weave-bead technique is the high crystal restructuring rate in the weld metal and in the basemetal adjacent to the fusion line – an advantage that gains good toughness properties.

Two narrow-gap welding variations with a rotating arc movement are shown in Figure 6.6. When the rotation method is applied, the arc movement is produced by an eccentrically protruding wire electrode (1.2 mm) from a contact tube nozzle which is rotating with frequencies between 100 and 150 Hz. When the wave
wire method is used, the 1.2 mm solid wire is being spiralwise deformed. This happens before it enters the rotating 3 roll wire feed device. With a turning speed of 120 to 150 revs per minute the welding wire is deformed. The effect of this is such that after leaving the contact piece the deformed wire creates a spiral diameter of 2.5 to 3.0 mm in the gap – adequate enough to weld plates with thicknesses of up to 200 mm at gap widths between 9 and 12 mm with a good sidewall fusion.

Figure 6.7 explains two GMA narrow gap welding methods which are operated without forced arc movement, where a reliable sidewall fusion is obtained either by the wire deflection through constant deformation (tandem wire method) or by forced wire deflection with the contact tip (twin-wire method). In both cases, two wire electrodes with thicknesses between 0.8 and 1.2 mm are used. When the tandem technique is applied, these electrodes are transported to the two weld heads which are arranged inside the gap in tandem and which are independently selectable.

When the twin-wire method is applied, two parallel switched electrodes are transported by a common wire feed unit, and, subsequently, adjusted in a common sword-type torch at an incline towards the weld edges at small spaces behind each other (approx. 8 mm) and molten.

In place of the SA narrow gap welding methods, mentioned in Figure 6.2, the method with a lengthwise positioned strip electrode as well as the twin-wire method are explained in more detail, Figure 6.8. SA narrow gap welding with strip electrode is carried out in the multi-pass layer technique, where the strip electrode is deflected at an angle of approx. 5° towards the edge in order to avoid collisions. After completing the first fillet weld and slag removal the opposite fillet is made. Solid wire as well as cored-strip electrodes with widths between 10
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and 25 mm are used. The gap width is, depending on the number of passes per layer, between 20 and 25 mm. **SA twin-wire welding** is, in general, carried out using two electrodes (1.2 to 1.6 mm) where one electrode is deflected towards one weld edge and the other towards the bottom of the groove or towards the opposite weld edge. Either a single pass layer or a two pass layer technique are applied. Dependent on the electrode diameter and also on the type of welding powder, is the gap width between 12 and 13 mm.

Figure 6.9 shows a comparison of **groove shapes** in relation to plate thickness for SA welding (DIN 8551 part 4) with those for GMA welding (EN 29692) and the unstandardised,

mainly used, narrow gap welding. Depending on the plate thickness, significant differences in the weld cross-sectional dimensions occur which may lead to substantial saving of material and energy during welding. For example, when welding thicknesses of 120 mm to 200 mm with the narrow gap welding technique, 66% up to 75% of the weld metal weight are saved, compared to the SA square edge weld.

The practical application of SA narrow gap welding for the production of a flanged calotte joint for a reactor pressure vessel cover is depicted in Figure 6.10. The inner diameter of the pressure vessel is more than 5,000 mm with
wall thicknesses of 400 mm and with a height of 40,000 mm. The total weight is 3,000 tons. The weld depth at the joint was 670 mm, so it had been necessary to select a gap width of at least 35 mm and to work in the three pass layer technique.

Electrogas welding (EG) is characterised by a vertical groove which is bound by two water-cooled copper shoes. In the groove, a filler wire electrode which is fed through a copper nozzle, is melted by a shielded arc, Figure 6.11. During this process, are groove edges fused. In relation with the ascending rate of the weld pool volume, the welding nozzle and the copper shoes are pulled upwards. In order to avoid poor fusion at the beginning of the welding, the process has to be started on a run-up plate which closes the bottom end of the groove. The shrinkholes forming at the weld end are transferred onto the run-off plate. If possible, any interruptions of the welding process should be avoided. Suitable power sources are rectifiers with a slightly dropping static characteristic. The electrode has a positive polarity.
The application of electrogas welding for low-alloyed steels is – more often than not - limited, as the toughness of the heat affected zone with the complex coarse grain formation does not meet sophisticated demands. Long-time exposure to temperatures of more than 1500°C and low crystallisation rates are responsible for this. The same applies to the weld metal. For a more wide-spread application of electrogas welding, the **High-Speed Electrogas Welding Method** has been developed in the ISF. In this process, the gap cross-section is reduced and additional metal powder is added to increase the deposition rate. By the increase of the welding speed, the dwell times of weld-adjacent regions above critical temperatures and thus the brittleness effects are significantly reduced.

Figure 6.12 shows the process principle of **Electroslag Welding**. Heating and melting of the groove faces occurs in a slag bath. The temperature of the slag bath must always exceed the melting temperature of the metal. The Joule effect, produced when the current is transferred through the conducting bath, keeps the slag bath temperature constant. The welding current is fed over one or more endless wire electrodes which melt in the highly heated slag bath. Molten pool and slag bath which both form the weld pool are, sideways retained by the groove faces and, in general, by
water-cooled copper shoes which are, with the complete welding unit, and in relation with the welding speed, moved progressively upwards. To avoid the inevitable welding defects at the beginning of the welding process (insufficient penetration, inclusion of unmolten powder) and at the end of the welding (shrinkholes, slag inclusions), run-up and run-off plates are used.

The electroslag welding process can be divided into **four process phases**, Figure 6.13. At the beginning of the welding process, in the so-called “ignition phase”, the arc is ignited for a short period and liquefies the non-conductive welding flux powder into conductive slag. The arc is extinguished as the electrical conductivity of the arc length exceeds that of the conductive slag. When the desired slag bath level is reached, the lower ignition parameters (current and voltage) are, during the so-called “Data-Increase-Phase”, raised to the values of the stationary welding process. This occurs on the run-up plate. The subsequent actual welding process starts, the **process phase**. At the end of the weld, the **switch-off phase** is initiated in the run-off plate. The solidifying slag bath is located on the run-off plate which is subsequently removed.

The **electroslag welding with consumable feed wire** (**channel-slot welding**) proved to be very useful for shorter welds.

The copper sliding shoes are replaced by fixed Cu cooling bars and the welding nozzle by a steel tube, Figure 6.14. The length of the sheathed steel tube, in general, corresponds with the weld seam length (mainly shorter than 2.500 mm) and the steel tube melts during welding in the ascending slag bath. Dependent on the plate thickness, welding can be carried out with one single or with several wire and strip electrodes. A feature of this process variation is the handiness of the welding device and the easier welding area preparation. Also curved seams can be welded with a bent consumable electrode. As the groove width can be significantly reduced when comparing
with conventional processes, and a strip shaped filler material with a consumable guide piece is used, this welding process is rightly placed under the group of narrow gap welding techniques.

Likewise in electrogas welding, the electroslag welding process is also characterised by a large molten pool with a – simultaneously - low heating and cooling rate. Due to the low cooling rate good degassing and thus almost porefree hardening of the slag bath is possible. Disadvantageous, however, is the formation of a coarse-grain structure. There are, however, possibilities to improve the weld properties, Figure 6.15.

To avoid postweld heat treatment the electroslag welding process with local continuous normalisation has been developed for plate thicknesses of up to approx. 60 mm, Figure 6.16. The welding temperature in the weld region drops below the $A_{r1}$-temperature and is subsequently heated to the normalising temperature ($>A_{c3}$). The specially designed torches follow the copper shoes along the weld seam. By reason of the residual heat in the workpiece the necessary temperature can be reached in a short time.
In order to circumvent an expensive postheat weld treatment which is often unrealistic for use on-site, the electroslag high-speed welding process with multilayer technique has been developed. Similar to electrogas welding, the weld cross-section is reduced and, by application of a twin-wire electrode in tandem arrangement and addition of metal powder, the weld speed is increased, as in contrast to the conventional technique. In the heat affected zones toughness values are determined which correspond with those of the unaffected base metal. The slag bath and the molten pool of the first layer are retained by a sliding shoe, Figure 6.17. The weld preparation is a double-V butt weld with a gap of approx. 15 mm, so the carried along sliding shoe seals the slag and the metal bath. Plate preparation is, as in conventional electroslag welding, exclusively done by flame cutting. Thus, the advantage of easier weld preparation can be maintained.

For larger plate thicknesses (70 to 100 mm), the three passes layer technique has been developed. When welding the first pass with a double-V-groove preparation (root width: 20 to 30 mm; gap width: approx. 15 mm) two sliding shoes which are adjusted to the weld
groove are used. The first layer is welded using the conventional technique, with one wire electrode without metal powder addition.

When welding the **outer passes** flat Cu shoes are again used, Figure 6.18. Three wire electrodes, arranged in a triangular formation, are used. Thus, one electrode is positioned close to the root and on the plate outer sides two electrodes in parallel arrangement are fed into the bath. The single as well as the parallel wire electrodes are fed with different metal powder quantities which as outcome permit a welding speed 5 times higher than the speed of the single layer conventional technique and also leads to strong increase of toughness in all zones of the welded joint.

If wall thicknesses of more than 100 mm are to be welded, several twin-wire electrodes with metal powder addition have to be used to reach deposition rates of approx. 200 kg/h. The electroslag welding process is limited by the possible crack formation in the centre of the weld metal. Reasons for this are the concentration of elements such as sulphur and phosphor in the weld centre as well as too fast a cooling of the molten pool in the proximity of the weld seam edges.