6 Metal arc welding with coated electrodes

6.1 Description of the method

Manual Metal Arc welding (MMA) is often referred to as Shielded Metal Arc Welding (SMAW) or stick electrode welding. It was the predominant form of fusion welding until the beginning of the 1980s. Electrode rods consist of a wire core with an external coating. They are made in a range of core diameters, with each diameter being intended for a particular current range. Welding involves striking an arc between the electrode and the workpiece, with the heat of the arc melting the electrode (i.e. the filler material), and with the coating melting to form a protective slag.

The equipment required is simple, as shown in Figure 6.1, which means that the method is straightforward to use. It is particularly suitable for jobs such as the erection of structures. It can also be used outdoors, as opposed to other methods requiring shielding gas, which are unsuitable in wind. However, its arc time factor is relatively low, due to the time required for chipping away slag after welding and changing the electrodes.

![Figure 6.1 Schematic diagram of manual metal arc welding.](image)

6.2 Equipment

**Power sources**

When welding with coated electrodes, the required current is set at the power source. The welding current must be kept within certain limits even though the arc length may vary. The short-circuit current should not be more than about 60% higher than the current setting, in order to avoid spatter from the short-circuiting of the arc caused by the droplets of molten metal in it. On the other hand, too low a rise in current can result in the electrode 'freezing' to the work. These requirements mean that the power source should have a drooping load characteristic.

Power sources for MMA welding do not need to have as high an intermittence factor as those for more mechanised methods: a normal value is 35%.

MMA welding can be performed using either DC or AC, which means that all types of power sources can be used. The advantages of using AC are that the power source is simple, and there is reduced magnetic arc blow effect on the arc. However, AC-welding
restricts the choice of type of electrode and necessitates the power source providing a sufficiently high open-circuit voltage, of at least 50 V or preferably more.

**Potential for mechanisation**

Mechanisation is possible using what is known as *gravity arc welding*, which involves securing the electrode and feeding it along the joint by a mechanical electrode feeder frame (Figure 6.2). In this way, a single welder can keep 3-5 arcs burning at the same time. With correctly set welding parameters, the use of this cheap and simple equipment enables one welder to make **280-400 m** of fillet welds in an 8-hour working day. Such a productivity level is difficult to achieve with any other types of welding equipment in a similar price class.

![Figure 6.2 Gravity arc welding equipment for 700 mm long electrodes.](image)

### 6.3 Electrodes

A wide selection of electrodes is available, to meet most requirements. The coatings consist of various mixtures of finely powdered chemicals and minerals, held together by a suitable binder.

The coating performs a number of important functions, including:

- **protecting** the metal droplets and the weld pool against reactions with the air, provided by the molten slag and the gases developed from the coating.

- improving the *stability of the arc*. Without arc-stabilising substances in the coating, the arc would be difficult to control and would produce excessive spatter. It would also extinguish easily, particularly when welding with AC. Arc-stabilising or *ionising* substances include titanium, zirconium and magnesium.

- **shaping** the upper surface of the weld and facilitating *removal of the hardened slag*. The use of coated electrodes produces a layer of slag on top of the joint that has to be removed after welding. This requires the use of a chipping hammer or wire brush, and can be easier or harder, depending on the type of electrode coating.

- **applying alloying and/or anti-oxidising substances** to the weld pool. The coating may also contain iron powder in order to improve the yield.

- providing sufficient *penetration* into the base material while welding. Penetration is determined by materials that can release a significant quantity of hot gas, such as carbonates or cellulose compounds.

Electrodes are divided into three groups, depending on the chemical composition of the slag: *acid*, *basic* and *rutile*. © 2003, Woodhead Publishing Ltd

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Acid electrodes

The coating of acid electrodes includes iron and manganese oxides. Acid electrodes produce smooth, shiny weld beads, with the slag solidifying slowly, being porous and easy to remove. The weld metal has a lower yield strength and ultimate tensile strength than that produced by rutile and basic electrodes, but a higher rupture strain. Although electrodes of this type were previously the most commonly used, nowadays they have only a small market share.

Rutile electrodes

The coating of rutile electrodes contains large quantities (about 2.5–4.5%) of the mineral rutile (TiO₂). Electrodes of this type produce an arc that is easy to strike and re-strike. They are very easy to use and produce neat welds with an easily removable slag. Unfortunately, they also produce a higher hydrogen content in the weld metal, which introduces the risk of hydrogen embrittlement and cracking and restricts their use to welding carbon steel having a minimum ultimate tensile strength less than 300 MPa.

There are two categories of rutile electrodes. The first has a lower proportion of cellulose constituents and a somewhat thicker coating, which produces a greater quantity of slag. These electrodes are intended primarily for horizontal welding, producing an almost spatter-free arc. The surface of the weld is smooth, and somewhat concave, but with good symmetry and uniformity.

The second category has a thinner coating, which produces a more rapid solidifying slag, with a more intensive arc due to the inclusion of a larger quantity of gas-forming substances. Electrodes of this type can be used for horizontal, vertical or overhead welding. Penetration is somewhat deeper, and the quantity of slag is less. Horizontal welds are flat to slightly convex, while downward vertical welds are concave.

Basic electrodes

Basic electrodes contain calcium fluoride (fluorspar – CaF₂) in the coating. The slag reacts as a base, thus leaving low sulphur and oxygen contents in the weld metal. The strength and toughness of the weld are therefore the strongest of those welds produced by any type of electrode, and the resistance to hot cracking is also higher. Basic electrodes produce a slag having a lower melting point than that from rutile and acid electrodes, which means that the risk of slag inclusions is slight, even if the slag has not been completely removed between passes. They are well suited for positional welding in all positions.

Due to the very high temperatures involved (up to 500°C) in the manufacture of electrodes, the moisture content of the coating is low when the electrodes are supplied. As a result, the hydrogen content in basic weld metals is low, thus providing good cold cracking performance.

Basic electrodes are, however, hygroscopic, which means that they must be stored in dry conditions. When delivered, they are normally packed in special diffusion-proof wrappings. Every welder should have access to a pouch, in which the electrodes can be kept at a temperature of 50–80°C throughout the working period. At the end of the day, the pouch can be emptied, and unused electrodes stored in an oven at a temperature of about 150°C.

The disadvantage of basic electrodes is that they produce a somewhat coarser and rougher weld surface, generally of a convex shape.
Cellulose electrodes

The coating of cellulose electrodes contains a relatively high proportion of cellulose substances, intended to produce excellent penetration by providing a high hydrogen content in the arc when welding in any position. These electrodes are used exclusively for welding oil or natural gas pipes. The coatings have a high moisture content and because the resulting weld metal contains a high dissolved hydrogen content, it is necessary to employ special methods of welding and to operate at elevated temperatures of 100–250°C even when welding relatively thin materials (>8–10 mm).

Penetration electrodes

Penetration electrodes are coated with a thick mixed rutile/acid coating, containing a high proportion of cellulose substances. They produce substantial gas emissions, that increase the arc penetration in the underlying base material. These electrodes are used only in the horizontal position and for welding I-joints (square butt joints).

<table>
<thead>
<tr>
<th>TABLE 3.2 Factors influencing the choice of welding electrode.</th>
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<tbody>
<tr>
<td>Factor</td>
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<td>Arc stability</td>
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<tr>
<td>Appearance of the weld bead</td>
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<tr>
<td>Striking the arc</td>
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<td>Strength of the weld</td>
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<td>Different welding positions</td>
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<td>Risk of slag inclusions</td>
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<td>Resistance to corrosion</td>
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<td>Fume formation</td>
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<td>Slag removal</td>
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<td>Hydrogen inclusion in the weld</td>
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</table>

High-yield electrodes

The productivity (the yield) of an electrode can be substantially improved by mixing iron powder with the coating. The resulting weld metal is produced both by the core electrode wire and the iron powder.

One can distinguish between normal-yield electrodes, having a yield of up to about 130%, and high-yield electrodes, which have a yield in excess of 130%, often up to 150–250%.
6.4 Weld defects

![X-ray film showing slag inclusions.](image)

**Slag inclusions**

The most common cause of slag inclusions is failure completely to remove the slag from one weld pass before making another. The inclusions may be in the form of individual particles or longer lines. Good working methods can reduce the risks.

- Slag should be carefully and thoroughly removed. Slag particles tend to be caught in hollows and sharp angles.
- Use the correct welding method. Avoid the use of excessively thick electrodes in confined joints. Try to weld in such a way as to avoid undercutting.

![Poor penetration gives a root defect.](image)

**Poor penetration**

A common form of root defect or poor penetration is that caused by insufficient penetration or the presence of slag residues in the root. It can be particularly difficult to achieve full penetration when restarting after replacing an electrode, and conditions are made more difficult by an uneven gap or joint shape. In such cases, it is often necessary to grind or chip the root side of the weld and to re-weld.