4.

TIG Welding and

Plasma Arc Welding
TIG welding and plasma welding belong to the group of the gas-shielded tungsten arc welding processes, Figure 4.1. In the gas-shielded tungsten arc welding processes mentioned in Figure 4.1, the arc burns between a **non-consumable tungsten electrode** and the work-piece or, in plasma arc welding, between the tungsten electrode and a live copper electrode inside the torch. Exclusively inert gases (Ar, He) are used as shielding gases.

The potential curve of the ideal arc, as shown in Figure 4.2, can be divided into three characteristic sectors:

1. **cathode-drop region**
2. **arc**
3. **anode-drop region**

In the cathode-drop region almost 50% of the total voltage drop occurs over a length of $10^{-4}$ mm.

A similarly high voltage drop occurs in the anode-drop region, here, however, over a length of 0.5 mm. The voltage drop on the remaining arc length is comparatively low. Main energy conversion occurs accordingly in the anode-drop and cathode-drop region.

Figure 4.3 shows the **potential distribution** by the example of a real TIG arc under the influence of different shielding gases. $U_A$ and $U_K$ have different values, the potential curve in the
arc is not exactly linear. There is no discernible expansion of the cathode-drop and anode-drop region.

The electrical characteristics of the arc differ, depending on the selected shielding gas, Figure 4.4. As the ionisation potential of helium in comparison with argon is higher, arc voltage must necessarily be higher.

The temperature distribution of a TIG arc is shown in Figure 4.5.
In TIG welding just approximately 30% of the **input electrical energy** may be used for melting the base metal, Figure 4.6. Losses result from the arc radiation and heat dissipation in the workpiece and also from the heat conversion in the tungsten electrode.

Figure 4.7 describes the **process principle of TIG welding**.

Figure 4.8 explains by an example the code for a TIG welding wire, as stipulated in the drafts of the European Standardisations.

A table with the chemical compositions of the filler materials is shown in Figure 4.9.

According to Figure 4.10, a **conventional TIG welding installation** consists of a transformer, a set of rectifiers and a torch. For most applications an electrode with a negative polarity is used. However, for welding of aluminium, alternating current must be used. For arc ignition a high-frequency high voltage is superimposed and causes ionisation between electrode and workpiece.
4. TIG Welding and Plasma Arc Welding

The central part of the torch for TIG welding is the tungsten electrode which is held in a collet inside the torch body, Figure 4.11. The hose package contains the supply lines for shielding gas and welding current. The shielding gas nozzle is mostly made of ceramic. Manually operated torches for TIG welding which are used for high amperages as well as machine torches for long duty cycles are water-cooled.

In order to keep the influence of torch distance variations on the current intensity and thus on the penetration depth as low as possible, power sources used for TIG welding always have a steeply dropping characteristic, Figure 4.12.

The non-contact reignition of the A.C. TIG arc after a voltage zero crossover requires ionisation of the electrode-workpiece gap by high-frequent high voltage pulses, Figure 4.13.

The chemical composition of filler rods and wires for TIG-welding is as follows:

<table>
<thead>
<tr>
<th>Code</th>
<th>C [%]</th>
<th>Si [%]</th>
<th>Mn [%]</th>
<th>P [%]</th>
<th>S [%]</th>
<th>Ni [%]</th>
<th>Mo [%]</th>
<th>Al [%]</th>
<th>Ti+Zr [%]</th>
<th>Other elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>W0</td>
<td>any other composition agreed upon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>W1</td>
<td>0.06-0.14</td>
<td>0.5-0.8</td>
<td>0.9-1.3</td>
<td>0.025</td>
<td>0.025</td>
<td>0.15</td>
<td>0.15</td>
<td>0.02</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>W2</td>
<td>0.06-0.14</td>
<td>0.7-1.2</td>
<td>1.3-1.6</td>
<td>0.025</td>
<td>0.025</td>
<td>0.15</td>
<td>0.16</td>
<td>0.02</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>W3</td>
<td>0.06-0.14</td>
<td>0.8-1.2</td>
<td>1.6-1.9</td>
<td>0.025</td>
<td>0.025</td>
<td>0.15</td>
<td>0.15</td>
<td>0.02</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>W5</td>
<td>0.06-0.14</td>
<td>0.5-0.8</td>
<td>1.1-1.4</td>
<td>0.025</td>
<td>0.025</td>
<td>0.15</td>
<td>0.15</td>
<td>0.05-0.20</td>
<td>0.05-0.25</td>
<td></td>
</tr>
<tr>
<td>W7</td>
<td>0.06-0.14</td>
<td>0.5-0.9</td>
<td>1.0-1.6</td>
<td>0.020</td>
<td>0.020</td>
<td>0.9-1.5</td>
<td>0.15</td>
<td>0.02</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>W8</td>
<td>0.06-0.14</td>
<td>0.4-0.8</td>
<td>1.0-1.4</td>
<td>0.020</td>
<td>0.020</td>
<td>2.1-2.7</td>
<td>0.15</td>
<td>0.02</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>W9</td>
<td>0.06-0.12</td>
<td>0.3-0.7</td>
<td>0.6-1.3</td>
<td>0.020</td>
<td>0.020</td>
<td>0.15</td>
<td>0.4-0.6</td>
<td>0.02</td>
<td>0.15</td>
<td></td>
</tr>
</tbody>
</table>

Individual values are maximum values.

* maximum proportion of copper residual in steel: 0.35%
When argon is used as a shielding gas, metals as, for example, aluminium and magnesium, which have low melting points and also simultaneously forming tight and high melting oxide skins, cannot be welded with a negative polarity electrode. With a positive polarity, however, a “cleaning effect” takes place which is caused by the impact of the positive charged ions from the shielding gas atmosphere on the negative charged work surface, thus destroying the oxide skin due to their large cross-section. However, as a positive polarity
would cause thermal overload of the electrode, these materials are welded with alternating current.

However, this has a disturbing side-effect. The electron emission and, consequently, the current flow are dependent on the temperature of the cathode. During the negative phase on the work surface the emission is, due to the lower melting temperature substantially lower than during the negative phase on the tungsten electrode. As a consequence, a positively connected electrode leads to lower welding current flows than this would be the case with a negatively connected electrode, Figure 4.14. A filter capacitor in the welding current circuit filters out the D.C. component which results in equal half-wave components. With modern transistorised power sources which use alternating current (square wave) for a faster zero cross-over, is duration and height of the phase components adjustable. The electrode thermal stress and the cleaning effect may be freely influenced.

Figure 4.15 shows that the thermal electrode load can be recognized from the shape of the electrode tip. While the normal-load negative connected electrode end has the shape of a pointed cone (point angle approx. 10°), a flattened electrode tip is the result
from a.c. welding (higher thermal load by positive half-waves). The tip of a thermally overloaded electrode is hemispherical and leads to a stronger spread of the arc and thus to wider welds with lower penetration.

All fusion weldable materials can be joined using the TIG process; from the economical point of view this applies especially to plate thickness of less than 5 mm. The method is, moreover, predestined for welding root passes without backing support, Figure 4.16.
For circumferential welding of fixed pipes, the TIG orbital welding method is applied. The welding torch moves orbitally around the pipe, i.e., the pipe is welded in the positions flat, vertical down, overhead, vertical-up and also inter-pass welding is applied. Moreover, a defect-free weld bead overlap must be achieved. Orbital welding installations are equipped with process operational controls which determine the appropriate process parameters, Figure 4.17.

In plasma arc welding burns the arc between the tungsten electrode (- pole) and the plasma gas nozzle (+ pole) and is called the “non-transferred” arc, Figure 4.18. The non-transferred arc is mainly used for metal-spraying and for the welding of metal-foil strips.

In plasma arc welding with transferred arc burns the arc between the tungsten electrode (- pole) and the workpiece (+ pole) and is called the “transferred arc”, Figure 4.19. The plasma gas constricts the arc and leads to a more concentrated heat input than in TIG welding and allows thus the exploitation of the “keyhole effect”. Plasma arc welding with transferred arc is mainly used for welding of joints.
Plasma arc welding with semi-transferred arc is a combination of the two methods mentioned above. This process variant is used for microplasma welding, plasma-arc powder surfacing and welding joining of aluminium, Figure 4.20.

The plasma welding equipment includes, besides the water-cooled welding torch, a gas supply for plasma gas (Ar) and shielding gas (ArH₂-mixture, Ar/He mixture or Ar); the gas supply is, in most cases, separated, Figure 4.21.

The copper anode and the additional focusing gas flow constrict the plasma arc which leads,
in comparison with TIG welding, to a more concentrated heat input and thus to deeper penetration. An arc that has been generated in this way burns more stable and is not easy to deflect, as, for example, at workpiece edges, Figure 4.21.

The TIG arc is cone shaped or bell shaped, respectively, and has an aperture angle of 45°. The plasma arc, in comparison, burns highly concentrated with almost parallel flanks, Figure 4.22.

The shielding gas used in plasma arc welding exerts, due to its thermal conductivity, a decisive influence onto the arc configuration. The use of a mixture of argon with hydrogen results in the often desired cylindrical arc shape, Figure 4.23.

In plasma arc welding of plates thicker than 2.5mm the so-called “keyhole effect” is utilised, Figure 4.24. The plasma jet penetrates the material, forming a weld keyhole. During welding the plasma jet with the keyhole moves along the joint edges. Behind the plasma jet as result of the surface tension and the vapour pressure in the keyhole, the liquid metal flows back together and the weld bead is created.
Very thin sheets and metal-foils can be welded using **microplasma welding** with amperages between 0.05 and 50 A.

Figures 4.25 and 4.26 show these **application examples**: The circumferential weld in a diaphragm disk with a wall thickness of 0.15mm and the joining of fine metal grids made of Cr-Ni steel.