INTERNATIONAL STANDARD

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Health and safety in welding and allied processes — Laboratory method for sampling fume and gases —

Part 3: Determination of ozone emission rate during arc welding

Hygiène et sécurité en soudage et techniques connexes — Méthode de laboratoire d'échantillonnage des fumées et des gaz —

Partie 3: Détermination du débit d'émission d'ozone lors du soudage à l'arc

Reference number
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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 15011-3 was prepared by Technical Committee ISO/TC 44, *Welding and allied processes*, Subcommittee SC 9, *Health and safety*.

This second edition cancels and replaces the first edition (15011-3:2002), which has been technically revised.

ISO 15011 consists of the following parts, under the general title *Health and safety in welding and allied processes — Laboratory method for sampling fume and gases*:

— *Part 1: Determination of fume emission rate during arc welding and collection of fume for analysis*

— *Part 2: Determination of the emission rates of carbon monoxide (CO), carbon dioxide (CO_2), nitrogen monoxide (NO) and nitrogen dioxide (NO_2) during arc welding, cutting and gouging*

— *Part 3: Determination of ozone emission rate during arc welding*

— *Part 4: Fume data sheets*

— *Part 5: Identification of thermal-degradation products generated when welding or cutting through products composed wholly or partly of organic materials*

The following part is under preparation:

— *Part 6: Procedure for quantitative determination of fume and gases from resistance spot welding* [Technical Specification]

Request for an official interpretation of technical aspects of this part of ISO 15011 should be directed to the secretariat of ISO/TC 44/SC 9 via the user's national standardization body; a listing of these bodies can be found at www.iso.org.

Introduction

Welding and allied processes generate fume and gases, which, if inhaled, can be harmful to human health. Knowledge of the composition and the emission rates of the fume and gases can be useful to occupational health professionals in assessing worker exposure and in determining appropriate control measures.

Absolute exposure is dependent upon factors such as welder position with respect to the plume and draughts and cannot be predicted from emission rate data. However, in the same work situation, a higher emission rate is expected to correlate with a higher exposure and a lower emission rate with a lower exposure. Hence, emission rate data can be used to predict relative changes in exposure that might occur in the workplace under different welding conditions and to identify measures for reducing such exposure, but they cannot be used to calculate ventilation requirements.

This part of ISO 15011 defines a method for measuring the emission rate of ozone during arc welding using a hood technique. The procedure simply prescribes a methodology, leaving selection of the test parameters to the user, so that the effects of different variables can be evaluated. Research [2] has shown that differences in ozone emission rate measured using this technique correlate well with changes in exposure in the workplace.

It is assumed that the executions of the provisions and the interpretation of the results obtained in this part of ISO 15011 are entrusted to appropriately qualified and experienced people.

Health and safety in welding and allied processes — Laboratory method for sampling fume and gases —

Part 3: Determination of ozone emission rate during arc welding

1 Scope

This part of ISO 15011 defines a laboratory method for measuring the emission rate of ozone during arc welding, using a hood technique. The method is directed primarily at measuring ozone emission rate when using gas-shielded arc welding processes, but it can also be employed with other processes, e.g. self-shielded flux-cored arc welding, provided that welding can be performed automatically under the hood.

The method can be used to evaluate the effects of welding wires, welding parameters, processes, shielding gases, test piece composition and test piece surface condition on emission rate.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/TR 25901 *Welding and related processes — Vocabulary*

ISO/IEC Guide 98-3, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/TR 25901 and the following apply.

3.1
bubble flow meter
primary device for measuring gas flow rate, where the time for a bubble of gas, defined by a soap film, to pass through a calibrated volume in a vertical tube is measured

3.2
test chamber
semi-enclosed, continuously extracted chamber used in emission rate tests performed during arc welding, cutting or gouging operations

NOTE Test chambers generally fall into three generic types:

— a test chamber without a floor, widely referred to as a “hood”;

— a test chamber having a floor, widely referred to as a “fume box”;

— a “fume box”, in which the floor of the test chamber is easily removed and replaced, facilitating its ready interconversion to and from a “hood”.

4 Principle

Arc welding is performed automatically, on a test piece, inside a continuously extracted test chamber of the "hood" type. The ozone concentration (in millilitres per cubic metre) at a fixed sampling position inside the hood and the air flow rate through the hood (in cubic metres per minute) are measured. The ozone emission rate (in millilitres per minute) is calculated by multiplying the ozone concentration at the fixed measuring point by the air flow rate.

5 Equipment and materials

5.1 Hood, semi-enclosed, continuously extracted chamber of the "hood" type, in which ozone emission rate tests are performed during arc welding. The hood shall be designed in accordance with the dimensions shown in Figure 1. The sampling position shall be 1 000 mm vertically from the base of the hood. The inside of the hood shall be non-reflecting.

NOTE See A.1 for guidance on the construction of the hood.

5.2 Extraction unit, capable of maintaining an air flow rate of 2 m^3/min through the hood (5.1), such that the ozone emitted is contained, but not so high as to compromise weld metal integrity (see A.2). The precise characteristics of the extraction unit are not critical.

5.3 Ozone meter and logging system, consisting of a calibrated ozone meter employing the chemiluminescence principle of measurement. The meter shall be capable of measuring ozone concentrations up to 10 ml/m^3. The ozone meter shall be connected to a digital logging system with a logging frequency of 1 s or less (see A.3). Ozone meters that provide equivalent performance to that obtained with chemiluminescence meters may also be used.

The calibration of the meter shall be traceable to national standards.

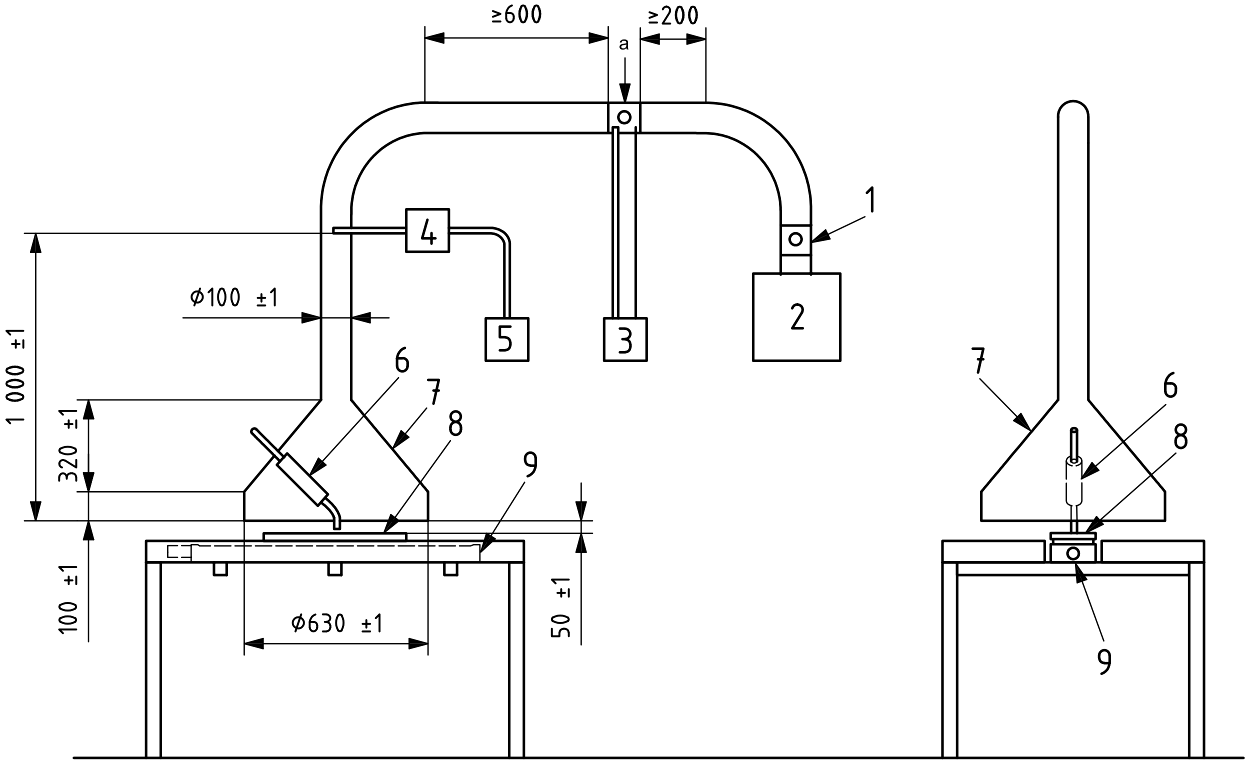
5.4 Sampling system, consisting of a sampling line between the sampling point and the ozone meter, manufactured from polytetrafluoroethylene (PTFE) or stainless steel or a combination of both. The sampling line shall have an internal diameter of 10 mm or less and shall be as short as is reasonably practicable. Fume shall be prevented from entering the sampling line using a PTFE filter. The filter shall be placed as close as is reasonably practicable to the sampling point (see A.4).

5.5 Ozone generator, used to precondition the sampling line and to calibrate the ozone meter.

NOTE Sometimes, ozone meters and generators are incorporated into the same piece of equipment.

If an ozone generator is used to calibrate the ozone meter (5.3), its calibration shall be traceable to national standards.

Dimensions in millimetres



Key

1 damper (if used)
2 extraction unit
3 manometer (if used)
4 polytetrafluoroethylene (PTFE) filter
5 ozone meter connected to sampling point
6 welding torch
7 hood
8 test piece
9 traverse
a Air flow rate measuring point.

Figure 1 — Hood design for ozone emission rate testing

5.6 Equipment for measuring air flow rate, capable of measuring an air flow rate of 2 m^3/min to within ± 5 % or better.

The following combinations of equipment are suitable (see A.5).

- A calibrated anemometer, together with a calibrated ruler, to measure the diameter (in metres) of the extraction ducting between the hood and the extraction unit. The calibrations of the anemometer and the ruler shall be traceable to national standards. The anemometer shall, itself, have a logging capability or be connected to a logging system with a logging frequency of 1 s or less.

- A flow meter with a calibrated relationship between pressure difference and air flow rate, e.g. an orifice plate, together with a digital manometer with a reading accuracy of at least 0,1 Pa to measure the pressure difference across it. The calibration of the flow meter and the digital manometer shall be traceable to national standards. The digital manometer shall, itself, have a logging capability or be connected to a logging system with a logging frequency of 1 s or less.

- A device for measuring air flow rate with equivalent performance.

The calibration of the equipment shall be traceable to national standards.

5.7 Equipment for measuring welding current, arc voltage and wire feed speed, capable of measuring the arithmetic mean of the current, voltage and wire feed speed to within ± 5 % or better. Electronic integrating equipment with frequent sampling intervals and a logging capability is recommended. In the absence of such equipment, current may be measured using a Hall effect probe connected to a moving coil meter or a shunt. Voltage may be measured using a moving coil meter. Wire feed speed can be determined by measuring the length of wire exiting the welding torch in a measured time.

The calibration of the equipment shall be traceable to national standards.

5.8 Equipment for measuring shielding gas flow rate, calibrated for the shielding gas in use and capable of measuring the flow rate to within ± 5 % or better (see A.6).

The calibration of the equipment shall be traceable to national standards.

5.9 Device for setting contact tip to workpiece distance (CTWD), consisting of a gauge made by machining a metal block to a thickness equivalent to the required CTWD to within ± 5 % or better, or a metal wedge with distance markings at appropriate points.

5.10 Device for setting electrode tip to workpiece distance (ETWD) for tungsten inert gas (TIG) welding, consisting of a gauge made by machining a metal block to a thickness equivalent to the required ETWD to within ± 5 % or better, or a metal wedge with distance markings at appropriate points.

5.11 Device for automatic welding, permitting the emission rate test to be performed under automated conditions, capable of advancing the test piece under a stationary arc welding torch at an appropriate rate (welding speed), whilst positioned over a plane surface (e.g. a table), which extends at least to the extremities of the hood. It shall be possible to secure the test piece to the device, such that it cannot bow or flex during welding.

5.12 Test pieces, of a material suitable for the process and consumable used, with dimensions that allow continuous welding for an arcing time of at least 60 s (see A.8).

6 Test procedures

6.1 Welding procedure selection

Perform tests using automatic welding.

6.2 Setting up the test equipment

Check that all measuring and logging equipment is within its calibration date and is functioning correctly, before carrying out any tests.

Arrange the test equipment as shown in Figure 1, in an interference-free environment (see A.9).

Adjust the air flow rate through the hood to 2 m^3/min (see A.2), using either the variable control on the extraction unit or a damper in the extract ducting. Make air flow measurements utilizing either an anemometer or a differential flow meter.

If an anemometer is to be used to measure the velocity of extracted air for use in the calculation of the air flow rate, measure the average velocity of extracted air through the extract ducting with the anemometer, measure the diameter of the extract ducting using the calibrated ruler, calculate the cross-sectional area (in square metres) of the extract ducting and multiply this by the average extracted air velocity (in metres per minute) to obtain the average air flow rate (in cubic metres per minute).

If a pressure differential flow meter is used to measure air flow rate, measure the average pressure drop across the device and calculate the average air flow rate using the calibration equation provided for the device.

6.3 Trial tests

Set the desired test conditions (see Annex B), performing a trial test, which may be outside the hood, to set the test current and voltage as follows, using the same monitoring equipment and materials to be used subsequently to perform the emission rate test proper.

Connect the equipment for measuring current, arc voltage, wire feed speed (5.7). See C.1 for further guidance on attaching the leads for measuring voltage and current.

Adjust the shielding gas flow rate to the desired value, if applicable (see B.6).

Secure a test piece inside the hood, so that it cannot move, bow or flex during welding and such that a constant CTWD is maintained throughout the test when MIG/MAG welding and that a constant ETWD is maintained when autogeneous TIG welding.

Position the welding torch at the desired angle (see B.2) and secure it.

Set the desired CTWD for continuous wire processes (see B.5.1) following the procedure described in C.2 or, for autogeneous TIG welding, set the desired ETWD (see B.5.2) following the procedure described in C.3.

Set the required welding speed (see B.3).

Commence welding and adjust the power source to provide the desired test current and voltage.

Stop welding and renew or reposition the test piece so that the next weld is deposited on a cool, unwelded metal surface, if necessary securing it so that it cannot move, bow or flex during welding. Check that the CTWD or ETWD is unchanged and reset if necessary. Recommence welding, continue for a suitable time period, e.g. 60 s, and record the average current and voltage over the test period.

Verify that the desired current and voltage have been attained and, if not, renew or reposition the test piece, re-adjust the power source and repeat the test.

When the required test conditions have been achieved, proceed to testing (see 6.4).

6.4 Emission rate testing

Renew or reposition the test piece so that the next weld is deposited on a cool, unwelded metal surface, if necessary securing it so that it cannot move, bow or flex during welding. Check that the CTWD or ETWD is unchanged and reset if necessary. Position the test piece under the torch ready to commence welding. Manoeuvre the hood over the torch so that the torch is positioned centrally and the bottom edge of the hood is 5 cm above the upper surface of the test piece (see A.7).

Install a PTFE filter in the sampling line (5.4), handling it with tweezers or wearing nylon gloves. Clean or renew the short length of sampling line between the filter and the sampling point. Connect the sampling system to the ozone meter (5.3) and switch it on. Precondition the sampling system line (5.4) by passing ozone from the ozone generator (5.5) through following the procedure given in C.4. Disconnect the ozone source from the sampling system and secure the inlet of the sampling system at the sampling point in the hood (see Figure 1).

Switch on the extraction unit (5.2) and all monitoring equipment (5.6 and 5.7). Check that the air flow through the hood is still at the required value (see 6.2) and adjust it if necessary. Start the device for automatic welding. Commence welding, start logging the ozone concentration, weld for a suitable time period, e.g. 60 s, stop logging the ozone concentration and then switch off the extraction unit.

Perform five replicate tests and calculate the average ozone emission rate (see Clause 7). If any individual result differs from the mean by more than ± 25 %, carry out three further tests and calculate the average value of all eight results. If any results are then unacceptable, checks shall be made to ensure that the equipment is functioning correctly and the entire procedure shall be repeated.

7 Calculating and reporting the results

For each replicate test, calculate the average concentration of the ozone emitted over the period when the ozone concentration is “stable” (see Annex D).

Calculate the average air flow rate and the average current and voltage for each replicate test.

Calculate the ozone emission rate for each replicate test (in millilitres per minute) by multiplying the average stable ozone concentration (in millilitres per cubic metre) by the air flow rate (in cubic metres per minute).

NOTE Ozone meters usually measure ozone concentrations in parts per million (ppm), which corresponds to millilitres per cubic metre.

Calculate the mean ozone emission rate for each set of replicate tests and estimate the uncertainty of the measurements in accordance with ISO/IEC Guide 98-3.

Complete all applicable details in the test report shown in Annex E.

Annex A
(informative)

Equipment notes

A.1 Construction of the hood

It is convenient and inexpensive to construct the hood from standard zinc-coated ventilation ducting of different diameters, together with a standard cone and bends. However, the hood may be fabricated from sheet materials if so desired. The inside surfaces of the hood can be made non-reflecting by painting the inside with matt black paint.

The dimensions of the hood and the position of the sampling point affect the ozone concentration measured. To be able to compare absolute values of ozone emission rate, it is essential that testing be carried out in hoods of identical dimensions.

A.2 Extraction unit

The extraction unit shall provide sufficient air flow to retain the ozone within the hood but not so high as to compromise the integrity of the process. At air flow rates below 1,7 m^3/min, all the ozone emitted is not retained within the hood. At air flow rates above 3 m^3/min, weld metal integrity can be compromised. The air flow rate of 2 m^3/min specified in this part of ISO 15011 is considered to be suitable [1].

If air flow rate is to be controlled using the extraction unit, it should be fitted with a variable control. It is also possible to control air flow rate by using a damper in the extraction ducting.

A.3 Ozone meter and logging system

Ozone meters that operate using the chemiluminesence principle have a very fast response time, making it possible to measure accurately the fast changes in ozone concentration that occur during arc welding. Ozone meters that operate by measuring the intensity of ultra-violet radiation have a much slower response time and are considered to be unsuitable for measuring ozone emissions from arc welding. Logging systems with a logging interval of 1 s or less permit accurate averaging of ozone concentrations over selected time periods.

A.4 Sampling system

Ozone is decomposed rapidly on contact with most materials, including welding fume. Consequently, the sampling system needs to be made of materials that minimize ozone decomposition, e.g. PTFE and stainless steel. A sampling system of small volume minimizes the time between sampling and measurement and the potential for reaction between ozone and the sampling system. The use of a particulate filter at the inlet to the sampling line reduces the potential for reaction between ozone and fume particles. This potential can be further reduced by frequent replacement of the filter. Grease transferred from hands can decompose ozone, therefore the filter should not be handled with bare hands. Preconditioning the sampling system by passing a stream of air containing ozone through the system prior to each test generally minimizes the potential for ozone decomposition. It is prudent to also place a filter close to the ozone meter to prevent fume from entering the meter, should a problem occur with the filter close to the sampling point.

A.5 Device for measuring air flow rate

Welding generates particulate fume and consideration should be given to the fact that the measuring device needs to operate in fume-laden air.

Use of a digital manometer or anemometer with logging capabilities is desirable because air flow rate can vary somewhat with time and the use of such equipment allows an average air flow rate to be calculated.

A.6 Equipment for measuring shielding gas flow rate

Gas flow rates are normally measured using a device, such as a rotameter, turbine, mass flow meter or bubble flow meter. For measurement of shielding gas flow rates in welding, the device should be connected to the gas nozzle of the torch. If the device is connected to a gas supply line, care should be taken to ensure that there are no gas leaks. For some equipment, such as rotameters, the flow rate measurement is dependent on the shielding gas composition.

A.7 Placement of the hood

The hood shall be placed over a plane surface. The small gap between the hood and the surface provides turbulence, causing mixing of the ozone generated with the extracted air, providing improved reproducibility. The plane surface can be provided by employing a specially constructed table, clamping metal sheets of appropriate dimensions to the traverse or by placing metal topped tables of appropriate height and dimensions on either side of the traverse.

A.8 Test pieces

Test pieces made from commercial bar stock, 50 mm wide × 10 mm thick × 500 mm long, are generally suitable for linear welding, but materials of other dimensions may be used. Test pieces shall be free of coatings, dirt, grease, oil, paint or rust, unless the purpose of the evaluation is to determine the effect of a surface condition on emission rates. In that case, the condition of the surface shall be as uniform as possible on all test pieces.

A.9 Interference-free environment

An interference-free environment is an environment that does not affect the amount of ozone measured. Therefore, it is free of significant concentrations of particles, such as welding fume and ozone-reducing gases, e.g. nitric oxide.

Annex B
(informative)

Welding parameters for ozone emission rate testing

B.1 Welding position

Tests can be carried out by welding bead-on-plate in the PA position (see IEC 60974-7 [1]) or in a horizontal/vertical fillet in the PB position (see IEC 60974-7 [1]).

B.2 Torch angle and welding direction

For MIG/MAG welding with solid and tubular-cored wires and welding with self-shielded tubular-cored wires, the torch should be at an angle of 80°, measured between the test piece and the wire axis, i.e. the end of the torch from which the wire exits should be almost vertical. Welding should be carried out using the appropriate pushing or pulling technique. For TIG welding, the tungsten electrode should be at 90° to the plate, i.e. the torch is vertical.

During welding, the welding torch should remain stationary whilst the workpiece traverses underneath.

B.3 Welding speed

The welding speed should be set by an experienced welder to provide a visually satisfactory weld deposit. In practice, this equates to a traverse speed of between 250 mm/min and 300 mm/min in most cases.

B.4 Polarity

Testing should be performed using the polarity recommended by the consumable manufacturer.

B.5 Distances between the process and the test piece

B.5.1 CTWD

For continuous wire processes, the CTWD suggested by the consumable manufacturer should be used. If this information is not available, the CTWDs shown in Tables B.1 and B.2 can be used.

Table B.1 — Recommended CTWDs for MIG/MAG welding with solid wires and spray transfer

Consumable diameter mm	**CTWD** mm
0,6	8
0,8	10
1,0	15
1,2	18
1,6	22
2,0	26
2,4	28

Table B.2 — Recommended CTWDs for MIG/MAG welding with tubular-cored wires

Consumable diameter mm	CTWD mm
0,9	15
1,0	18
1,2	20
1,4	22
1,6	25
2,0	28
2,4	30

The manufacturer's recommended value should be used when welding with flux-cored and metal-cored wires.

The values are based on those recommended in IEC 60974-7 [1].

B.5.2 ETWD

For TIG welding, an ETWD of 3 mm is used.

B.6 Shielding gas flow rate

The shielding gas flow rate recommended by the manufacturer should be employed for each welding parameter combination tested. The flow rate should be measured at the gas nozzle, using an external flow meter with an accuracy of 5 % or better.

B.7 Gas nozzle

For MIG/MAG welding with solid, tubular-cored wires and self-shielded tubular-cored wires, the gas nozzle should be fit-for-purpose for the process and welding conditions and should be recorded. Typically, the internal diameter is between 15 mm and 20 mm.

For MIG/MAG welding with solid wires and short-circuiting transfer, the contact tip extends 1 mm to 2 mm outside the gas nozzle.

For MIG/MAG welding with solid wires and spray transfer, the contact tip is 2 mm to 3 mm inside the gas nozzle.

For TIG welding, the ETWD is approximately 3 mm. The distance should be measured and recorded to within 0,5 mm. The electrode tip should project between 3 mm and 6 mm outside the gas cup.

Annex C
(normative)

Test procedures

C.1 Attaching the leads for measuring voltage and current

For continuous wire welding processes, attach the voltage leads to the wire feed unit and the test piece. For TIG welding, attach one voltage lead as close to the tungsten electrode as possible and attach the other voltage lead to the test piece.

NOTE It is recognized that there can be a very small voltage drop between the wire feed unit and the torch during continuous wire welding, but it is very difficult to dismantle the torch and connect a voltage lead.

If used, the Hall effect probe shall be positioned on the current return lead so that the direction of current flow matches the direction indicated on the probe.

C.2 Setting the CTWD

Remove the gas nozzle from the torch. Fix the test piece in position and place the gauge or metal wedge used for setting the CTWD (5.9) on the test piece. Lower the torch until the contact tip touches the gauge and secure the torch.

Drive the traverse until the torch is in a position where the gas nozzle can be re-attached and re-attach it, ensuring that the torch does not move when this is performed.

C.3 Setting the ETWD

Fix the test piece in position and place the gauge or metal wedge used for setting the ETWD (5.11) on the test piece. Lower the torch until the contact tip touches the gauge and secure the torch.

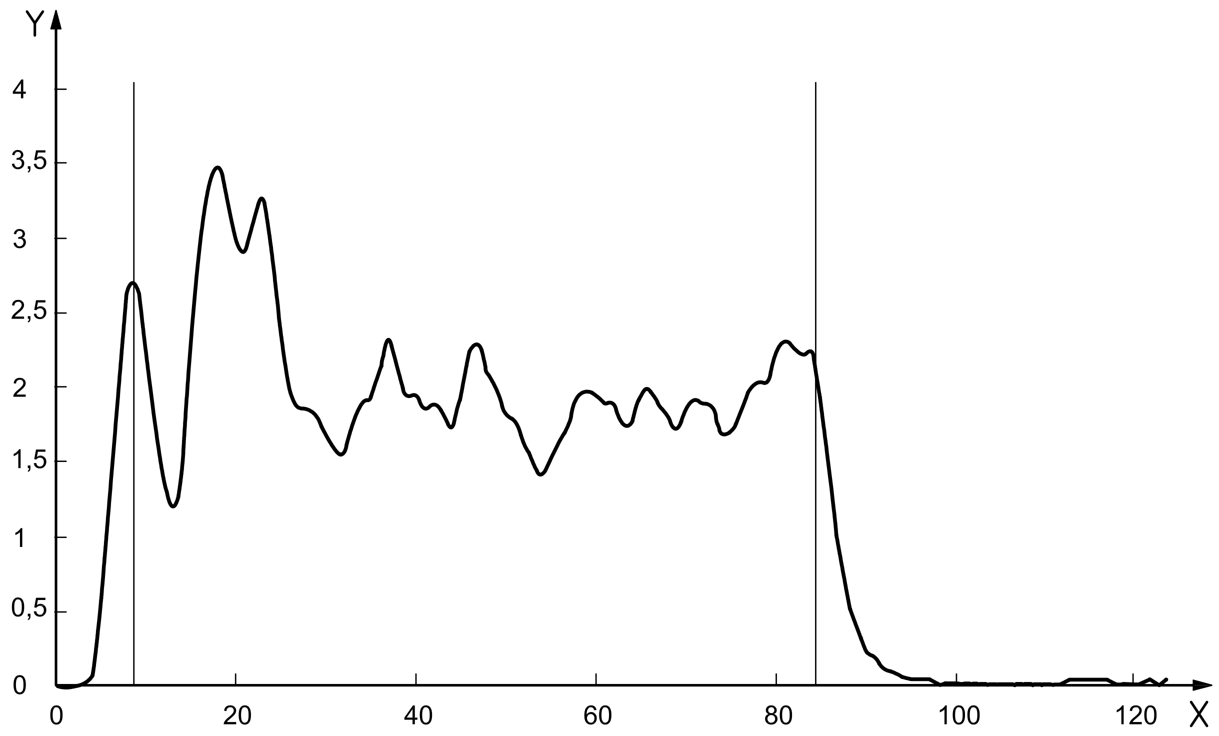
C.4 Preconditioning the sampling system

Pass ozone from an ozone source through the entire sampling system until a steady reading is obtained on the ozone meter. If the concentration delivered by the ozone source is known, i.e. the ozone is generated by an ozone calibrator, the steady reading shall equate to the value of the source.

Annex D
(normative)

Calculation of the average stable ozone concentration

Figure D.1 shows a typical plot of the ozone concentration at the sampling point against arcing time for a single replicate test. Arcing commences at time = 0 s and terminates at time = 85 s. Line markers are placed at the extremities of the area selected as providing a stable ozone concentration.



Key

X time after arc ignition (s)

Y ozone concentration (ml/m^3)

Figure D.1 — Plot of ozone concentration against time

Calculate the average stable ozone concentration by averaging the ozone concentrations measured within the time period selected as providing a stable ozone concentration.

Annex E
(normative)

Test report

Date of test						
Laboratory/Operator						
Project No./Test No.						
Welding	Process: Torch angle: Welding speed: Polarity:			Gas nozzle diameter and shape: CTWD: Contact tip position relative to gas nozzle: Pushing or pulling:		
Consumable	Manufacturer/Name/Diameter/Classification/Remarks:					
Test piece	Composition/Dimensions/Surface condition/Remarks:					
Shielding gas	Trade name/Composition/Flow rate/Classification/Remarks:					
Power source	Manufacturer/Type/Model/Set-up/Remarks:					
Air flow measuring equipment	Type/Model/Remarks:					
Arc monitoring equipment	Make/Model/Reference number/Connections/Remarks:					
Pulse details						
Measurement details	Test 1	Test 2	Test 3	Test 4	Test 5	Mean
Arc current (A)						
Arc voltage (V)						
Wire feed speed (m/min)						
Stable ozone concentration (ml/m^3)						
Air velocity or pressure difference						
Air flow (m^3/h)						
Ozone emission rate (ml/min)						
Estimated uncertainty in accordance with ISO/IEC Guide 98-3:						
Remarks:						

Bibliography

[1] IEC 60974-7, *Arc welding equipment — Part 7: Torches*

[2] *Evaluation of laboratory emission rate measurement procedures for WELD-OZONE: Examination of the measurement and control of ozone emissions during gas-shielded arc welding*. European Commission WELD-OZONE Project No: GRD1-1999-20008, contract no. G6RD-CT-2000-00270, Brondby, 2002

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