

/ Perfect Welding / Solar Energy / Perfect Charging



# MANUAL ARC WELDING WELDSRIPT

# USEFUL FACTS ABOUT THE HISTORY OF MANUAL ARC WELDING

These days, welding is carried out almost everywhere: whether underwater or in space, on large structures or in the smallest of components. But have you ever considered that we have been joining materials for over 5,000 years?

Around 3,000 years B.C., gold, silver and copper pieces were being joined together by means of thermal brazing. The forge welding of malleable iron then made it possible to produce artefacts and weapons. Since these early beginnings, welding technology has evolved tremendously and produced a wide variety of welding processes, one of which is manual arc welding. You can read about some of the milestones in the history of this particular welding process below:



The physicist Georg Christoph Lichtenberg successfully fuses together a watch spring and the blade of a knife using electricity. This marks the beginning of arc technology in the German-speaking part of Europe.



Professor Vasily Petrov of St. Petersburg studies the process of arc discharge. He also investigates the possibility of using discharge heat to melt metals.



The English chemist and physicist Sir Humphrey Davy examines the possibilities of the arc and its deflection by magnetic fields.



The Russian physician and mechanical engineer Nikolay Nikolayevich Benardos uses a carbon arc to fuse metal. A filler rod creates the necessary joint without any flow of current (carbon-workpiece arc).



Dr. H. Zerener of Berlin patents a device that can be used to heat up and melt solid bodies by means of electric currents or an electric arc. With this process, the arc is formed between two carbon electrodes (carbon-carbon arc).



The Russian engineer Nikolay Gavrilovich Slavyanov develops Benardos' idea further and dispenses with the additional electrode. Instead he generates the arc between the workpiece and a metal electrode, which also acts as the filler material (metal-workpiece arc). This approach gradually develops into the most widely-used form of arc welding technology.

The electrode used by Slavyanov was bare and therefore very difficult to weld. However, it was soon discovered that the welding process was much more stable if the filler rod contained a larger proportion of non-metallic inclusions. These inclusions were mostly in the form of oxides or silicates and originated during the production of the filler rod. During melting, these inclusions influenced the surface tension of the droplet and were also more readily ionised in the arc. Dedicated attempts to introduce more of these non-metallic materials into the filler rod ultimately led to the development of the selenium electrode with a core made from non-metallic components.



Oscar Kjellberg is granted German Imperial Patent No. 231733 "Electrode and process for electric brazing" and is thus considered the inventor of the coated electrode. This marks another important milestone in the development of manual arc welding.

Welding with covered electrodes is still very important in welding technology – for example, in pipeline construction.

# CONTENTS

<b>USEFUL FACTS ABOUT THE HISTORY OF MANUAL ARC WELDING .....</b>	<b>2</b>
<b>WELCOME! .....</b>	<b>7</b>
<b>1. THE LEARNING OBJECTIVES.....</b>	<b>8</b>
<b>2. BASIC KNOWLEDGE: JOINING MATERIALS .....</b>	<b>9</b>
<b>3. THE "MANUAL ARC WELDING" PROCESS .....</b>	<b>10</b>
3.1 Designations.....	10
3.2 Features and application areas .....	10
3.3 Setup and basic principle .....	11
3.4 Advantages and disadvantages of manual arc welding.....	12
3.5 Comprehension questions .....	12
<b>4. WELDING POSITIONS .....</b>	<b>13</b>
4.1 Definition .....	13
4.2 Classification.....	13
4.3 Comprehension questions .....	14
<b>5. ELECTRICITY AND MANUAL ARC WELDING .....</b>	<b>15</b>
5.1 Electric current.....	15
5.2 Electrical voltage.....	15
5.3 Electrical resistance.....	16
5.4 Ohm's law.....	16
5.5 Circuits .....	17
5.6 Short circuit.....	18
5.7 Types of voltage and current.....	19
5.7.1 DC voltage.....	19
5.7.2 Direct current .....	19
5.7.3 AC voltage .....	20
5.7.4 Alternating current.....	20
5.8 The welding current.....	21
5.9 The arc.....	21
5.10 Comprehension questions .....	22
<b>6. WELDING SYSTEM TECHNOLOGY .....</b>	<b>23</b>
6.1 Power sources .....	23
6.1.1 Constant current transformers.....	23
6.1.2 Thyristor-controlled power sources .....	24
6.1.3 Inverter power sources .....	25
6.1.4 AccuPocket.....	26
6.1.5 Welding transformer .....	27
6.2 Accessories .....	28
6.2.1 Preparing the manual arc welding process/checking accessories .....	28

6.2.2	Welding power-leads.....	28
6.2.3	Electrode holder .....	29
6.2.4	Current-return cable and earth clamp .....	30
6.3	Comprehension questions .....	30
<b>7.</b>	<b>POWER SOURCE CHARACTERISTIC – ARC CHARACTERISTIC – OPERATING POINT .....</b>	<b>31</b>
7.1	CC and CV characteristic.....	31
7.2	Technological parameters .....	33
7.2.1	Amperage and arc length .....	33
7.2.2	Working voltage .....	34
7.2.3	Arc-force dynamic (arc-force control) .....	34
7.2.4	Anti-stick function .....	34
7.2.5	HotStart .....	35
7.2.6	SoftStart.....	35
7.3	Comprehension questions .....	35
<b>8.</b>	<b>COVERED ELECTRODES .....</b>	<b>36</b>
8.1	Tasks of the electrode covering .....	36
8.2	Classification of covered electrodes.....	37
8.3	Types of covering and their characteristic properties .....	37
8.3.1	Acid electrodes (code: A).....	37
8.3.2	Cellulosic electrodes (code: C) .....	38
8.3.3	Rutile electrodes (code: R) .....	38
8.3.4	Basic covered rod electrodes (code: B).....	39
8.3.5	Overview of types of covering and their properties .....	40
8.4	Electrode efficiency and extension-length of rod electrodes.....	40
8.5	Storage.....	41
8.6	Rebaking .....	41
8.7	Requirements for covered electrodes .....	42
8.7.1	Welding-engineering requirements for rod electrodes.....	42
8.7.2	Metallurgical requirements for rod electrodes .....	42
8.7.3	Economic requirements for rod electrodes.....	42
8.8	Marking of covered electrodes .....	43
8.8.1	Marking on the rod electrode .....	43
8.8.2	Marking on the smallest packing unit.....	43
8.8.3	Standard-compliant marking .....	44
8.8.4	Basic approach for the designation of an unalloyed covered electrode for manual arc welding in accordance with DIN EN ISO 2560-A .....	44
8.8.5	Basic approach for the designation of a high-alloy covered electrode for welding austenitic, stainless steel in accordance with DIN EN ISO 3581 .....	45
8.9	Comprehension questions .....	45
<b>9.</b>	<b>GENERAL WELDING PROCEDURE.....</b>	<b>46</b>
9.1	Weld seam profiles .....	46
9.2	Weld-seam preparation .....	46
9.3	Electrode guidance .....	47
9.4	Comprehension questions .....	48

<b>10.</b>	<b>MANUAL ARC WELDING DEFECTS .....</b>	<b>49</b>
10.1	Types of defect and their causes .....	49
10.2	Comprehension questions .....	50
<b>11.</b>	<b>ELECTRIC ARC BLOW .....</b>	<b>51</b>
11.1.	Magnetic fields and their effect .....	51
11.2	Magnetic fields in the case of steel and other easily magnetised materials .....	52
11.3	Measures for dealing with arc blow .....	52
11.4	Comprehension questions .....	53
<b>12.</b>	<b>GOUGING .....</b>	<b>54</b>
12.1	ArcAir gouging .....	54
12.2	Instructions for ArcAir gouging .....	55
12.3	Comprehension questions .....	55
<b>13.</b>	<b>EQUIPMENT TO ENSURE A SAFE WORKPLACE FOR MANUAL ARC WELDING .....</b>	<b>56</b>
13.1	Safe working .....	56
13.2	Comprehension questions .....	57
<b>14.</b>	<b>ACCIDENT PREVENTION AND HEALTH PROTECTION .....</b>	<b>58</b>
14.1	Dangers due to arc radiation .....	58
14.2	Dangers due to electric current .....	59
14.2.1	Open circuit voltage .....	59
14.2.2	Safety precautions when working with electric current .....	60
14.3	Dangers due to welding fumes and gases .....	61
14.4	Comprehension questions .....	61
<b>Glossary .....</b>	<b>I-III</b>	



# WELCOME!

Thank you for your interest in our training on manual arc welding.

This document is intended to provide support during your training. You will therefore find lots of helpful information about manual arc welding on the following pages. You can look up useful information and find the appropriate answers to questions that may arise.

We hope you enjoy this training programme and wish you every success!





# 1. THE LEARNING OBJECTIVES

Once you have completed our "Manual Arc Welding" training, you will know a great deal about this welding process:

- / You will be familiar with the basic principles of the welding process and the device technology.
- / You will be familiar with the tasks and properties of the rod electrode.
- / You will be able to explain the process of manual arc welding.
- / You will be able to name the device technology required for manual arc welding and explain why the power sources must have a steeply drooping characteristic.
- / You will be able to name the main factors that influence the intensity of the welding current amperage.
- / You will know which tasks the electrode covering performs.
- / You will be able to explain how the type and thickness of the electrode covering affects the welding process.
- / And you will be able to name the characteristic properties of the various types of electrode covering.

Are you curious to find out more?  
Excellent! Let's get started!



Let's go!



## 2. BASIC KNOWLEDGE: JOINING MATERIALS

There are various manufacturing processes. These include forming, cutting, surfacing and joining materials.

According to DIN 8580 "Manufacturing processes – Terms and definitions", the joining of materials represents a main group to which all processes belong where two or more solid bodies with a geometrically defined design are permanently connected (joined).



When joining materials, a distinction is made between detachable and permanent joints.



Detachable and permanent joints

- / Examples of detachable joints:  
Screws, pinned joints, keys.
- / Examples of permanent joints:  
Welding, brazing, bonding, riveting.



A further classification for the joining of materials refers to the way in which the joint is created. Here, a distinction is made between solid, form-locked and non-positive joints.



Solid, form-locked and non-positive joints

- / Solid joints create a joint in the material itself. These include welded and brazed joints.
- / Form-locked joints use the form of the components to join them. These include hooks and eyes.
- / Non-positive joints are held together by frictional forces.

# 3. THE "MANUAL ARC WELDING" PROCESS

## 3.1 Designations

Various designations are used for the "manual arc welding" process:

AREA OF APPLICATION	DESIGNATION
International standard DIN EN ISO 4063	Welding process with the number 111
Germany	E-Hand
United Kingdom	Manual Metal Arc Welding (MMAW)
USA	Shielded Metal Arc Welding (SMAW)

Tab. 1: Designation variants for manual arc welding.



The major advantage of manual arc welding is that nearly all metals can be welded using this process.



Almost all metals can be joined using manual arc welding.

## 3.2 Features and application areas

The main application area for manual arc welding is steel and pipeline construction. This welding process is also often used in the metalworking sector. Manual arc welding is the preferred welding process for assembly work, as the mechanical effort is relatively low compared to other welding processes.

Manual arc welding can be carried out with fault-free results, even in unfavourable weather conditions, such as wind and rain. This is useful when working outdoors, for example.

Another advantage of manual arc welding over other welding processes is that welding can often be carried out without any defects, even if the join is not bare metal throughout.

Manual arc welding can also be performed underwater.

Manual arc welding has a market share of 5 to 10% of the total consumption of weld filler metals in Europe.

The impressive features of manual arc welding include the low mechanical effort and the many and varied areas of application.

### 3.3 Setup and basic principle

The setup: A power source with two poles is used; the rod electrode is connected to one pole and the workpiece to the other. The rod electrode is connected to the pole by means of a welding power-lead and the electrode holder. The workpiece is connected to the other pole by means of another welding power-lead and a workpiece clamp (Figure 1).

Alternating or direct current can be used for manual arc welding, although not all electrodes can be welded with alternating current.

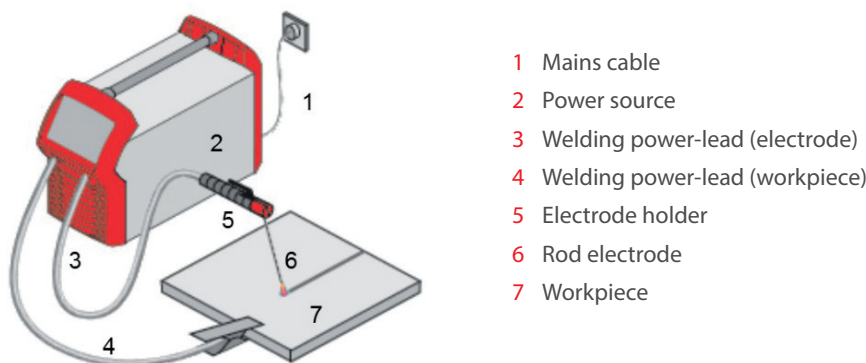


Fig. 1: Components and setup of a workplace for manual arc welding.

In manual arc welding, the welding heat is generated by an electric arc. An arc is a short path of air or gas through which electric current flows.

The arc

The basic principle: After turning on the power source, the arc is ignited by bringing the rod electrode into contact with the workpiece. Through this action the two poles are short circuited for a fraction of a second, allowing current to flow. The ignited arc burns between the workpiece and a consumable, covered electrode and generates the necessary heat of fusion. The protective slag and gas shroud are created by the consumable core wire and the consumable covering of the electrode.

Slag and gas shroud

A low voltage and high amperage are required for manual arc welding. The power source transforms the high mains voltage into a considerably lower welding voltage. At the same time, the power source supplies the high amperage required, which can also be adjusted and regulated using the power source.

Voltage and amperage

In manual arc welding, the amperage is the main parameter that determines the quality of the welded joint. It is therefore important that the amperage remains as constant as possible – even if the arc length changes. In order to ensure a constant amperage, power sources for manual arc welding always have a drooping characteristic (see also page 27f).

Drooping characteristic

### 3.4 Advantages and disadvantages of manual arc welding



#### Advantages

- + Easy to use
- + Can be used anywhere: in the workshop, outdoors, underwater
- + Low noise level (with rectifier)
- + Low purchase costs
- + Weld seam is protected by slag formation
- + Relative insensitivity to contamination such as rust, scale, oil and grease
- + Almost all metallic materials can be welded
- + Highquality weld seam and good mechanical properties



#### Disadvantages

- Low welding speed
- Large build-up of smoke
- Arc blow
- Greater source of error due to end-craters and approach points
- Electrode diameter depends on the sheet thickness and welding position
- Long set-up and downtimes: rebaking electrodes in standard packaging, clamping electrodes, removing stubs, removing slag and spatter
- Cannot be mechanised



The advantages and disadvantages of the welding process at a glance

### 3.5 Comprehension questions

/ What other designations are used for manual arc welding?

/ Which components characterise the setup at a workplace for manual arc welding?

/ What is the basic principle of manual arc welding?

/ What are the advantages and disadvantages of manual arc welding?



# 4. WELDING POSITIONS

## 4.1 Definition

Based on the way in which the components are welded together, a fundamental distinction is made between:

1. Butt welds
2. Fillet welds

In the case of butt-welded joints, the components are positioned at a 180° angle to each other and are therefore welded evenly. To ensure that the weld seam runs through the entire workpiece, an angle grinder is first used on materials roughly 5 mm thick or more to create a V-shaped opening between the workpieces that are to be joined.

Butt welds

In the case of fillet-welded joints, the components that are to be welded together are at an angle to each other (usually a right angle). Depending on the way in which the components are joined, a distinction is made between different types of fillet welding processes, such as side fillet weld, edge fillet weld, root-face weld, chord weld or corner weld.

Fillet welds



Welding positions describe the position of the weld seam during the welding process.



Definition of welding positions.

Each welding position requires a specific welding technology, which in turn can influence the choice of electrodes and/or amperage.

The position of the workpieces to be welded and the position of the electrode in relation to the weld seam result in a wide range of welding positions.

## 4.2 Classification

The welding positions are classified in accordance with international standard DIN EN ISO 6947. In line with this standard, the different welding positions have a classification that is valid worldwide (Figure 2):



<b>PA</b>	Flat position for butt and fillet welds	<b>PF</b>	Vertical up position
<b>PB</b>	Horizontal vertical position	<b>PG</b>	Vertical down position
<b>PC</b>	Horizontal position	<b>PH</b>	Pipe position for welding upwards
<b>PD</b>	Horizontal overhead position	<b>PJ</b>	Pipe position for welding downwards
<b>PE</b>	Overhead position		



Classification of welding positions according to DIN EN ISO 6947.



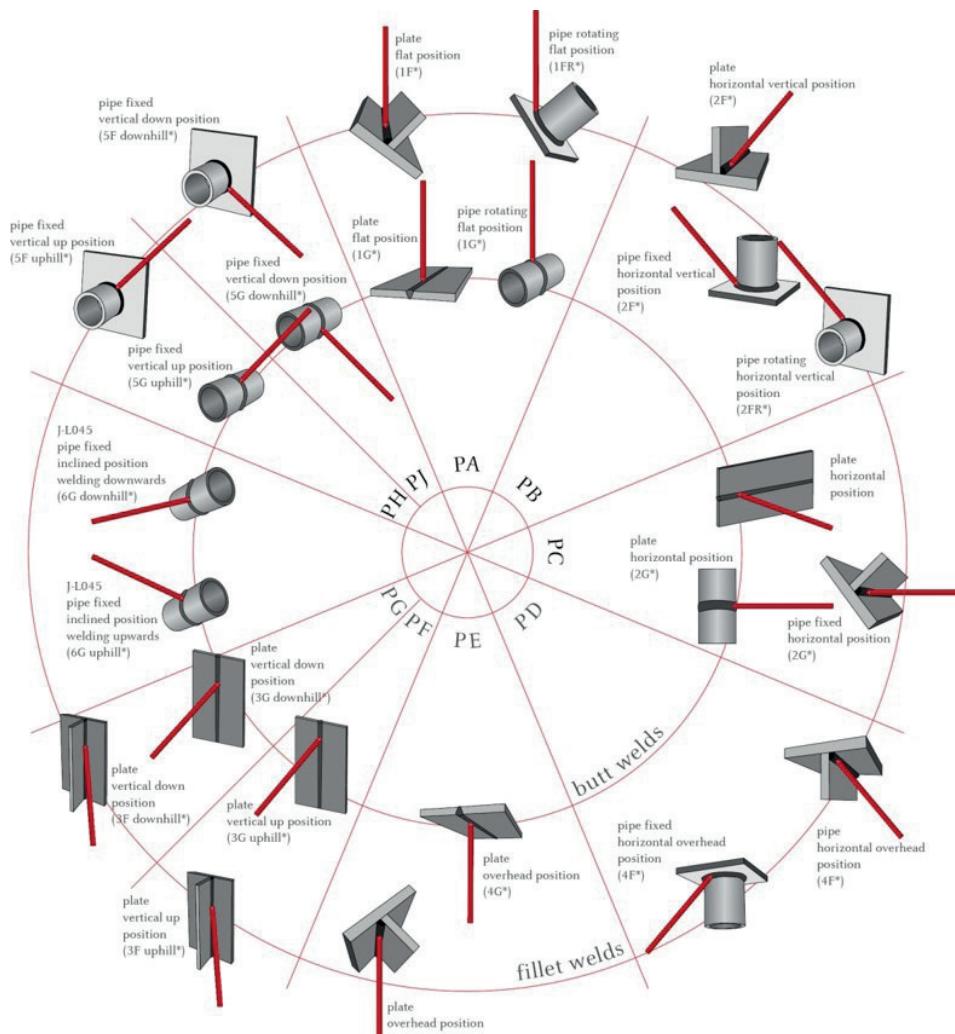


Fig. 2: Welding positions according to DIN EN ISO 6947.

### 4.3 Comprehension questions

/ According to DIN EN ISO 6947, what is the welding position for the vertical up position on sheets?



/ According to DIN EN ISO 6947, what is the welding position for the overhead position on sheets?

# 5. ELECTRICITY AND MANUAL ARC WELDING

## 5.1 Electric current

Symbol: I      Unit: Ampere (A)

Current is the directional movement of negatively charged carriers (electrons). The symbol I describes the amount of current flowing through the conductor over a certain period of time.

For current to flow, it requires an electrical voltage. This occurs between two oppositely charged poles and is the driving force that causes the movement of the electrical charge, in a similar way to water pressure. The higher the voltage, the more current can flow.

Resistance is the "adversary" of voltage, as voltage is lost when resistance is encountered.

Atoms have a nucleus which contains protons and neutrons; electrons are located on the atomic shell, which consists of several layers. The proton is positively charged, the neutron has no charge, and the electron is negatively charged. Although the number of protons, neutrons, and electrons differs for every material, the atomic nucleus is always positively charged.

Atoms, protons  
and electrons.



The technical direction of flow (e.g. in drawings) runs from the positive pole to the negative pole.

The actual physical direction of flow runs from the negative pole to the positive pole.



Technical and  
physical direction  
of flow

## 5.2 Electrical voltage

Symbol: U      Unit: Volt (V)

Electrical voltage occurs between two points with opposite charge potential, for example between a positive and negative pole.

Charges of various magnitude try to balance each other out through the flow of a current. This difference is referred to as the voltage. The greater the voltage, the greater the distances that can be bridged. Only the voltage will allow current to flow.

The symbol U indicates the magnitude of the difference in the electrical charge.

Electrical voltage causes  
current flow.

## 5.3 Electrical resistance

Symbol: R      Unit: Ohm ( $\Omega$ )

The electrical resistance indicates how much the electrons are slowed down while the current flows. The resistance is therefore the core value for electrical conductivity: materials with high electrical conductivity have a low resistance, poor conductors have a high resistance.

Electrical resistance slows down current flow.

All materials have different levels of resistance to the flow of electrons. A distinction is made between conductors, semiconductors and non-conductors. In the case of electrical conductors (metals, etc.), the electrical charge carriers move. In the case of non-conductors (e.g. glass or rubber), they are fixed.

## 5.4 Ohm's law

Ohm's law is named after the man who discovered it, George Simon Ohm. He found that there is a linear relationship between current, voltage and resistance:

1. The amperage and the electrical voltage are dependent upon each other.
2. At constant resistance, the amperage and the voltage increase proportionally.
3. At constant current, the voltage and resistance are proportional: the greater the resistance, the higher the voltage.
4. At constant voltage, the amperage is inversely proportional to the resistance: as the resistance increases, the current decreases.



The formula for Ohm's law is therefore:  $U = R \times I$



Ohm's law

## 5.5 Circuits

An electrical circuit consists of at least one power source and various electrical components that can be connected together.



The basic components of a circuit:

- / Voltage or current source as the power generator (power supply unit, battery, dynamo, etc.)
- / Power consumers, connected together via cables (motor, lamp, etc.)
- / Switches
- / Cables



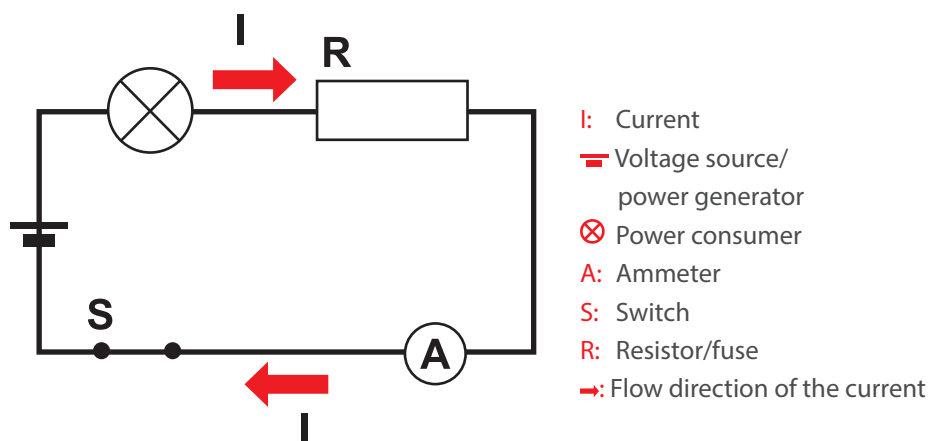
Basic components of a circuit

There are two different types of circuits:

1. Closed circuits
2. Open circuits

Types of circuits

In a closed circuit, the individual elements are connected together in such a way that charge can be transported: current flows (Figure 3).



Closed circuit

Fig. 3: Closed circuit.

For manual arc welding, it is important to understand electric circuits and welding circuits, and to be familiar with their common characteristics and differences.

In an open circuit, the connection is interrupted, i.e. no current flows (Figure 4). The interruption can either be triggered intentionally with a switch or it happens inadvertently, e.g. due to a loose contact, missing cable or similar.

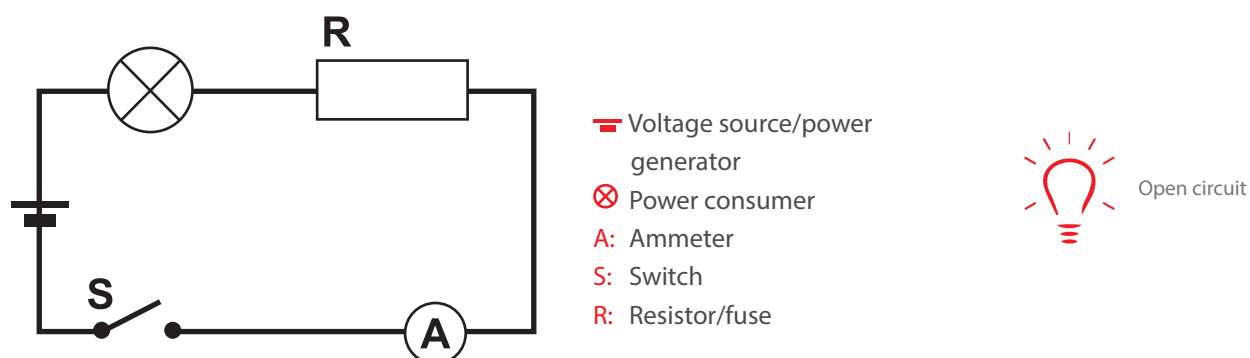


Fig. 4: Open circuit.

## 5.6 Short circuit

An electrical short circuit is a practically unopposed connection between the two poles of an electric current or voltage source. The voltage drops to almost zero in the event of a short circuit.

When a short circuit occurs, the current reaches its maximum value (initial short circuit current). This current is only limited by the resistance of the cable and the effective inner resistance of the current or voltage source.

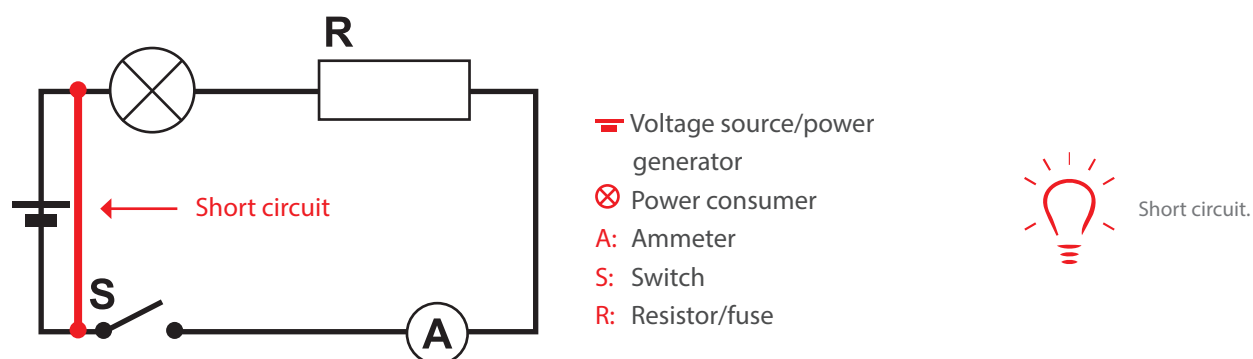


Fig. 5: Short circuit



## 5.7 Types of voltage and current

### 5.7.1 DC voltage

From a technical and presentational viewpoint, current always flows from the positive pole to the negative pole of a voltage source. If the assignment of the poles does not change and the flow direction of the current therefore also remains unchanged, this is referred to as DC (direct current) voltage.



DC voltage is an electrical voltage where the intensity (value) and direction (polarity) do not change (Figure 6).



Definition of DC voltage

### 5.7.2 Direct current

Designation variants:

<b>GERMAN DESIGNATION</b>	Gleichstrom
<b>INTERNATIONAL DESIGNATION</b>	Direct Current
<b>ABBREVIATION</b>	DC
<b>SYMBOL</b>	— — —

Tab. 2: Designation variants for direct current.



Direct current is an electric current where the intensity (value) and direction (polarity) do not change (Figure 6).



Definition of direct current

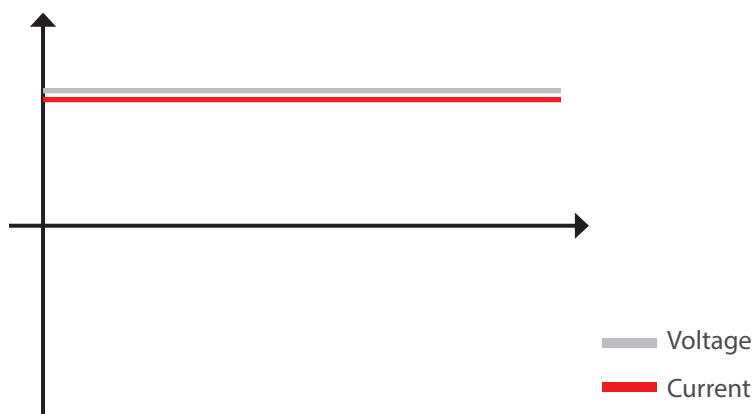


Fig. 6: Direct current and DC voltage.

Mixed current with DC as the predominant component is also referred to as direct current, provided that the fluctuations that occur are negligible for the intended use.

### 5.7.3 AC voltage

There are voltage sources (e.g. sockets) where the polarity changes on a recurring basis. The voltage change also changes the flow direction of the current. This voltage is referred to as AC (alternating current) voltage.



AC voltage is an electrical voltage where the intensity (value) and direction (polarity) change at regular, recurring intervals (Figure 7).



Definition of AC voltage

### 5.7.4 Alternating current

Designation variants:

<b>GERMAN DESIGNATION</b>	Wechselstrom
<b>INTERNATIONAL DESIGNATION</b>	Alternating Current
<b>ABBREVIATION</b>	AC
<b>SYMBOL</b>	~

Tab. 3: Designation variants for alternating current.



Alternating current is an electric current where the intensity (value) and direction (polarity) change at regular, recurring intervals. Due to the periodic repetition of positive and negative values, the average amperage over time is zero (Figure 7).



Definition of alternating current

There are various types of alternating current. The waveform of the AC voltage describes the alternating quantity. Square-wave voltage, saw-tooth voltage, delta voltage and sinusoidal voltage, or a combination of all of these variants, are pure alternating quantities.

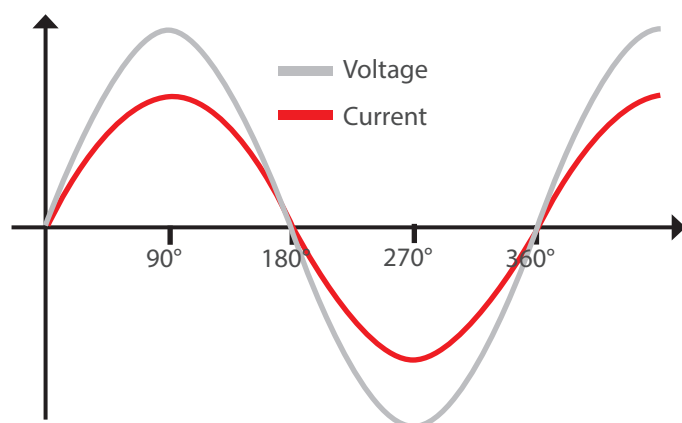


Fig. 7: Alternating current and AC voltage.

## 5.8 The welding current

A welding circuit behaves like an electric circuit, which is why Ohm's law also applies for the welding circuit.

However, in contrast to an electric circuit, a welding circuit consists of other components.



The components of a welding circuit:

- / Power source
- / Electrode holder
- / Electrode
- / Workpiece



Components of a welding circuit

The welding circuit is crucial for the formation of the arc, without which manual arc welding is not possible.

In a welding circuit, the symbol for the welding current is  $I_s$  (A); the welding voltage is specified with  $U_s$  (V).

## 5.9 The arc

A closed circuit is a prerequisite for the formation of an arc. Every circuit has a positively and a negatively charged pole. At the negatively charged pole (cathode), there is an excess of electrons that are attracted by the positively charged pole (anode). This attractive force causes electrons to flow from the negative pole to the positive pole (physical direction of flow). The power source in the welding circuit ensures that a controlled flow of electrons is maintained (Figure 8).

Electron flow from the negative to the positive pole

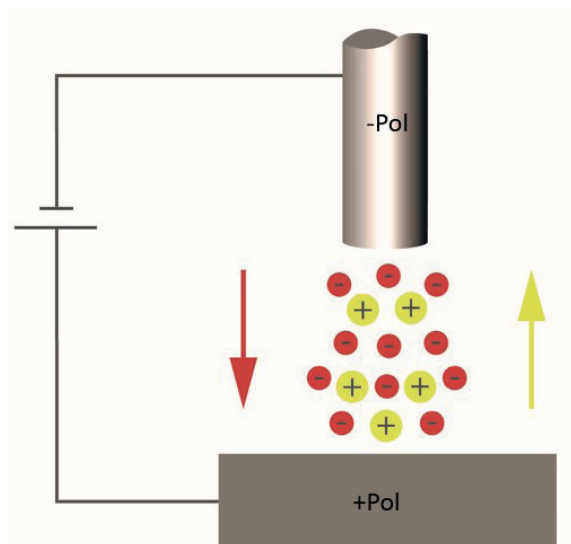


Fig. 8: Electron flow between the poles.

In the closed welding circuit, during electron flow, the electrons must overcome a gap between the electrode and workpiece. This distance is bridged by way of the arc. As a moving electrical conductor, it closes the welding circuit and ensures that the electrons can flow. In the welding circuit, the arc also exhibits resistance.

The arc as an electrical conductor

The state which arises in the arc is referred to as the "plasma" state. An important attribute of plasma is its ability to generate a great deal of thermal energy in a tightly restricted space, ultimately forming the welding arc.



Plasma is the fourth state of aggregation alongside the solid, liquid and gaseous states.



Plasma

## 5.10 Comprehension questions

/ What is the name of the unit used for electrical voltage?

---

/ What is the name of the unit used for electric current?

---

/ What are the different types of current and voltage?

---



# 6. WELDING SYSTEM TECHNOLOGY

## 6.1 Power sources

Arc welding requires a high amperage and a low electrical voltage. To achieve this, a power source is needed. Power sources transform the high-voltage, low-amperage current from the grid into a current suitable for welding. Furthermore, power sources ensure that the AC voltage from the grid is rectified (except in the case of constant current transformers) and the welding current is regulated.

Tasks of the power source

The following types of power sources can be used for manual arc welding:

### 6.1.1 Constant current transformers

In welding system technology, constant current transformers (Figure 9) are the devices with the simplest design.

Constant current transformers

The transformer consists of two separate windings on a single iron core (Figure 10). The primary coil has many windings, the secondary coil has a lot fewer. The welding current is regulated by tapping the primary coil. To enable continuous regulation of the welding current amperage, a moving yoke is often installed between the secondary and primary coil, which enables the spread of the magnetic field to be changed (yoke control). A constant current transformer only supplies alternating current.

Yoke control



Fig. 9: Constant current transformer.

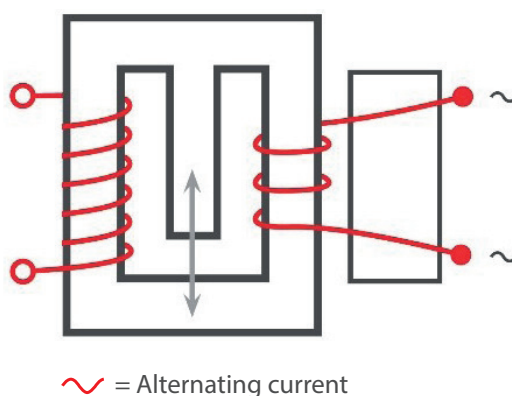


Fig. 10: Schematic structure of the constant current transformer.





### Advantages

- + Low purchase costs
- + Very robust due to the simple design



### Disadvantages

- Large reactive current component
- Heavy
- Large size
- Current can be set remotely only through complicated mechanical means
- Due to the alternating current, not suitable for some types of welding electrode



The advantages and disadvantages of constant current transformers at a glance

## 6.1.2 Thyristor-controlled power sources

Thyristor power sources (Figure 11) use a rectifier to transform the alternating current into rectified welding current (Figure 12). The current is regulated via controllable switching elements in the rectifier: the thyristors. A built-in induction coil smooths out unwanted current peaks, thereby reducing welding spatter.



Fig. 11: Thyristor-controlled power source.

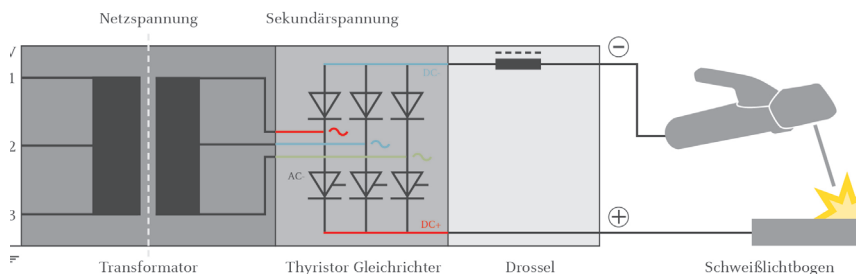


Fig. 12: How the thyristor-controlled power source works.



### Advantages

- + Easy to control and regulate
- + Remote control possible
- + Direct current as the welding current
- + Simple and inexpensive to maintain
- + Moderate arc blow



### Disadvantages

- Takes up a lot of space due to its large size
- Heavy
- Slow control process
- Higher purchase costs than a welding transformer
- The bulky output smoothing choke that is required means that the efficiency is no more than 70 percent



The advantages and disadvantages of the thyristor-controlled power source at a glance.



Constant current transformers and thyristor-controlled power sources are operated at a grid frequency of 50 Hz. As a result, these two device types require a relatively big welding transformer and a large smoothing choke, both of which make the devices heavy and bulky. These two power sources are now hardly ever used in industrial applications.



Constant current transformers and thyristor-controlled power sources are being replaced by inverter technology.

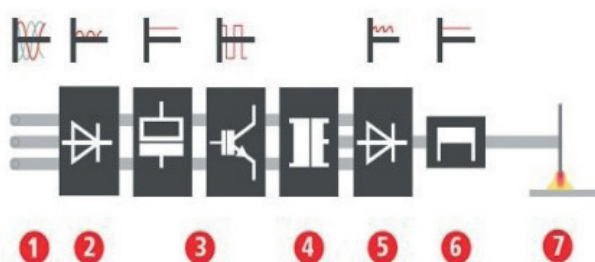
### 6.1.3 Inverter power sources

Inverter power sources (Figure 13) are state-of-the-art power sources. The devices generate a high-frequency pulsed voltage from the mains voltage. With inverter power sources, the mains voltage is rectified immediately downstream of the main switch (hence the name "inverter") and is then broken down by a transistor stage. This transistor stage, also referred to as the primary power module, works with 25 to 100 kHz, depending on the type of device. This means that the welding transformer is supplied with up to 100,000 Hz rather than 50 Hz. This voltage arrives at the welding transformer which, thanks to the high frequency, can be designed as a light, compact and efficient device.

Inverter power sources also have a rectifier. However, the low current ripple of the transformer output current allows for a much more compact design, in some cases even eliminating the output choke completely. The rectifier for inverter power sources therefore consists solely of uncontrolled diodes.



Fig. 13: Inverter-controlled power source.



- 1: Input: sinusoidal alternating current
- 2: Rectification (primary)
- 3: Buffering and switching
- 4: Transformation
- 5: Rectification (secondary)
- 6: Smoothing
- 7: Welding output

Fig. 14: How an inverter power source works.

The latest generation of MMA inverters features a resonance inverter with specially arranged capacitors. The capacitors generate and store energy by interacting with the welding transformer. At the same time, the welding transformer also builds up energy by recovering electricity from the magnetism which it itself produces during discharge. When the transformer and capacitors are coordinated in such a way that they charge each other, this is referred to as resonance.

Resonance inverter  
and resonance

By cleverly combining resonance and the storage function, valuable power reserves are created which are then available to the arc if required. The result is an ideal characteristic that enables perfect welding results that can be reproduced at any time and optimum process reliability. Even mains leads longer than 100 m, fluctuations in the mains voltage and generator-powered operation do not have a negative impact on the welding result. Another advantage of the resonance inverter is that it can be used to weld all electrode types.



#### Advantages

- + Small and lightweight
- + Can be remote-controlled
- + Rapid control gives good weld properties
- + Direct current as the welding current
- + All electrode types can be welded with resonance invert



#### Disadvantages

- Complex design
- Higher maintenance costs



The advantages and disadvantages of the inverter-controlled power source at a glance.

### 6.1.4 AccuPocket

Battery-powered power sources offer ample freedom of movement. In practice, this means better welding results than could be obtained with a comparable mains-only MMA welding system. In addition, time-consuming preparatory work is reduced, since long mains leads or large generators are no longer necessary.



Battery-powered, portable power sources include the following components:

1. Power source
2. Battery
3. Battery charging system



Components of a battery-powered power source

Battery-powered power sources combine a comparatively low weight and independence from the grid with a relatively long operating time. When fully charged, this welding system (Figure 15) can weld up to six 3.25-mm electrodes or 16 electrodes with a diameter of 2.5 mm.

The batteries for these types of mains-independent power sources are specifically tailored to the devices. Special control systems (AccuBoost Technology) ensure that the battery, power source and welding electronics work together in perfect harmony.



Fig. 15: AccuPocket.



Fig. 16: ActiveCharger.

Since portable, battery-powered power sources usually need to be ready for use in no time at all, special requirements must be met by the battery charging systems. To enable a short charging time, battery charging systems such as the ActiveCharger (Figure 16) use Active Inverter Technology. This technology enables the battery to be almost fully charged in a short amount of time in rapid charging mode – up to 90% in just 30 minutes.



#### Advantages

- + Lightweight
- + Powerful battery
- + Ample freedom of movement
- + Ready for use in no time at all



#### Disadvantages

- Power time depends on the battery power
- Limited service life of batteries



The advantages and disadvantages of the AccuPocket at a glance.

### 6.1.5 Welding transformer

Welding transformers, also referred to as a welding set or welding generator, are driven by a combustion engine (Figure 17). Welding transformers are therefore used in locations where there is no access to the electricity grid, for example on construction sites. Welding transformers are generally reserved for special applications, such as the field welding of pipelines.



Fig. 17: Diesel welding set and generator



### Advantages

- + Independence from the mains supply



### Disadvantages

- Noisy
- Heavy
- Only for use in special applications



The advantages and disadvantages of the welding transformer at a glance

## 6.2 Accessories

For a stable arc and good welding results, it is essential that the appropriate accessories are used correctly and that they are in perfect condition.



Manual arc welding accessories include:

- / Welding power-leads
- / Electrode holders



Accessories for manual arc welding.

### 6.2.1 Preparing the manual arc welding process/checking accessories

The following must always be checked before starting up:

- ☐ Is the insulation of the welding power-leads damaged?
- ☐ Is the insulation of the electrode holder damaged?
- ☐ Are the cross-sections at the connection points OK and not reduced due to strand breakage?



Observe the checklist

**Damaged parts must be repaired or replaced IMMEDIATELY!**

**Important safety instruction!**

### 6.2.2 Welding power-leads

The following applies to welding power-leads:

1. The longer the cables are and the smaller the cable cross-section, the greater the electrical resistance.
2. As the amperage increases (e.g. above 200 A), so too do voltage losses. The cable length and the copper cross-sections must be coordinated so as not to overload the welding power-leads and to minimise voltage losses.





**Important:**

1. ALWAYS connect the welding power-leads and grounding cable before switching on the welding system.
2. When reversing the polarity of the welding power-leads, the device MUST be switched off if there is no polarity switch.
3. Connect the grounding cable directly to the workpiece or the workpiece support and AS CLOSE AS POSSIBLE to the welding location.

Important safety instructions regarding the handling of welding power-leads!

The table below shows the load capacity of welding power-leads at a duty cycle of 60%:

WELDING CURRENT AMPERAGE	CABLE CROSS-SECTION UP TO 10 M	CABLE CROSS-SECTION UP TO 50 M	CABLE CROSS-SECTION UP TO 100 M	CABLE CROSS-SECTION ABOVE 100 M
150 A	16 mm ø	25 mm ø	35 mm ø	50 mm ø
200 A	25 mm ø	35 mm ø	50 mm ø	70 mm ø
250 A	35 mm ø	50 mm ø	70 mm ø	-
300 A	50 mm ø	70 mm ø	95 mm ø	-
400 A	70 mm ø	95 mm ø	-	-
500 A	95 mm ø			-

Tab. 4: Relationship between welding current amperage and cable cross-sections.

Explanatory example: At 250 amperes and a cable length of 25 metres, a power cable of at least 50 mm<sup>2</sup> must be used.

To ensure good power transmission, it is also important that appropriate couplings (Figure 18) are used to connect the cables to the power source.



Fig. 18: Welding power-leads with couplings.

### 6.2.3 Electrode holder



The following points must be observed when using electrode holders:

- / Fully-insulated electrode holders must be used to prevent electrification.
- / Electrode holders must not be held under your arm.
- / If possible, use electrode holders that allow electrodes to be clamped at different angles.



Important information regarding the handling of electrode holders.



Fig. 19: Insulated electrode holder, 150 A, 60% D.C.



Fig. 20: Insulated electrode holder, 250 A, 60% D.C.

#### 6.2.4 Current-return cable and earth clamp

The welding current-return cable is connected directly to the workpiece or the support. Either clamps or magnetic connectors are used for this.



Other parts, such as steel structures, tracks, pipelines, crane support ropes, chains or similar must not be used instead of the welding current-return cable.



Important safety instruction!

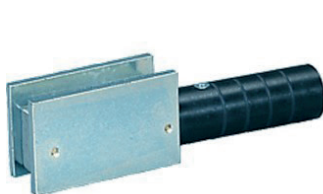


Fig. 21: Current-return cables and earthing clamps or magnetic earth clamp.

### 6.3 Comprehension questions

/ What is the advantage of an inverter power source?

/ What must you be aware of when using longer welding power-leads?



# 7. POWER SOURCE CHARACTERISTIC – ARC CHARACTERISTIC – OPERATING POINT

## 7.1 CC and CV characteristic

A power source must be able to maintain the set welding current, even if the length of the arc changes (distance between the electrode and workpiece).



If the arc becomes longer, the welding voltage increases. If the arc becomes shorter, the welding voltage decreases. This relationship is referred to as control response.



Definition of control response

According to Ohm's law  $U = R \times I$  applies to the amperage I:

$$\text{Amperage (I)} = \frac{\text{Voltage (U)}}{\text{Resistance (R)}}$$

According to this formula, voltage and resistance must be proportional to each other in order to maintain a constant current value.

In manual arc welding, it is not possible to keep the arc length constant 100% of the time. This is why a constant-current characteristic (CC characteristic) is used for this welding process. The CC characteristic regulates the arc length using the electrical voltage. This means that the amperage remains constant and the arc is still maintained if the electrode guidance changes.

Constant-current characteristic

In turn, the welding voltage  $U_s$  (V) is defined by the arc characteristic. Its position depends on the electrode diameter used and the type of electrode.

Representation of a CC characteristic:

The welding voltage  $U_s$  (V) is continuously adapted, the welding current  $I_s$  (A) is kept constant. This current is also referred to as the constant current. The characteristic, which is also referred to as a constant-current characteristic, is strongly drooping (Figure 22).

Strongly drooping characteristic

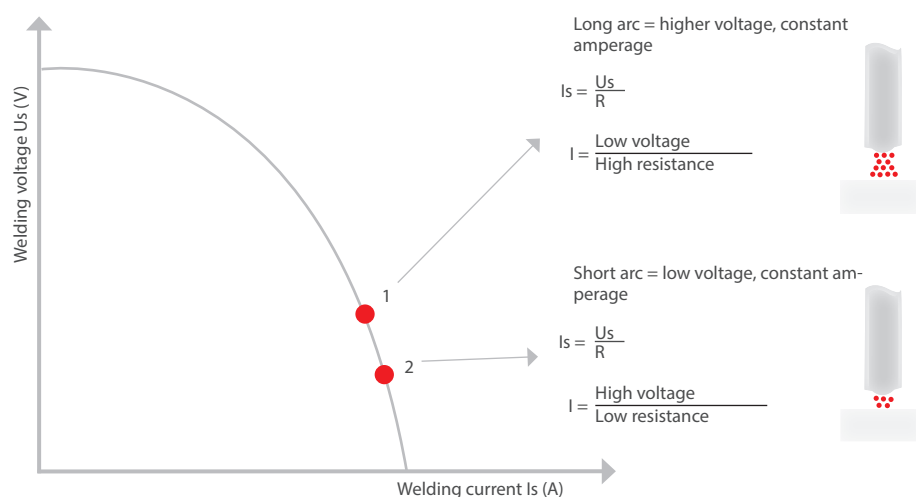


Fig. 22: The strongly drooping characteristic of the CC characteristic.

In manual arc welding, the welding current amperage  $I_s$  (A) is set by selecting the power source characteristic.

If the power source characteristic and the arc characteristic are presented together in a diagram (Figure 23), the static operating point can be read at their point of intersection. This indicates the arc's effective welding current  $I_s$  (A) and the welding voltage  $U_s$  (V).

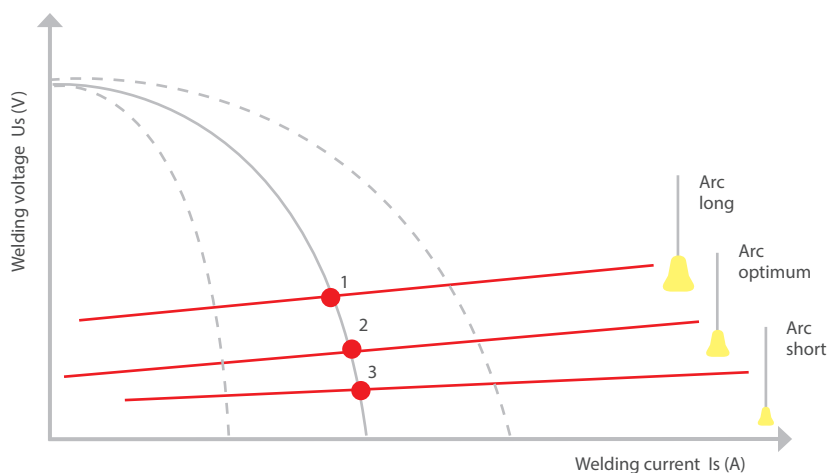


Fig. 23: Power source characteristic – arc characteristic – operating point

Determining the operating point based on the power source characteristic and the arc characteristic.

### CV characteristic:

The counterpart to a constant-current characteristic is a constant-voltage characteristic (CV characteristic).

Current-voltage characteristic

For power sources with the CV characteristic, the welding voltage  $U_s$  (V) remains constant during welding and the welding current amperage  $I_s$  (A) is continuously adapted. The welding current is increased or decreased to regulate the welding process.

Power sources with the CV characteristic are not suitable for manual arc welding, as the arc would be extinguished immediately whenever the electrode was drawn back. Multiprocess systems are an exception.

Power sources with CV characteristic are therefore used for metal inert gas welding (MIG) and metal active gas welding (MAG).

## 7.2 Technological parameters

### 7.2.1 Amperage and arc length

The main parameter for manual arc welding is the welding current amperage  $I_s$  (A).

The welding current amperage

/ ... is continuously adjusted at the power source.

/ ... depends on the core-wire diameter.



Rule of thumb for the welding current  $I_s$ :

$$I_s \text{ (A)} = \text{core-wire diameter (mm)} \times 40$$



Formula for calculating the welding current amperage

The welding voltage  $U_s$  (V) is defined by the selected arc length. It varies in the range between approx. 20 and 35 V and is determined manually by keeping the arc length as uniform as possible. Welding is mainly performed under direct current.

/ Rutile electrodes can be welded with good results under negative direct current.

/ Basic electrodes can be welded with good results under positive direct current.

The arc length depends on the type of electrode. Nevertheless, the arc should always be kept relatively short.



The following rules of thumb apply:

Rutile, acid and cellulose electrode types:

$$\text{Arc length} = 1 \times \text{core-wire diameter}$$

Basic high-alloy electrode types:

$$\text{Arc length} = 0.5 \times \text{core-wire diameter}$$



Relationship between the electrode type and arc length

## 7.2.2 Working voltage

For power sources for manual arc welding, the working voltage  $U_s$  (V) is standardised according to DIN EN 60974-1.



The following applies:

$$U_s = 20 + 0.04 (I_s) \text{ where } (I_s) \leq 600 \text{ A or}$$

$$U_s = 44 (I_s) \text{ where } (I_s) \geq 600 \text{ A}$$



Formulas for calculating the working voltage

## 7.2.3 Arc-force dynamic (arc-force control)

If welding is performed by means of globular material transfer using just a small amount of current, i.e. underloaded, there is a risk of the electrode sticking. To prevent this from happening, more current is supplied for a fraction of a second just before sticking occurs, thanks to arc-force control. This allows the electrode to burn itself free, thus preventing it from sticking.

Arc-force control

Arc-force control therefore allows rod electrodes to be welded at a very low amperage, which is an advantage for edge applications, for example.

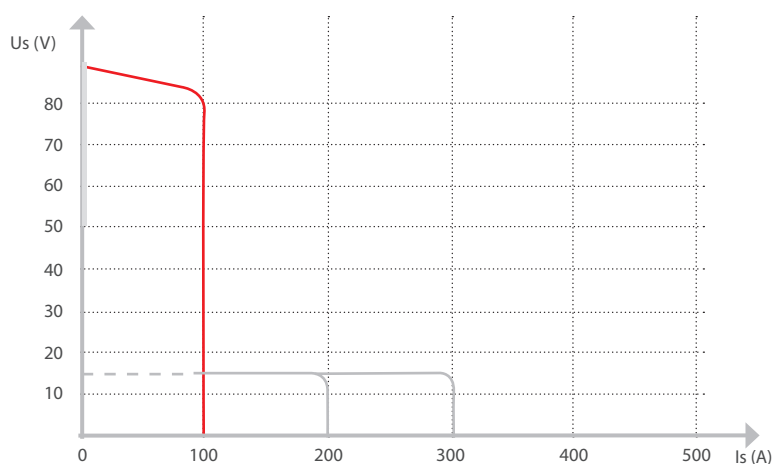


Fig. 24: Influence on the constant current characteristic through the arc-force dial.

## 7.2.4 Anti-stick function

If the electrode sticks, a short circuit occurs. In order to prevent the electrode being destroyed, the power source is immediately and automatically switched off by the anti-stick function.

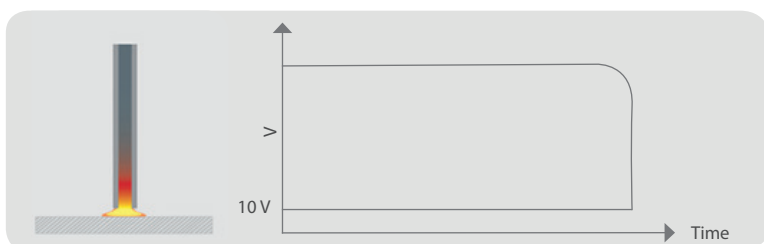


Fig. 25: Anti-stick function.

Anti-stick function

### 7.2.5 HotStart

With a HotStart at the power source, the current is increased for a fraction of a second during ignition to make the electrode easier to ignite.

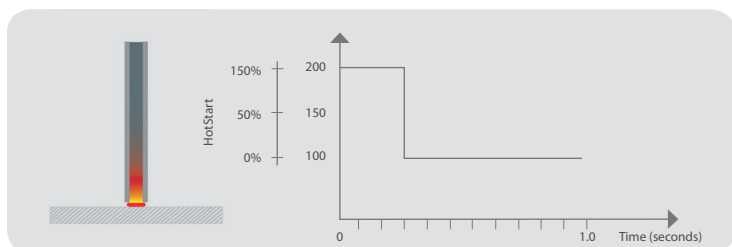


Fig. 26: Ignition phase with HotStart. Set welding current  $I_s$ : 100 A.

HotStart

### 7.2.6 SoftStart

The SoftStart method is used with basic electrodes in particular to reduce pore formation during ignition.

With a SoftStart, the low starting energy means that the base material does not melt to any great depth, thus making it possible to weld over the starting point and allowing the weld pool to outgas better. This prevents pore formation at the start of the weld seam.

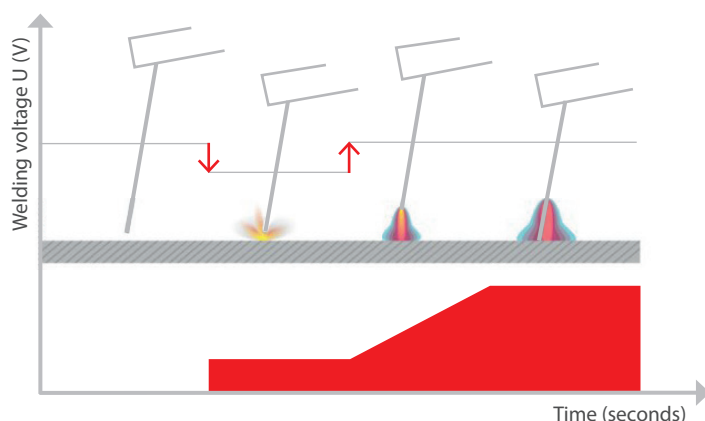


Fig. 27: SoftStart ignition.

SoftStart

## 7.3 Comprehension questions

/ Which power sources are used for manual arc welding?

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/ What principle governs the arc length in manual arc welding?

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/ What additional function do modern power sources have to make ignition easier with basic covered rod electrodes?

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## 8. COVERED ELECTRODES

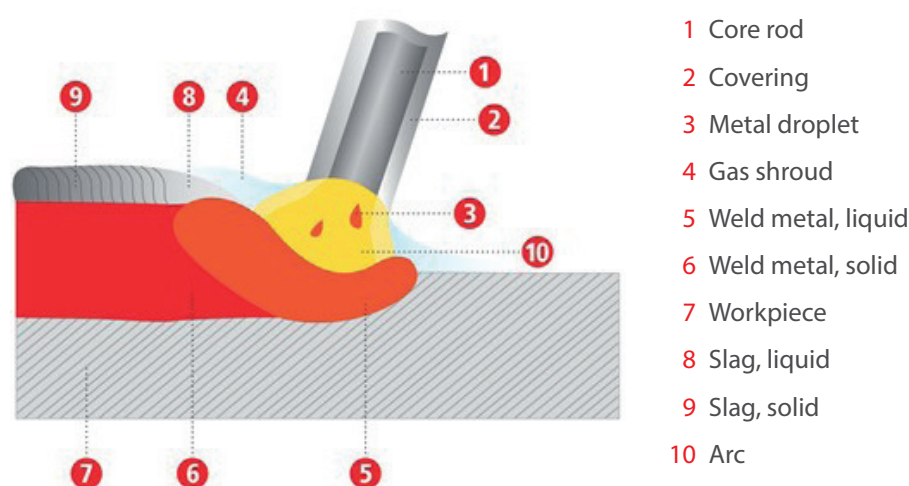
### 8.1 Tasks of the electrode covering

The electrode covering performs various tasks during the welding process:

- / Contact-gap ionisation
- / Gas shroud formation  
The gas shroud is formed by the decomposition and evaporation of organic materials (e.g. cellulose), minerals (e.g. calcium, carbon trioxide, calcite) and metals (e.g. magnesium).
- / Slag formation  
This process can be compared to steel production: the slag covers the metal droplets that pass from the electrode into the weld pool. This prevents the metal droplets coming into contact with the air in an uncontrolled manner. The liquid slag also influences the droplet size, bead shape, and the wetting and flow behaviour of the weld pool.
- / Arc stabilisation
- / Controlling deoxidation
- / Controlling alloying and de-alloying processes in the weld pool
- / Influencing the cooling speed of the weld seam
- / Increasing the deposition rate (electrode efficiency)

Effect of the electrode covering

These properties of rod electrodes influence the welding process (Figure 28).



Welding with covered electrodes

Fig. 28: Schematic diagram of the welding process with a covered electrode.



## 8.2 Classification of covered electrodes

Covered electrodes can be classified according to various aspects.

- / Purpose  
E.g. overlay welding, joint welding, cutting, underwater cutting or underwater welding.
- / Chemical composition of the weld metal  
E.g. unalloyed, low-alloy or high-alloy rod electrodes for high-strength, creep-resistant, heat-resistant, corrosion-resistant steels or non-ferrous metals, and cast iron.
- / Technological properties  
E.g. the mechanical-technological properties of the weld metal, the type of current, the polarity, the deposition rate, the electrode efficiency, the welding position, the weld seam profile and the hydrogen content in the weld metal.
- / Manufacturing method  
E.g. Extrusion-covered, double-layer extrusion-covered, immersion electrodes
- / Type of covering

Differentiating criteria for rod electrodes

According to DIN EN 2560-A, a distinction is made between the following types of covering for rod electrodes:

CODE	ELECTRODE TYPE
A	Acid
C	Cellulosic
R	Rutile
RR	Rutile thick coated
RC	Rutile cellulosic
RA	Rutile acid
RB	Rutile basic
B	Basic

Abbreviated names of electrode types

Tab. 5: Electrode types according to DIN EN 2560-A.

## 8.3 Types of covering and their characteristic properties

### 8.3.1 Acid electrodes (code: A)

The covering of these electrodes contains a high proportion of iron oxide, ferro-manganese and quartz.

Acid electrodes

The electrodes have good arc stability and are therefore suitable for alternating current (AC) and direct current (DC) in equal measure. When using acid electrodes, a highly fluid weld pool is created, which is why these rod electrodes are not suitable for out-of-position welding. The weld metal of rod electrodes only has moderate mechanical-technological properties. Acid electrodes are very rarely used these days.

Type example for acid electrodes according to EN ISO 2560-A:

/ E-35 0 A 12

### 8.3.2 Cellulosic electrodes (code: C)

The covering of this type of rod electrode contains a high proportion of cellulose.

When using cellulosic electrodes, an intensive arc is formed. These rod electrodes are therefore particularly suitable for welding in the vertical down position (PG; PJ). However, in order to form this intensive arc, the electrode covering must have a defined residual moisture content. Due to the high gasification level of cellulose, very little slag is formed during welding. In addition, the rapid build-up of hydrogen results in a "hot" weld pool, melting a significant quantity of the base material. Deep penetration is thus achieved with a small amount of slag in the weld pool.

Cellulosic electrodes

When using cellulosic electrodes, the mechanical-technological properties of the weld metal are excellent; however, the outward appearance is not so good. In addition, these rod electrodes cannot be rebaked. Cellulosic electrodes are welded with direct current and are mainly used in pipeline construction.

With cellulosic electrodes, root passes are welded at the cooler negative pole in order to avoid burn-through. For hot-pass, filling and final runs, the electrodes are connected to the warmer positive pole. This provides a better deposition rate and cleaner edge coverage.

Type examples for cellulosic electrodes according to DIN EN ISO 2560-A:

/ E 383 2 C 21 (Fox Cel) and E 46 41 NI C 25 (Fox Cel 85)



#### Advantages

- + Spray transfer
- + Deep penetration
- + Suitable for all welding positions, especially downwards
- + Good mechanical properties



#### Disadvantages

- Very difficult to weld
- Not suitable for all welding systems
- Large build-up of smoke



The advantages and disadvantages of cellulosic electrodes at a glance

### 8.3.3 Rutile electrodes (code: R)

The main component of the covering for this rod electrode is rutile ( $\text{TiO}_2$ ). It has a less oxidising effect in the arc, the arc atmosphere is more neutral and the alloy burn-off is low.

Rutile electrodes

Particular consideration needs to be given to the mechanical-technological properties of the weld metal of rutile electrodes in the case of steels that have a high manganese content.

Rutile electrodes result in a more globular droplet transfer than rutile thick-coated electrodes, which is why type R rod electrodes are particularly suitable for welding thin sheets. Rutile electrodes can be welded with alternating current or direct current at the negative pole. This electrode type can be used for almost all welding positions, however it is not suitable for vertical down welding positions (PG; PJ).

One of the disadvantages of rutile electrodes is the significant end-crater formation.

Type example for rutile thick-coated electrodes according to EN ISO 2560-A:

/ E-42 0 RR 12



#### Advantages

- + Spray transfer
- + Easy to weld
- + Attractive, flat seam
- + Suitable for direct current and alternating current



#### Disadvantages

- Some welding positions are not possible
- Mechanical-technological properties are not as good as basic electrodes
- Poor gap-bridging ability



The advantages and disadvantages of rutile electrodes at a glance.

### 8.3.4 Basic covered rod electrodes (code: B)

Basic covered rod electrodes have excellent strength and toughness properties down to -50°C. These rod electrodes are suitable for high-quality welded joints in steel, boiler, container and vehicle construction, shipbuilding and mechanical engineering, for buffer layers in overlay welding on high carbon steels, and for welding steels with low purity and high carbon content. Basic covered rod electrodes are particularly suitable for offshore structures.

Since basic covered rod electrodes absorb moisture, they must be kept as dry as possible when stored. The weld metal of basic covered rod electrodes has a high hydrogen content and an electrode efficiency of approx. 110%. Especially at low temperatures, the impact energy of the weld metal is higher than that of all other types of covering. Of all the different electrode types, basic covered rod electrodes are by far the most resistant to cracking. In the case of hot cracks, this resistance is due to the high metallurgical purity of the weld metal. The low susceptibility to cold cracks is down to the low hydrogen content (H). This is lower than for any of the other types and should not exceed  $H = 5 \text{ ml/100 g}$  of weld metal. However, to prevent the risk of cold cracks forming, the rod electrodes must be kept dry.

Basic covered rod electrodes

Basic covered rod electrodes are suitable for welding in almost all positions, except for the vertical down seam. In pipeline construction, basic covered vertical down-seam electrodes with a special covering composition are therefore used.



#### Advantages

- + Globular transfer
- + Versatile in-position weldability
- + Good mechanical-technological properties
- + DC+ generally used for welding



#### Disadvantages

- Slightly harder to weld than rutile electrodes
- Electrodes in standard packaging need to be rebaked



The advantages and disadvantages of basic covered rod electrodes at a glance

Type example: E 42 5 B 42 H5 (FOX EV 50)

### 8.3.5 Overview of types of covering and their properties

Acid type A	Cellulose type C	Rutile type R	Basic type B
Magnetite Fe <sub>3</sub> O <sub>4</sub> 50	Cellulose: 40	Rutile TiO <sub>2</sub> 45	Fluorspar CaF <sub>2</sub> 30
Quartz SiO <sub>2</sub> 20	Rutile TiO <sub>2</sub> 20	Magnetite Fe <sub>3</sub> O <sub>4</sub> 10	Calcite CaCO <sub>3</sub> 30
Calcite CaCO <sub>3</sub> 10	Quartz SiO <sub>2</sub> 25	Quartz SiO <sub>2</sub> 20	Quartz SiO <sub>2</sub> 10
Fe Mn 20	Fe Mn 15	Calcite CaCO <sub>3</sub> 10	Fe Mn 5
		Fe Mn 15	FeSi 7
			Iron powder 18
Sodium silicate	Sodium silicate	Sodium silicate	Sodium silicate
Droplet transfer: Fine spray	Droplet transfer: Medium droplets	Droplet transfer: Medium to fine droplets	Droplet transfer: Medium to large droplets
Toughness values: Normal	Toughness values: Good	Toughness values: Good	Toughness values: Very good

Types of covering and their properties

Tab. 6: Types of covering and their main properties.

### 8.4 Electrode efficiency and extension-length of rod electrodes

The electrode efficiency describes the ratio between the mass of the core that has been melted-off, and the mass of the weld metal applied to the joint:

$$\text{Electrode efficiency in \%} = \frac{\text{Mass of the weld metal applied to the joint} \times 100}{\text{Mass of the core that has been melted-off}}$$



The seam length welded with a rod electrode is also referred to as the extension-length and is specified with the symbol  $L$ . The extension-length means that the welder knows exactly how many centimetres he may weld or must weld in order to:

- / Achieve a constant energy input.
- / Reach the appropriate cooling time for the material, which is determined by the energy input.



The extension-length provides information about the heat input and cooling time.

The extension-length always depends on the electrode type. Different sorts of electrodes have different extension-lengths. The welder can easily implement the extension-length specified for the relevant electrode type if they strictly adhere to the electrode-specific amperage.

As the value derived from the amperage and arc-on time is practically always constant, the extension-length influences the energy input  $E$ . In manual arc welding, the welding speed  $v$  is a qualitative variable.

The welding speed  $v$  and input energy  $E$  can be calculated based on the extension-length. However, in contrast to the extension-length, determining the welding speed is a complex matter and requires specialist knowledge on the part of the welder.

## 8.5 Storage

Electrode coverings absorb moisture from the ambient air. This can cause cracking in the weld seam, which is why rod electrodes should be stored in a dry location and in undamaged standard packaging until they are used. For added protection, carton electrode packages are also often shrink-wrapped to protect them from moisture and dirt.

Storage of rod electrodes

## 8.6 Rebaking

Certain components in the electrode covering absorb hydrogen from the air, which means they are hygroscopic.

Depending on the type of electrode covering, the moisture that is absorbed may be harmless or it may actually damage the weld seam. Too much hydrogen in the weld seam can cause cracking, for example. This is why many rod electrodes have to be rebaked after a prolonged period of storage.

Rebaking of rod electrodes

Rebaking is carried out in an oven, with the rod electrodes stacked no more than three layers deep. When the electrodes are placed in the oven, the oven temperature should be a maximum of 100°C and the heating rate should not exceed 150°C per hour. Rebaking takes around two to three hours. The electrodes should then be allowed to cool down gradually.

## 8.7 Requirements for covered electrodes

Rod electrodes must meet various important requirements covering welding-engineering, metallurgical and economic aspects.

### 8.7.1 Welding-engineering requirements for rod electrodes

- / Good ignition and re-ignition properties
- / Good gap-bridging ability
- / Good weldability in out-of-position welding
- / Stable arc
- / Resistant covering
- / Minimal smoke build-up
- / Non-toxic gases and vapours

Welding-engineering  
requirements for rod electrodes

### 8.7.2 Metallurgical requirements for rod electrodes

- / Good mechanical-technological properties
- / Resistance to porosity
- / Insensitivity to rust, scale, oil and dirt from the steel surface
- / Insensitivity to segregation with respect to S and P impurities in the base material
- / Resistance to hot and cold cracks
- / Insensitivity to moisture absorption of the covering

Metallurgical requirements for  
rod electrodes

### 8.7.3 Economic requirements for rod electrodes

- / High deposition rate, high electrode efficiency
- / Minimal spatter losses
- / Good slag removability
- / High welding speed
- / Long extension-length
- / Attractive seam surface

Economic requirements for rod  
electrodes

## 8.8 Marking of covered electrodes

### 8.8.1 Marking on the rod electrode

Covered electrodes must be permanently labelled with a traceable trade name and a valid standard designation. The marking appears on the covering and is placed near the end that is clamped (Figure 29).



Fig. 29: Stamped manufacturer's trade name and/or standard-compliant designation.

### 8.8.2 Marking on the smallest packing unit

In accordance with regulations, detailed information regarding manufacture, composition, use, and health and safety aspects appears on every electrode package (Figure 30).

The marking includes the following specific items of information:

- / Name of the manufacturer and serial number
- / Batch and manufacturing numbers
- / Manufacturer's trade name
- / Standard designation in accordance with international standard
- / Type of current and recommended current range
- / Weldability in various welding positions
- / Diameter and length measurements
- / Quantity and/or net weight
- / Suitability testing and approvals (e.g. TÜV, ÖBB)
- / Instructions for rebaking (e.g. in the case of basic electrodes)
- / Health and safety instructions

In accordance with regulations, extensive information regarding the origin and application of electrodes is provided on the packaging.

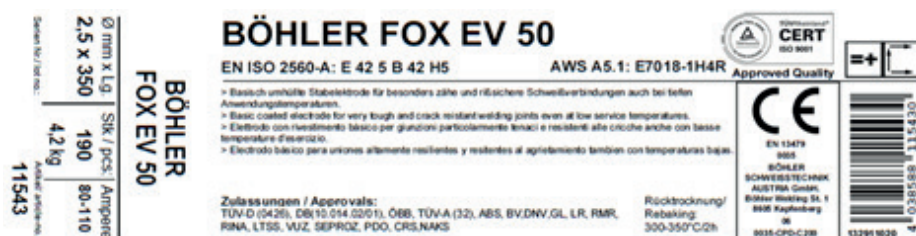


Fig. 30: Designation on the packaging.

### 8.8.3 Standard-compliant marking

Various international standards specify which rod electrodes may be used for specific materials. The standards also specify how the rod electrodes must be marked.

MATERIAL	Unalloyed and FK steels	Ultra-strong steels	Creep-resistant high-temperature steels	Stainless steels	Nickel and nickel alloys
STANDARD	DIN EN ISO 2560	DIN EN ISO 18275	DIN EN ISO 3580	DIN EN ISO 3581	DIN EN ISO 14172

Standards specify which electrodes may be used for a specific material.

Tab. 7: Materials and the corresponding standards.

The standard-compliant marking of a rod electrode always follows the same principle. This combines the specification of the relevant standard with an identification code, which contains mandatory and non-mandatory information.

Example: DIN EN ISO 2560: E 42 5 B 42 H5

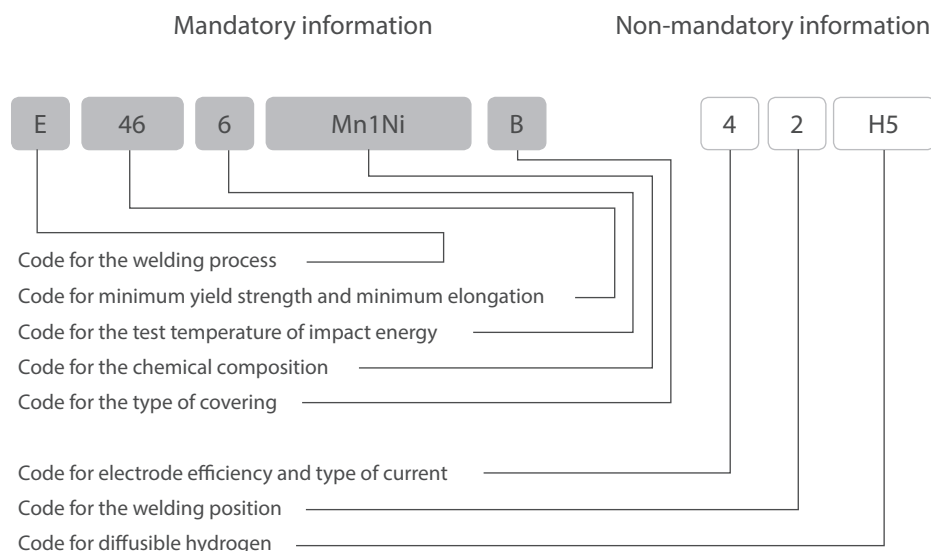
Standard

Identification code



Standard and identification code provide information about the composition and use of the rod electrode.

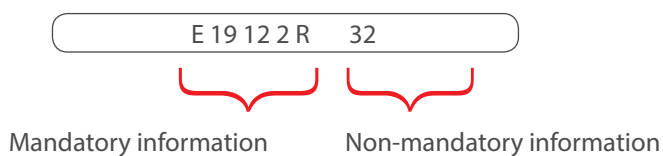
### 8.8.4 Basic approach for the designation of an unalloyed covered electrode for manual arc welding in accordance with DIN EN ISO 2560-A





### 8.8.5 Basic approach for the designation of a high-alloy covered electrode for welding austenitic, stainless steel in accordance with DIN EN ISO 3581

EN ISO 3581



Explanation of the identification code:

**E** = Designation

**19 12 2** = Chemical composition (19% chrome, 12% nickel, 2% molybdenum)

**R** = Rutile electrode

**3** = Suitable for alternating current (AC) and direct current (DC), electrode efficiency 120%

**2** = Suitable for all welding positions except vertical down seam (2)

## 8.9 Comprehension questions

/ What are the different types of covering for rod electrodes?

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/ How does the type of covering influence the welding behaviour?

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/ What must you be aware of when storing and rebaking electrodes?

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/ What does "electrode efficiency" mean?

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/ What is meant by the extension-length of a rod electrode?

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# 9. GENERAL WELDING PROCEDURE

## 9.1 Weld seam profiles

The weld seam profile specifies two key aspects of the welding process:

1. The preparation of the join
2. The form of the weld seam

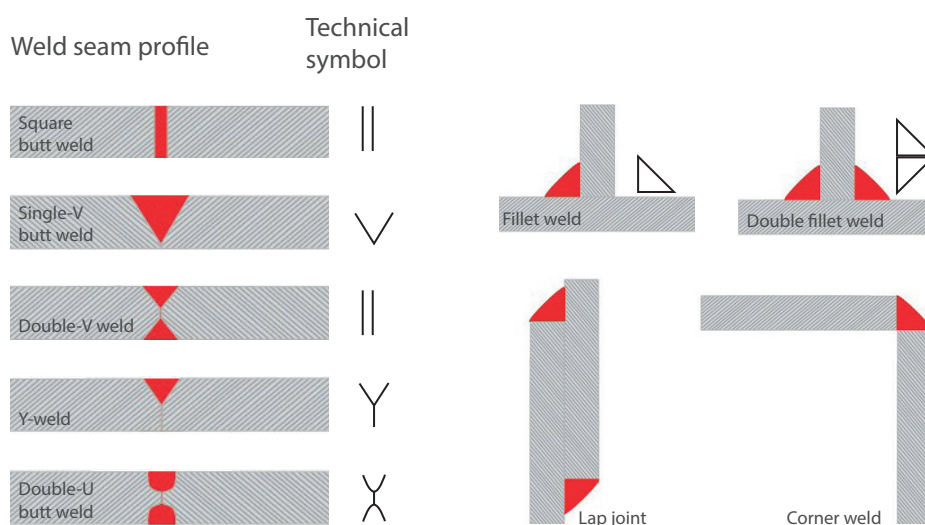
Various factors determine which weld seam profile should be selected for the welding process:

- / Type of material
- / Thickness of material
- / Welding process

Weld seam profiles influence the welding process

The most common weld seam profile is the fillet weld, where the workpieces are welded together at an angle. Butt welds join workpieces which are situated on the same plane (180° angle) (see also page 10).

To achieve a completely one-sided full-penetration butt weld, the edges must be prepared if the wall thickness is greater than approx. 4 mm.



Weld seam profiles and their representation in technical drawings.

Fig. 31: Weld seam profiles and their technical representation.

## 9.2 Weld-seam preparation

Clean weld-seam preparation makes welding easier and allows for a faster welding speed.

The interface should therefore be cleaned thoroughly before starting manual arc welding. This means removing oxide layers such as those caused by flame cutting, coatings, paint, etc.

For smaller diameter pipes in pipeline construction, weld-seam preparation usually involves grinding with angle grinders.

In the case of thick-walled pipes, e.g. in hydraulic and power station construction, single-U butt weld preparation is often advantageous. This is more cost-effective due to the smaller weld seam volume.

### 9.3 Electrode guidance

To obtain a fault-free welded joint, it is crucial that the welding parameters are correct and that welding is carried out correctly. The welding performance very much depends on how the rod electrode is held and guided during the welding process (Figure 32). An angle of  $70^\circ$  is ideal.

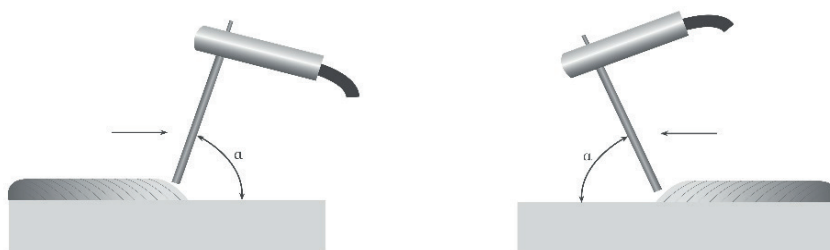


Fig. 32: The tilt angle for the welding process should be approx.  $70^\circ$ .

The angle when welding should be around  $70^\circ$ .

At normal welding speeds and without transverse movement (weaving), the weld seam is around 2 to 3 mm wider than the electrode diameter.

Normal weld seam thickness

If weaving is performed during welding, the weld seam can be twice or even three times the size of the electrode diameter. If the weaving amplitude becomes greater than three times the electrode diameter, the protection of the weld pool is jeopardised. This has a negative impact on the quality of the welded joint. Excessive weaving motions should therefore be avoided at all cost during welding.

Weld seam thickness when weaving is performed



Weaving can be performed in various ways. The type of weaving motion adopted depends on the welding position. It is important to keep the motion even.

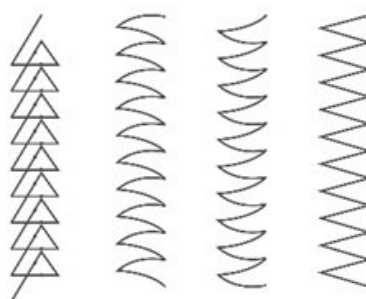


Fig. 33: Examples of weaving motions.



Examples of weaving motions

Correct guidance of the electrode is very important for root pass welding (Figure 34) and single-layer joint welding of thin sheets (Figure 35). In both cases, guiding the electrode correctly ensures that groove faces melt completely. This guarantees full penetration and also prevents burn-through.

Workpieces with a larger cross-section are welded in several layers following appropriate weld-seam preparation (Figure 36). In order to prevent typical welding faults, such as slag inclusions, lack of fusion, and undercuts, there are three main things to watch out for.

1. The order of layers is followed precisely.
2. Slag is removed cleanly after every bead.
3. The groove faces melt perfectly.

Root pass welding, upwards

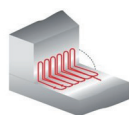


Fig. 34: Guidance of the electrode for single-layer single-V butt and fillet welds.

Welding of final runs



Fillet weld, vertical



Single-V butt weld, vertical



Fillet weld, horizontal



Single-V butt weld, horizontal

Fig. 35: Weaving when manual arc welding.

Welding of filling runs

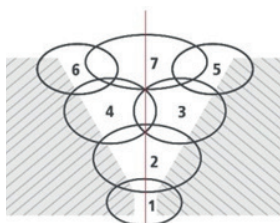


Fig. 36: Order of the layers in a multi-layer single-V butt weld.

Electrode guidance for special welding tasks.

When welding in horizontal, vertical and overhead positions, the force of gravity adversely affects the welding process. The weld pool must therefore be as small as possible and able to solidify quickly. This is achieved by using a short arc, guiding the electrode quickly, and using a low amperage.

Information about welding in a horizontal, vertical and overhead position

Welding in the overhead position (PE) presents particular challenges for the welder and the welding process. The high level of difficulty associated with this welding position can easily lead to defects. In addition, due to welding out-of-position, there is a danger that there will be significantly more non-metallic inclusions in the overhead weld seam. This is why lower quality requirements are defined for overhead welding.

## 9.4 Comprehension questions

- / What do you need to watch out for when it comes to weld-seam preparation for manual arc welding?

- / What are the names of the main weld seam profiles?



# 10. MANUAL ARC WELDING DEFECTS

## 10.1 Types of defect and their causes

Even with good preparation and optimum guidance of the electrode, defects can occur during manual arc welding. The terms imperfections or discontinuities are also used in this context.



A distinction is made between different types of defects:

1. Process-related defects.
2. Defects that are dependent on the welder's proficiency.
3. Defects that are dependent on the material.



Causes of defects in manual arc welding

Process-related defects in manual arc welding with covered electrodes include:

- / Undercuts
- / Slag inclusions
- / Pore formation
- / End-crater cavities

Process-related defects

Undercuts occur at the weld seam edges where the base material has melted, but was not sufficiently filled with filler material. Undercuts can also occur if the arc is too long.

Undercuts

Slag inclusions in the weld metal can be caused by various things. These inclusions occur, for example, if the slag advances ahead of the welding direction during the welding process. In addition, when welding several layers, slag inclusions can occur if the slag was not correctly removed from the previously welded bead. Slag inclusions are also more common if rust, grease or paint is present.

Slag inclusions

Pore formation is caused by gas bubbles which are trapped when the weld metal solidifies. When gaps occur between the sheets to be joined, for example, in the case of fillet welds or lap joints, this is referred to as mechanical pore formation. Metallurgical pore formation by nitrogen occurs when nitrogen in the ambient air enters the weld pool due to welding with an arc that was too long. Damp electrode coverings can also cause hydrogen porosity – and therefore pore formation.

Pore formation

In contrast to pores, end-crater cavities are cavities which are caused by solidification and shrinkage. As the name suggests, they can usually be seen at the end of a weld seam.

Defects involving incomplete root penetration or a lack of fusion are dependent on the welder's proficiency. In contrast, cracking usually originates in the material.

## 10.2 Comprehension questions

/ What defects can occur when using covered electrodes?

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/ How can these defects be prevented?

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/ What causes undercuts to occur?

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# 11. ELECTRIC ARC BLOW

## 11.1. Magnetic fields and their effect

When electric current flows through a conductor, a field is created around the conductor in which magnetic forces flow. This magnetic field can be revealed using a magnetic needle or a fine iron powder which arranges itself in a ring around the conductor.

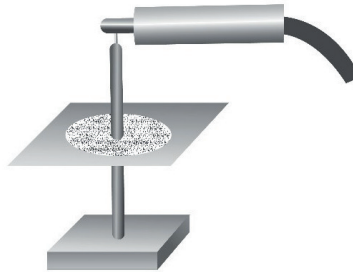


Fig. 37: Field of magnetic force of a live conductor.

These sorts of magnetic fields also occur in manual arc welding as a result of the current flow. They occur around the electrode, the arc and the current path in the workpiece. Due to their arrangement, the magnetic fields deflect the moving arc, which then starts to flicker. This effect is referred to as arc blow.



Electric arc blow is the irregular flickering of the arc in unwanted directions. Arc blow is caused by magnetic fields.



Definition of arc blow.

If arc blow causes the arc to alternately shorten and lengthen, there is a danger that parts of the base material will fail to melt sufficiently. This may result in scoring, slag inclusions and spatter, thereby reducing the quality of the weld seam.



Important: Electric arc blow has nothing to do with the deflection of the arc when welding in the open air (e.g. due to wind) or when exposed to draughts.



Arc movements caused by wind or other external factors are not arc blow.

## 11.2 Magnetic fields in the case of steel and other easily magnetised materials

Steel belongs to a group of materials that can be very easily magnetised. This means that very powerful magnetic fields are formed in the steel, thus also making the effect of arc blow very pronounced. It is usually not possible to predict where and to what extent magnetic fields will occur. In certain scenarios, however, there are some indications of the likelihood of magnetic fields occurring:

Indications of arc blow occurrence in the case of easily magnetised materials

- / The arc is always deflected in the direction that the electrode is tilted (Figure 38). The inclination of the electrode causes the lines of force to be so condensed that the arc is pushed in the direction of the electrode tilt.
- / Large steel masses attract the arc (Figure 39). In overlay welding, the arc is attracted by the previously laid bead, and when lap joints are being welded, the sheet that is placed down deflects the arc.
- / The arc always blows from the edge of the workpiece towards the middle (Figure 40). Magnetic lines of force congregate at the edges, because they can disperse from here better than in the poorly conductive air at the weld gap, for example. This accumulation of the lines of force results in a magnetic force that causes the arc "edge effect".

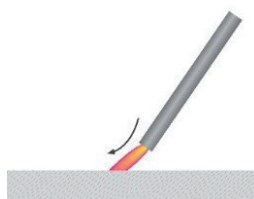


Fig. 38: The arc is similar to the inclination.

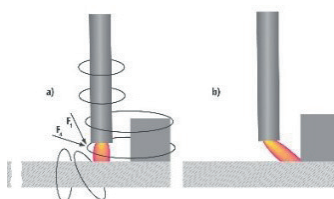


Fig. 39: Steel masses attract the arc.

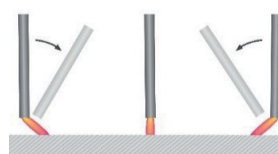


Fig. 40: The arc blows from the edge towards the middle.

## 11.3 Measures for dealing with arc blow

There are various ways to control electric arc blow. These measures can be taken individually or used in combination:

- / The most important measure to combat arc blow is to tilt the electrode during welding. Depending on the tilt angle of the electrode, it is possible to counteract the arc-deflecting forces.
- / If there is a large number of strong tack-welds on the parts to be joined, this has a positive effect on the magnetic lines of force, such that they no longer have such a strong influence on the arc.

Tips for dealing with arc blow in the case of easily magnetised materials.



- / Using the back-step method, where weld segments are alternately welded from the front and rear part of the section to be welded.
- / Attaching run-on plates.
- / Adding additional steel masses.
- / Using a moving earth connection or consequent pole.
- / Providing a power connection on both sides, rather than just one side.
- / Welding with alternating current.
- / Using cold electrodes, as areas subject to severe arc blow are sometimes impossible to weld with electrode ends that have heated up. Once these have been replaced with cold electrodes, welding can often be completed without any difficulties.
- / Selecting a smaller electrode diameter.
- / Selecting an electrode with a thick covering, because the thicker the covering, the less pronounced the arc blow effect.
- / Demagnetising the workpiece with cable windings and a transformer.

## 11.4 Comprehension questions

- / What is arc blow?



- / What measures can be taken to control arc blow?

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# 12. GOUGING

Gouging is a process used to remove surplus metal from the workpiece. At the relevant point, the metal is first heated, melted and then removed.

The advantage of gouging is that this process can be used for many different purposes. These include:

- / Preparing joins
- / Developing fillet welds
- / Removing defective weld seams
- / Gouging out weld seam roots
- / Removing cracks in the weld seam
- / Removing surplus metal
- / Preparing for rewelding work

Gouging can be used for many purposes

## 12.1 ArcAir gouging



ArcAir gouging is an arc gouging method. The first step in this process is to generate an electric arc, which melts the material. The melted metal is then blown away. Compressed air is required in addition to a graphite carbon electrode (Figure 41).



Fig. 41: Schematic diagram of ArcAir gouging.



Gouging using the ArcAir principle

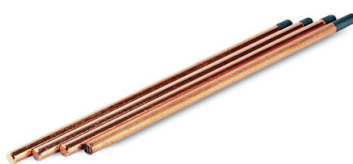


Fig. 42: Carbon electrode.

ArcAir gouging is used to remove shrink holes, pores or slag inclusions from workpieces. In casting applications, the ArcAir process is also used to detach sprue or finish entire workpiece surfaces. In addition, ArcAir gouging can be used to prepare the edges for heavy plates.

There are two other forms of gouging in addition to ArcAir gouging:

1. Flame gouging
2. Plasma gouging
3. Gouging electrode (special electrode for gouging various materials without oxygen)

## 12.2 Instructions for ArcAir gouging

1. Plug the gouging torch power cable into the positive current socket of the system and twist it clockwise to latch it in place (minimum cable cross-section of 70 mm<sup>2</sup>).
2. Connect the compressed air connection on the gouging torch to the compressor. A constant air pressure of 6 to 10 bar is required.
3. Plug the grounding cable into the negative current socket of the system and latch it in place.
4. Connect the workpiece and make sure contact is good.
5. Plug in the mains plug.
6. Turn the main selector switch from "0" to "On".
7. Clamp the carbon electrode so that there is a gap of approx. 100 mm from the electrode tip and the air outlet openings on the gouging torch are at the bottom.
8. Open the compressed air valve in the handle of the gouging torch (this can be used to regulate the air flow rate) and start gouging.



Instructions for gouging using the ArcAir principle



The depth of the gap is determined by the tilt angle of the carbon electrode and by changing the gouging speed.



Controlling the gap depth

## 12.3 Comprehension questions

/ In ArcAir gouging, what polarity should be selected for the power cable?



/ What do you need to watch out for with respect to the compressed air supply?

# 13. EQUIPMENT TO ENSURE A SAFE WORKPLACE FOR MANUAL ARC WELDING

## 13.1 Safe working

Safe working for the welder is extremely important throughout the entire welding process. This specifically includes joint preparation and reworking.

In order to ensure the highest possible level of safety for the welder, various protective measures must be taken into consideration when it comes to equipping the workplace for manual arc welding.



A safe workplace for manual arc welding is equipped with the following:

- / Local ventilation or full room ventilation (Figure 43)
- / Protective workwear (Figure 44)
- / A protective visor or safety helmet with standard-compliant welding filters (Figure 45)
- / Protective gloves (Figure 46)
- / Safety goggles to protect against penetration of radiation from the side and against flying slag particles when processing the weld seam
- / Fully-insulated electrode holders
- / Welding power-leads (manual electrode cable and grounding cable) with a minimum cross-section that is appropriate for the welding current amperage and cable length.



Protective measures in the welding workplace



Fig. 43: Portable fume extractor.



Fig. 44: Flame-retardant protective clothing.



Fig. 45: Welding helmet with respirator.



Fig. 46: Gloves with gauntlets.

Additional accessories that are required in a workplace for manual arc welding are:

- / Screw clamp or magnetic consequent pole
- / Chipping hammer (Figure 47)
- / Wire brush
- / Fire tongs
- / Electrode quiver



Fig. 47: Hand shield and chipping hammer, wire brush, and electrode drying set.

## 13.2 Comprehension questions

- / What are the key items of welding equipment for manual arc welding?




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# 14. ACCIDENT PREVENTION AND HEALTH PROTECTION

## 14.1 Dangers due to arc radiation

The electric arc emits various types of radiation, which may be visible or invisible. The level of radiation depends on the type of welding process and the selected welding current amperage.



The electric arc emits the following types of radiation: visible radiation, invisible infrared radiation or thermal radiation and also invisible ultraviolet radiation. The electric arc does not emit any X-ray-like radiation during arc welding.



Types of radiation emitted by the arc

### / Visible light beams

Potential hazard:

In the event that protection is absent or inadequate, visible light beams cause glare. Repeated, frequent and prolonged exposure to visible light beams can impair your eyesight in the long term – especially your twilight vision.

Protective measures:

To provide protection against visible radiation, visors or helmets with suitably dark-tinted standard-complaint welding filters are worn.

### / Infrared radiation or thermal radiation

Potential hazard:

Invisible infrared or thermal radiation mainly heats up parts of the body that are in the immediate vicinity of the area that is to be welded, i.e. chiefly the hands and torso. There is also the risk of accident involving the eyes. In the event that eye protection is inadequate or absent, long-term exposure to these invisible beams can cause a clouding of the lens in the eye (heat cataract).

Protective measures:

To provide protection against thermal radiation, heat-resistant protective clothing and special welding gloves are worn by the welder. The eyes are protected from infrared radiation or thermal radiation by standard-compliant welding filters.

Visible light beams

Infrared radiation and thermal radiation

## / Ultraviolet radiation

### Potential hazard:

Ultraviolet (UV) radiation is also invisible. Just a short period of exposure to this radiation can cause eye injuries in the form of "flash burns" as well as burns to unprotected parts of the body.

Ultraviolet radiation

### Protective measures:

Burns are prevented by heat-resistant protective clothing in the form of overalls and gloves. Standard-compliant welding filters protect the eyes against possible flash burns. If suitable precautions are not taken during welding and flash burns do occur, apply cold compresses to the eyes and, after consulting a doctor, administer eye drops.

## 14.2 Dangers due to electric current

### 14.2.1 Open circuit voltage

If there is no arc burning, the power source in manual arc welding causes an open circuit voltage UL at two points: firstly, between the terminal of the grounding cable and the welding power-lead, and secondly, between the clamping jaws of the electrode holder and the workpiece.

Dangers due to open circuit voltage

These voltages are potentially fatal if the welder touches the metal clamping jaws of the electrode holder and the workpiece with their bare hands. Open circuit voltage is particularly dangerous if the skin is damp, as moisture conducts electric current.

The insulation provided by shoes, work clothing and leather gloves offers effective protection against open circuit voltage.

OPERATING CONDITIONS	RATED VALUE FOR OPEN CIRCUIT VOLTAGE	
Increased risk of electric shock	Direct current Alternating current and	113 V peak value 68 V peak value 48 V effective value
No increased risk of electric shock	Direct current Alternating current and	113 V peak value 113 V peak value 80 V effective value
Mechanically guided welding torches with increased protection for the welder	Direct current Alternating current and	141 V peak value 141 V peak value 100 V effective value

Tab. 8: Dangers due to electric current.



Important safety instruction!

**S**

**CE**








Symbol for primary-switched power source	 www.fronius.com		Model No.		Standard specification for manufacturer																								
Symbol for welding process			Part No.																										
Protection class			Ser. No.																										
Open circuit voltage			IEC 60974-1/-10 Cl.A																										
Max. occurring peak voltage			8 A / 10.3 V ~ 230 A / 21.3 V																										
Symbols for approval to work under increased electrical risk			<table border="1"> <thead> <tr> <th></th><th>35%</th><th>80%</th><th>100%</th></tr> </thead> <tbody> <tr> <td>U<sub>i</sub> 50-250Hz</td><td>120 V</td><td>170 A</td><td>140 A</td></tr> <tr> <td>U<sub>i</sub> 100 V</td><td>U<sub>i</sub></td><td>120 V</td><td>120 A</td></tr> <tr> <td>U<sub>i</sub> 10 kV</td><td>230 V</td><td>16.8 V</td><td>15.6 V</td></tr> <tr> <td>U<sub>i</sub> 10 kV</td><td>230 V</td><td>16.8 V</td><td>16.6 V</td></tr> <tr> <td>U<sub>i</sub> 50-60Hz</td><td>U<sub>i</sub></td><td>19.2 V</td><td>17.8 V</td></tr> </tbody> </table>				35%	80%	100%	U <sub>i</sub> 50-250Hz	120 V	170 A	140 A	U <sub>i</sub> 100 V	U <sub>i</sub>	120 V	120 A	U <sub>i</sub> 10 kV	230 V	16.8 V	15.6 V	U <sub>i</sub> 10 kV	230 V	16.8 V	16.6 V	U <sub>i</sub> 50-60Hz	U <sub>i</sub>	19.2 V	17.8 V
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Symbol for mains connection			<table border="1"> <thead> <tr> <th></th><th>I<sub>t max</sub></th><th>I<sub>t</sub> 50%</th></tr> </thead> <tbody> <tr> <td>U<sub>i</sub></td><td>120 V</td><td>20 A</td></tr> <tr> <td>U<sub>i</sub> 100 V</td><td>30.2 A</td><td>17.9 A</td></tr> <tr> <td>U<sub>i</sub> 10 kV</td><td>16 A</td><td>25.1 A</td></tr> <tr> <td>U<sub>i</sub> 50-60Hz</td><td>16 A</td><td>14.9 A</td></tr> </tbody> </table>				I <sub>t max</sub>	I <sub>t</sub> 50%	U <sub>i</sub>	120 V	20 A	U <sub>i</sub> 100 V	30.2 A	17.9 A	U <sub>i</sub> 10 kV	16 A	25.1 A	U <sub>i</sub> 50-60Hz	16 A	14.9 A									
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U <sub>i</sub> 10 kV	16 A	25.1 A																											
U <sub>i</sub> 50-60Hz	16 A	14.9 A																											

Fig. 48: Rating plate.

In order to protect against the dangers associated with electric current during manual arc welding, the following **safety precautions** must always be taken:

- / Always wear leather gloves when you pick up the electrode holder.
- / Never weld with a bare torso, even if it is very hot.
- / Never hold electrode holders or cables under your arm.
- / Do not wear shoes with nailed soles.
- / Never sit or lie down on metal without a piece of wood or felt mat beneath you.
- / In containers and confined spaces, always make sure there is a piece of wood or felt between you and the metal walls.
- / Never use damaged cables.
- / Never weld in containers, large enclosures, box girders, etc., using conventional transformers; and never use conventional hand lamps with mains voltage in these locations – the voltage used should never exceed 42 volts.

### Safety precautions for manual arc welding



## 14.3 Dangers due to welding fumes and gases

Gaseous and particulate toxic emissions with a particle size that is usually smaller than 1 µm occur during welding. Due to the small size of these respirable particles, welding fumes enter the alveoli in the lungs. Therefore in order to protect the welder, welding fumes must be extracted directly at the point of generation in workshops.

Paint and coatings that have not been removed from the area that is to be welded also present a danger. When coating materials of this nature evaporate in the arc, hazardous gases can occur, such as zinc oxide, which causes poisoning. A great deal of care must therefore be taken when preparing the welding location for manual arc welding!



The use of CrNi electrodes poses another potential hazard that needs to be highlighted. Basic CrNi electrodes contain very high levels of chromium (VI) compounds and nickel oxides, which result in carcinogenic welding fumes. Rutile CrNi electrodes have a substantially lower impact. Nevertheless, a highly effective extraction system is absolutely essential when using either of these electrodes (see also BGI 616 /9/).



CrNi electrodes require special handling!

## 14.4 Comprehension questions

/ What are the general hazards associated with manual arc welding?

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/ What types of radiation are emitted by the electric arc?

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/ How do you protect yourself and others from the hazards posed by electric current?

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# GLOSSARY

## Alloy burn-off

Chemical reactions in the arc influence the actual alloy content of a weld metal. Due to alloy burn-off, there are differences in the alloy content of the electrode and of the weld metal that has been melted off.

## Anode

The counter-electrode to the cathode is the anode, which emits electrons as part of reduction processes.

## Arc characteristic

The arc characteristic indicates the relationship between the arc voltage and the arc current.

## Arc-force dial

The arc-force dial influences the short circuit current at the instant of droplet detachment.

## Cathode

The cathode is the counter-electrode to the anode. Ions or free electrons move between these two electrodes.

## Demagnetisation

Demagnetisation is a process by which the magnetic field that influences the arc disappears.

## Drooping characteristic

When welding with electrodes, the welding current needs to be kept as constant as possible, even if the distance between the electrode and workpiece changes. This is achieved thanks to the "drooping" characteristic of the power source.

## Earthing clamp

The earthing clamp is a quickly detachable mechanical connection between the workpiece and current-return cable in the welding circuit.

## Efficiency

Efficiency describes the relationship between the electrical power consumed and output by a power source.

## Lines of force

Components that are subjected to predominantly dynamic stresses require gradual weld toes (line of force progressions) in order to avoid a notch effect.

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**A**


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**C**


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**D**


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**E**


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**L**

# GLOSSARY

## Mechanical properties

A static analysis of a structure is based on the mechanical properties of a base material or a welded joint. The mechanical properties therefore play a decisive role when it comes to selecting the base material for manufacturing and production and the filler metals.

## Outgassing

Outgassing refers to the release of gases from a liquid or solid material during the welding process.

## Quality requirements

Standardised, verifiable quality requirements are defined for every weld seam according to the loads and operating conditions of the welded component.

## Reactive current

Reactive current is a phenomenon that only occurs with alternating current and three-phase current: the energy moves back and forth between the generator and consumer, which means that the cable is energised, but to no useful effect.

## Rectifier

A rectifier converts three-phase alternating current into direct current for welding purposes.

## Sinusoidal voltage

Sinusoidal voltage is an oscillating AC voltage such as the mains voltage in the public energy supply grid. The sinusoidal voltage oscillates back and forth between a maximum and minimum voltage over a defined period of time.

## Slag

Rod electrodes have a covering that also melts off in the arc, some of which vaporises and forms shielding gases and slag. Slag covers the weld seam and must be removed once cooled down.

## Smoothing choke

A smoothing choke is used to reduce the ripple and is therefore crucial in determining the weld properties, e.g. the ignition of the arc and spattering.

## Static operating point

The operating point in welding is the point where the set power source characteristic and the arc characteristic intersect.

## Transistor stage

The transistor stage is an electronic switch.

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**M**


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**O**


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**Q**


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**R**


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**S**


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**T**

# GLOSSARY

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## W

### **Weld filler metals**

Weld filler metals form the weld seam of the components to be joined. The selection of weld filler metals primarily depends on the base material to be welded and the application of the component.

### **Welding current-return cable**

The welding current-return cable safely closes the circuit between the electrode and the welding system.

# NOTES

# NOTES

# NOTES