3.

Submerged Arc Welding
In **submerged arc welding** a mineral weld flux layer protects the welding point and the freezing weld from the influence of the surrounding atmosphere, Figure 3.1. The arc burns in a cavity filled with ionised gases and vapours where the droplets from the continuously-fed wire electrode are transferred into the weld pool. Unfused flux can be extracted from behind the welding head and subsequently recycled.

**Main components** of a submerged arc welding unit are: the wire electrode reel, the wire feed motor equipped with grooved wire feed rolls which are suitable for the demanded wire diameters, a wire straightener as well as a torch head for current transmission, Figure 3.2.

Flux supply is carried out via a hose from the flux container to the feeding hopper which is mounted on the torch head. Depending on the degree of automation it is possible to install a flux excess pickup behind the torch. Submerged
Submerged Arc Welding

Welding can be operated using either an a.c. power source or a d.c. power source where the electrode is normally connected to the positive terminal.

Welding advance is provided by the welding machine or by workpiece movement.

Identification of wire electrodes for submerged arc welding is based on the average Mn-content and is carried out in steps of 0.5%, Figure 3.3. Standardisation for welding filler materials for unalloyed steels as well as for fine-grain structural steels is contained in DIN EN 756, for creep-resistant steels in DIN pr EN 12070 (previously DIN 8575) and for stainless and heat-resistant steels in DIN pr EN 12072 (previously DIN 8556-10).

The proportions of additional alloying elements are dependent on the materials to be welded and on the mechanical-technological demands which emerge from the prevailing operating conditions, Figure 3.4. Connected to this, most important alloying elements are manganese for strength, molybdenum for high-temperature strength and nickel for toughness.

![Figure 3.3](image1.png)

![Figure 3.4](image2.png)
The identification of wire electrodes for submerged arc welding is standardised in DIN EN 756, Figure 3.5.

During manufacture of fused welding fluxes the individual mineral constituents are, with regard of their future composition, weighed and subsequently fused in a cupola or electric furnace, Figure 3.6. In the dry granulation process, the melt is poured stresses break the crust into large fragments. During water granulation the melt hardens to form small grains with a diameter of approximately 5 mm.

As a third variant, compressed air is additionally blown into the water tank resulting in finely blistered grains with low bulk weight. The fragments or grains are subsequently ground and screened – thus bringing about the desired grain size.
During manufacture of agglomerated weld fluxes the raw materials are very finely ground, Figure 3.7. After weighing and with the aid of a suitable binding agent (waterglass) a pre-stage granulate is produced in the mixer. Manufacture of the granulate is finished on a rotary dish granulator where the individual grains are rolled up to their desired size and consolidate. Water evaporation in the drying oven hardens the grains. In the annealing furnace the remaining water is subsequently removed at temperatures of between 500°C and 900°C, depending on the type of flux.

The fused welding fluxes are characterised by high homogeneity, low sensitivity to moisture, good storing properties and high abrasion resistance. An important advantage of the agglomerated fluxes is the relatively low manufacturing temperature, Figure 3.8. The technological properties of the welded joint can be improved by the addition of temperature-sensitive deoxidation and alloying constituents to the flux. Agglomerated fluxes have, in general, a lower bulk weight (lower consumption) which allows the use of components which are reacting among

<table>
<thead>
<tr>
<th>Properties</th>
<th>Fused Fluxes(^1)</th>
<th>Agglomerated Fluxes(^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>uniformity of grain size distribution</td>
<td>+/+/-</td>
<td>-/+/-</td>
</tr>
<tr>
<td>grain strength</td>
<td>+/+/-</td>
<td>-/+/-</td>
</tr>
<tr>
<td>homogeneity</td>
<td>+/++/</td>
<td>-/+/-</td>
</tr>
<tr>
<td>susceptibility to moisture</td>
<td>+/++/</td>
<td>-/++/</td>
</tr>
<tr>
<td>storing properties</td>
<td>+/++/</td>
<td>-/++/</td>
</tr>
<tr>
<td>resistance to dirt</td>
<td>--/+/-</td>
<td>-/++/</td>
</tr>
<tr>
<td>current carrying capacity</td>
<td>+/++/</td>
<td>++/++/</td>
</tr>
<tr>
<td>slag removability</td>
<td>-/-/</td>
<td>++/++/</td>
</tr>
<tr>
<td>high-speed welding properties</td>
<td>+/++/</td>
<td>++/++/</td>
</tr>
<tr>
<td>multiple-wire weldability</td>
<td>-/+/-</td>
<td>++/++/</td>
</tr>
<tr>
<td>flux consumption</td>
<td>-/+/-</td>
<td>++/++/</td>
</tr>
</tbody>
</table>

\(^1\) assessment: -- bad, - moderate, + good, ++ very good
\(^2\) core agglomerated flux

Figure 3.7

Figure 3.8
3. Submerged Arc Welding

themselves during the melting process. However, the higher susceptibility to moisture during storage and processing has to be taken into consideration.

The SA welding fluxes are, in accordance with their mineralogical constituents, classified into nine groups, Figure 3.9. The composition of the individual flux groups is to be considered as in principle, as fluxes which belong to the same group may differ substantially with regards to their welding or weld metal properties.

In addition to the groups mentioned above there is also the Z-group which allows free compositions of the flux.

The calcium silicate fluxes are recognized by their effective silicon pickup. A low Si pickup has low cracking tendency and liability to rust, on the other hand the lower current carrying capacity of these fluxes has to be accepted. A high Si pickup leads to a high current currying capacity up to 2500 A and a deep penetration. Aluminate-basic fluxes have, due to the higher Mn pickup, good mechanical
properties. With the application of wire electrodes, as S1, S2 or S2Mo, a low cracking tendency can be obtained.

**Fluoride-basic** fluxes are characterised by good weld metal impact values and high cracking insensitivity. Figures 3.10a and 3.10b show typical properties and application areas for the different flux types.

Figure 3.11 shows the **identification of a welding flux** according to DIN EN 760 by the example of a fused calcium silicate flux. This type of flux is suitable for the welding of joints as well as for overlap welds. The flux can be used for SA welding of unalloyed and low-alloy steels, as, e.g. general structural steels, as well as for welding high-tensile and creep resistant steels. The silicon pickup is $0.1 - 0.3\%$ (6), while the manganese pickup is expected to be $0.3 - 0.5\%$ (7). Either d.c. or a.c. can be used, as, in principle, a.c. weldability allows also for d.c. power source. The hydrogen content in the clean weld metal is lower than the 10 ml/100 g weld metal.
The flux classes 1-3 (table 1) explain the suitability of a flux for welding certain material groups, for welding of joints and for overlap welding. The flux classes also characterise the metallurgical material behaviour. In table 2 defines the identification figure for the pickup or burn-off behaviour of the respective element. Table 4 shows the gradation of the diffusible hydrogen content in the weld metal, Figure 3.12.

**Figure 3.12**

Figure 3.13 shows the identification of a wire-flux combination and the resultant weld metal. It is a case of a combination for multipass SA welding where the weld metal shows a minimum yield point of 460 N/mm² (46) and a minimum metal impact value of 47 J at −30°C (3). The flux type is aluminate-basic (AB) and is used with a wire of the quality S2.

**Figure 3.13**
The tables for the identification of the tensile properties as well as of the impact energy are combined in Figure 3.14.

<table>
<thead>
<tr>
<th>Identification</th>
<th>Minimum Yield Point N/mm²</th>
<th>Tensile Strength N/mm²</th>
<th>Minimum Fracture Strain %</th>
</tr>
</thead>
<tbody>
<tr>
<td>35</td>
<td>355</td>
<td>440 up to 570</td>
<td>22</td>
</tr>
<tr>
<td>38</td>
<td>380</td>
<td>470 up to 600</td>
<td>20</td>
</tr>
<tr>
<td>42</td>
<td>420</td>
<td>500 up to 640</td>
<td>20</td>
</tr>
<tr>
<td>46</td>
<td>460</td>
<td>530 up to 680</td>
<td>20</td>
</tr>
<tr>
<td>50</td>
<td>500</td>
<td>560 up to 720</td>
<td>18</td>
</tr>
</tbody>
</table>

The chemical composition of the weld metal and the structural constitution are dependent on the different metallurgical reactions during the welding process as well as on the used materials, Figure 3.15. The welding flux influences the slag viscosity, the pool motion and the bead surface. The different combinations of filler material and welding flux cause, in direct dependence on the weld parameters (current, voltage), a different melting behaviour and also different chemical reactions. The dilution with the base metal leads to various strong weld pool reactions, this being dependent on the weld parameters.

The diagram of the characteristics for 3 different welding fluxes assists, in dependence of the used wire electrodes, to determine the pickup and burn-off behaviour of the element manganese, Figure 3.16. For example: A welding flux with
3. Submerged Arc Welding

The **pickup and burn-off behaviour** is, besides the filler material and the welding flux, also directly dependent on the welding amperage and welding voltage, Figure 3.17. By the example of the selected flux a higher welding voltage causes a more steeply descending manganese characteristic at a constant neutral point. Silicon pickup increases with the increased voltage. The influence of current and voltage on the carbon content is, as a rule, negligible.

Inversely proportional to the voltage is the rising characteristic as regards manganese in dependence on the welding current, Figure 3.18. Higher currents cause the characteristic curve to flatten. As the welding voltage, the welding current also has practically no influence on the location of the neutral point. Silicon pickup decreases with increasing current intensity.

The mean characteristic and when a wire electrode S3 is used, has a neutral point where neither pickup nor burn-off occur.
The Mn-content of the weld metal can be determined by means of a welding flux diagram, Figure 3.19.

In this example, the two points on the axis which determine the flux characteristic are defined for the parameters 600A welding current and 29V welding voltage, with the aid of the auxiliary straight line and the neutral point curve ($Mn_{NP}$). In this case, the two points are positioned at 0.6% $\Delta Mn$ and 1.25% $Mn_{SZ}$. Dependent on the manganese content of the used filler material, the pickup or burn-off contents can be recognized by the reflection with respect to the characteristic line.

Figure 3.18

(0.38% Mn-pickup with a wire containing 0.5%Mn, 0.2% Mn-burnoff with a wire containing 1.75%Mn).

The structure of the characteristic line for the determination of the silicon pickup content, is, in principle, exactly the same as described above, Figure 3.20. As silicon has only pickup properties and therefore no neutral point exists, the second auxiliary straight line must be considered for the determination of the second characteristic line point.

Figure 3.19
Weld preparations for **multipass fabrication** are dependent on the thickness of the plates to be welded, Figure 3.21. If no root is planned during weld preparation and also no support of the weld pool is made, the root pass must be welded using low energy input.

When welding very thick plates which are accessible from both sides, the **double-U butt** weld may be applied, Figure 3.22. Before the opposite side is welded, the root must be milled out (gouging/sanding). This type of weld cannot be produced by flame cutting and is, as milling is necessary, more expensive, although exact weld preparation and correct selection of the welding parameters lead to a high weld quality.

Another variation of heavy-plate welded joints is the so-called **“steep single-V butt weld”**, Figure 3.23. The very steep edges keep the welding volume at a very low level. This technique, however, requires the application of special narrow-gap torches. The geometry during slag detachment and
3. Submerged Arc Welding

also during reworking weld-related defects may cause problems. Here, high demands are made on torch manipulation and process control. Special narrow-gap welding fluxes facilitate slag removal.

The most important welding parameters as regards weld bead formation are welding current, voltage and speed, Figure 3.24. A higher welding current causes higher deposition rates and energy input, which leads to reinforced beads and a deeper penetration. The weld width remains roughly constant. The increased welding voltage leads to a longer arc which also causes the bead to be wider. The change in welding speed causes - on both sides of an optimum - a decrease of the penetration depth. At lower weld speeds, the weld pool running ahead of the welding arc acts as a buffer between arc and base metal. At high speeds, the energy per unit length decreases which leads, besides lower penetration, also to narrower beads.

Figure 3.22

Figure 3.23
Weld flux consumption is dependent on the selected weld type, Figure 3.25. Due to geometrical shape, the flux consumption of a fillet weld is significantly lower than that of a butt weld. Because of their lower bulk weight, the specific consumption of agglomerated fluxes is lower than that of fused fluxes.

Two different control concepts allow the regulation of the arc length (the principle is shown in Figure 3.26). The application of the appropriate control system is
dependent on the available power source characteristics. The **external regulation** of the arc length by the control of the wire feed speed requires a power source with a steeply descending characteristic, Figure 3.27. In this case, the shortening of the arc caused by some process disturbance, entails a strong voltage drop at a low current rise. As a regulated quantity, this voltage drop reduces the wire feed speed. Thus, the initial arc length can be regulated at an almost constant deposition rate.

In contrast, the **internal regulation** effects, when the arc is reduced, a strong current rise at a low voltage drop (slightly descending characteristic). At a constant wire feed speed the initial arc length is independently regulated by the increased burn-off rate which again is a consequence of the high current.

The reaction of the **internal regulation** to process disturbance is very fast. This process is self regulating and does not require any machine expenditure.

In submerged arc welding of butt joints, it is, depending on the weld preparation, necessary to support the
liquid weld pool with a backing, Figure 3.28. This is normally done with either a ceramic or copper backing with a flux layer or by a backing flux. Dependent on the shape of the backing bar, direct formation of the underside seam can be achieved.

When welding circumferential tubes, the inclination angle of the electrode has a direct influence onto the formation of the weld bead, Figure 3.29. For external as well as for internal tube welds, the best weld shapes may be obtained with an adjusted angular position of the torch. If the advance is too low, the molten bath runs ahead and produces a narrow weld with a medium-sized ridge, too high an advance causes the flowback of the molten bath and a wide seam with a formed trough in the centre. The processes described here for external tube welds are, the other way round, also applicable to internal tube welds.

To increase the efficiency of submerged arc welding, different process variations are applied, Figure 3.30. In multiwire welding, where up to 6 wires are used, each welding torch is operated from a separate power source. In twin wire
In **submerged arc welding with iron powder addition** can the deposition rate be substantially increased at constant electrical parameters, Figure 3.31. The increased deposition rate is realised by either the addition of a currentless wire (**cold wire**) or of a preheated filler wire (**hot wire**). The use of a rectangular strip instead of a wire electrode allows a higher current carrying capacity and opens the SA method also for the wide application range of surfacing.

However, the mentioned **process variations** can be combined over wide ranges, where the electrode distances and positions have to be appropriately optimised, Figure 3.32. Current type, polarity, geometrical coordination of the individual weld heads and the selected weld parameters also have substantial influence on the weld result.
The description of these individual process variations of submerged arc welding shows that this method can be applied sensibly and economically over a very wide operating range, Figure 3.33. It is a high-efficiency welding process with a deposition rate of up to 100 kg/h. Due to large molten pools and flux application positional welding is not possible.

When more than one wire is used in order to obtain a high deposition rate, arc interactions occur due to magnetic arc blow, Figure 3.34. Therefore, the selection of the current type (d.c. or a.c.) and also sensible phase displacements between the individual welding torches are very important.