EN ISO 15011-4: Round robín examination of fume emission rates from welding consumables

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Abstract

EN ISO 15011-1 prescribes a method for determination of the emission rate and chemical composition of welding fume. The standard prescribes test methodology, but leaves it to the user to define appropriate test conditions for a particular application. A supplementary standard has therefore been drafted prescribing test conditions for generation of fume data that consumable manufacturers can include on safety data sheets. In due course, this standard will be published as EN ISO 15011-4.

Unfortunately, little information has previously been available on the influence of test parameters on fume emission rate (FER), making it difficult to define how precisely these parameters should be controlled and impossible to give performance data for inclusion in the proposed standard. Particular concern has been expressed about whether the test method exhibits adequate repeatability and reproducibility. Laboratory experiments were therefore performed and a round robin carried out to determine whether EN ISO 15011-4 gives results that are fit-for-purpose.

The repeatability of FER measurements made using the test method prescribed in the draft standard was found to be good, typically in the range 2-10 %. Reproducibility was such that the test method is considered to be fit-for-purpose for most of the processes examined, with 95 % confidence limits in the range ± 10 % to ± 40 %, and recommendations have been made for improving the reproducibility of FER measurements, such that the method is expected be fit-for-purpose for all processes when they have been acted upon. The repeatability of fume composition measurements was also found to be good, typically being in the range 5-10 % for major constituents of the fume.

1 Introduction

EN ISO 15011-1:2002 *Health and safety in welding and allied processes — Laboratory method for sampling fume and gases generated by arc welding — Determination of emission rate and sampling for analysis of particulate fume* [1] prescribes a method for collecting samples of welding fume for determination of the emission rate and chemical composition of the fume. However, this standard only deals with the test method itself, leaving it to the user to define and record appropriate test conditions for a particular application. Therefore, a supplementary standard, prEN ISO/DIS 15011-4 *Health and safety in welding and allied processes — Laboratory method for sampling fume and gases — Fume data sheets* [2], has been drafted prescribing test conditions to be used by welding consumable manufacturers when they generate fume data for safety data sheets. The resulting data can also be used for risk assessment purposes and in the classification of welding consumables.

Unfortunately, little information has previously been available on the influence of test parameters that can affect fume emission rate (FER), making it difficult to define how precisely these parameters should be controlled and impossible to give performance data for inclusion in the proposed standard. Consequently, there has been lingering concern about whether the EN ISO 15011-1 method exhibits suitable repeatability and reproducibility, especially for continuous wire processes, when the conditions prescribed in EN ISO 15011-4 are applied. This situation was exacerbated by a presentation made to Commission IIE of the International Institute of Welding [3] that outlined the results of an interlaboratory trial carried out in-house by a major consumable manufacturer. The results of this work suggested that it was not possible to obtain good interlaboratory agreement in FER measurement. However, although the welding conditions used in this study were nominally identical and similar to those prescribed in EN ISO 15011-4, inadequate reporting made it impossible to establish the extent to which this was actually the case. Continued belief that significantly better reproducibility could be obtained if tests were to be carried out in strict accordance with the protocol defined in EN ISO 15011-4 therefore led to the Health and Safety Laboratory (HSL) and TWI organising a round robin that it was believed would demonstrate this fact and thus, hopefully, ensure acceptance of the draft standard.

2 Draft European and International Standard prEN ISO/DIS 15011-4

2.1 Background

The purpose of prEN ISO/DIS 15011-4 is to prescribe test conditions for generating welding fume in accordance with the method prescribed in EN ISO 15011-1 when the purpose of generating that fume is to produce FER and fume composition data. The basic procedure for fume box testing prescribed in EN ISO 15011-1 has been described elsewhere [4]. In addition, prEN ISO/DIS 15011-4: prescribes a format in which FER and fume composition data are to be reported, known as a fume data sheet; sets out transitional arrangements for use of existing data, requirements for retesting of consumables and data sharing; and provides information on uses of fume data, principal and key components of welding fume, and a possible welding fume consumable classification system. However, the scope of this paper is restricted to dealing with the performance of the test method prescribed in the standard.

2.2 Development of the standard

The enquiry draft of prEN ISO/DIS 15011-4 was developed by CEN/TC 121/SC 9/WG 5 *Welding/Health and safety in welding and allied processes/Fume data sheets*. The working group had no difficulty establishing consensus regarding the conditions under which welding fume should be generated to obtain fume composition data, aided by the fact that previous work carried out by HSL and TWI [5] had already demonstrated that changes in welding conditions do not have a significant effect on fume composition.

However, welding parameters can have a dramatic influence on FER and therefore the working group found it much more difficult to reach agreement on how to prescribe conditions under which to perform FER measurements. In fact it took over four years and nine working group meetings to resolve this and other contentious issues concerning the proposed standard and to reach the stage where the draft was ready for parallel enquiry within CEN and ISO. The enquiry eventually took place between August 2004 and January 2005, and the opportunity was seized to carry out the proposed round robin in parallel with the enquiry in order that the findings could inform the voting process.

2.3 Welding processes covered by prEN ISO/DIS 15011-4

A number of different welding processes are included in the scope of prEN ISO/DIS 15011-4, in particular:

- manual metal arc welding (MMA);
- gas-shielded metal arc welding with solid wires, which includes both metal inert gas (MIG) welding and metal active gas (MAG) welding;
- gas-shielded metal arc welding with flux-cored wires, or flux-cored arc welding (FCAW);
- gas-shielded metal arc welding with metal-cored wires, or metal-cored arc welding (MCAW); and
- self-shielded metal arc welding with flux-cored wires, or self-shielded flux-cored arc welding (SSFCAW).

2.4 Test conditions prescribed in prEN ISO/DIS 15011-4

An overview of the test methodology prescribed in prEN ISO/DIS 15011-4, as it was at the time when the draft standard was circulated for parallel enquiry, is provided in Table 1.There are three significant things to note about this table. Firstly, the information it gives is only a summary of the more important test conditions specified in the standard, which in fact contains six interlinked tables specifying in considerably greater detail exactly how welding is to be carried out. Secondly, the working group that prescribed the test conditions had in the forefront of their minds that the FER of any particular welding consumable can vary significantly according to the conditions under which it is used. The test conditions that the working group specified were therefore chosen to achieve maximum reproducibility, in line with the concept of standardisation, whilst also being as representative as possible of those which would most commonly be used in practice for the consumable concerned. Finally, the test conditions shown in Table 1 were modified somewhat as a result of the lessons learnt in the round robin, so that they are not in all cases the exact conditions that will be prescribed in the published standard.

Table 1: *prEN ISO/DIS 15011-4 test conditions*

Parameter	Test conditions
Diameter	MIG/MAG: all diameters Other processes: the smallest and largest diameters and others by interpolation
Current	90% of the maximum of current range recommended by the consumable manufacturer
Contact tip to workpiece distance (CTWD)	MIG/MAG, FCAW and MCAW: CTWD specified in the standard SSFCAW: CTWD recommended by the consumable manufacturer
Voltage	Voltage for optimum operating conditions established by an experienced welder: MIG/MAG: spray transfer conditions FCAW and MCAW: smooth metal transfer conditions
Polarity	MIG/MAG: dc+ Other processes: the polarity recommended by the consumable manufacturer
Gas type and gas flow	Most oxidising gas mixture given by the formula: ($1 \times CO_2$) and ($2 \times O_2$), with a gas flow that provides adequate shielding (generally in the range 15 to 20 l/min).
Welding speed	Optimum welding speed. as established by an experienced welder
Test piece	Material: as similar as possible to that of the weld metal Size: commercial bar stock cut to a suitable length Preparation: surface is degreased and free from surface coating.
Power source	Inverter power source with ripple-free current
Torch	Water-cooled, standard diameter gas shroud
Configuration	Bead-on-plate, torch angle at 90° to the test piece

It can be seen from Table 1 that test conditions are specified for a wide range of welding parameters. However, some of these have a much greater influence on FER than others. It was therefore decided to perform some preliminary investigative work to assess the robustness of the methodology before the start of the round robin proper.

3 Robustness tests

3.1 Background

prEN ISO 15011-4 demands that tests are performed according to protocol in which the values of some parameters are prescribed very precisely, whilst others are described rather subjectively. For example, exact values of contact tip to work piece distance (CTWD) are prescribed in the standard and the maximum of current range recommended by the consumable manufacturer has to be extracted from the manufacturers' trade literature. However, other parameters, the most significant of which is arc voltage, have to be optimised by an experienced welder. Prior to this work, the extent to which these welder-optimised test conditions might vary, and the effect of this variation on FER, were unknown. The preliminary robustness tests were therefore intended to assess the effect of variability in test conditions on FER and identify possibilities for tightening up test conditions prior to starting the round robin, bearing in mind that there would still be opportunity to refine the test protocol described in prEN ISO 15011-4 before the standard was published.

3.2 Consumables tested

Details of the consumables tested in the preliminary robustness tests and in the subsequent round robin are given in Table 2. One example of a manual metal arc electrode, a solid wire, a metal cored wire and a self shielded flux cored wire were tested, together with one example of each of two types of gas shielded flux cored wires (rutile and basic).

Table 2: *Details of consumables tested*

Manufacturer	Name	Classification / description	Diameter (mm)	Current (A)
Avesta-Polarit	308L-17	AWS A5.4-92 E308L-17 MMA electrode	3.2	120
Lincoln Electric	LNM 316LSi	AWS A5.9-93: ER316LSi Solid MIG/MAG wire	1.2	220-240
FILARC	PZ 6113	AWS A5.20: E71-T1 Rutile gas shielded FCAW wire	1.2	130-350
ESAB	OK Tubrod 15.00	AWS A5.20: E71-T5 Basic gas shielded FCAW wire	1.2	100-250
Lincoln Electric	Outershield MC710-H	AWS A5.18: E70-6MH4 Gas shielded MCAW wire	1.2	180-340
Lincoln Electric	Innershield NR-211MP	AWS A5.20: E71-T11 Self shielded FCAW wire	1.1	120-170

3.3 Tests performed

The robustness of the methodology was examined by determining the relative standard deviation of results from a series of tests in which the effect of varying the test conditions from those specified in prEN ISO/DIS 15011-4 was examined. The subjective variables evaluated were arc voltage, traverse speed and welding direction, i.e. pulling or pushing. Voltage and traverse speed were studied by varying their values within a realistic, practical range above and below the optimum value established by experienced welders. For voltage, the extremes of the range tested were the highest and lowest values of the optimised values obtained by five welders, except for MMA, for which only a higher voltage could be tested. For traverse speed, the upper and lower traverse speeds were the optimum value ± 30%. In the case of welding direction, testing was performed by welding in the accepted and opposite directions with the torch at an angle of 75º, with an additional test with the welding torch at 90º. A number of other variables were also evaluated. In particular, tests were carried out to determine if the make of inverter power source used influences FER and to establish whether SSFCAW carried out with a MIG/MAG torch gives the same results with and without the gas shroud removed. Full details of the work carried out are available in a TWI report [6].

3.4 Test results

The results of the robustness tests showed that the parameter with the greatest effect on FER is voltage and this led to a recommendation that, rather than the test condition being established by a single experienced welder, if possible the median of the test conditions established by a number of experienced welders should be used. Various other recommendations were made and these were incorporated into prEN ISO/DIS 15011-4 before the draft standard was circulated for parallel enquiry and before the start of the round robin. The range of voltages tested and the resulting FER data are given in Table 3.

Table 3: *Results of FER robustness tests*

Process	Range of voltages tested (V)	FER		
		Average (mg/s)	SD (mg/s)	RSD (%)
MMA	25.7 – 26.2	5.2	1.0	18
MAG	23.0 – 23.5	0.7	0.3	49
Rutile FCAW	29.2 – 33.1	17.8	1.4	8
Basic FCAW	25.4 – 26.1	19.7	3.8	19
MCAW	33.4 – 36.4	21.4	4.0	19
SSFCAW	17.5 - 20.4	7.1	2.0	28

The relative standard deviation of results obtained was generally less than 30 %. This was considered to be fairly low, bearing in mind that FER measurements had been deliberately made at the extremes of the range of conditions under which it might reasonably be expected that the tests will be performed. The higher figure of nearly 50 % for MAG welding is due to the fact that there is a high dependence on voltage for this technique. A plot of FER v voltage (Figure 1) shows a sharp trough at the point at which the optimum voltage for spray transfer occurs, which is the condition under which FER measurements are made. On the basis of the results obtained it was concluded that, although expectations should not be too high regarding the likely reproducibility of round robin data, 95 % confidence limits might reasonably be expected to within ± 50 % for most processes.

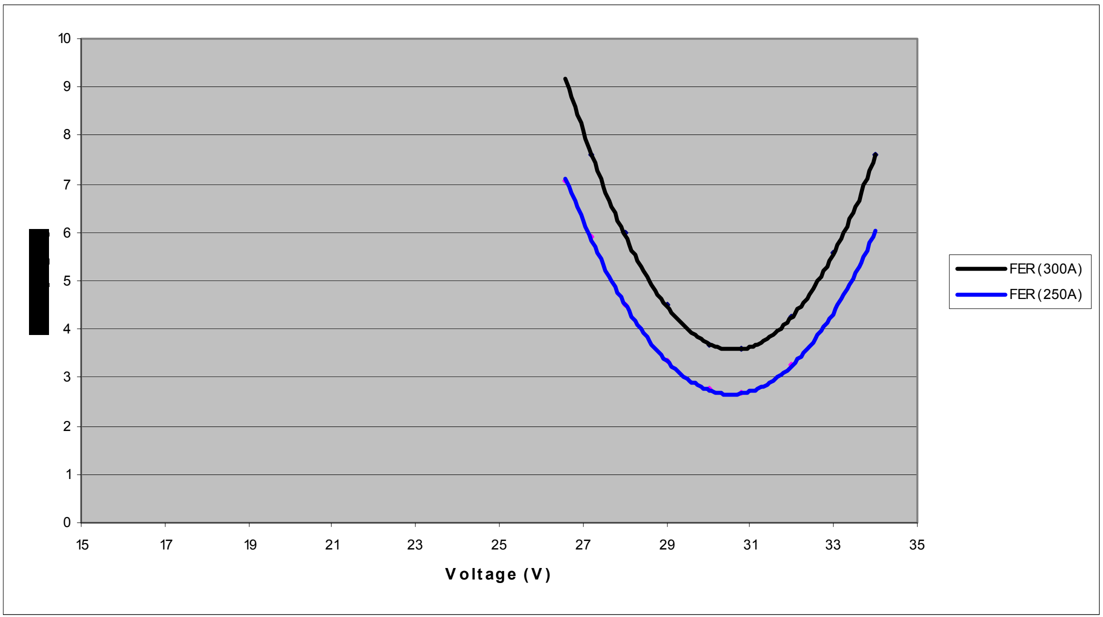

Figure 1: *FER v voltage for stainless steel MMA welding with Ar/2% CO_2 shielding gas (courtesy of Air Liquide ALTEC)*

4 Round robin

4.1 Participants

Participants in the round robin included both consumable manufacturers and research institutes, as listed below:

Air Liquide

Avesta-Polarit

Böhler-Thyssen (ISF, Aachen)

ESAB (Gothenburg and Vamberk)

Force Technology

Institut de Soudure

Instytut Spawalnictwa

Lincoln Electric

TWI/HSL

4.2 Objectives

The objectives of the round robin were to:

- obtain an estimate of the repeatability of FER measurements from the results of each round robin participant;
- estimate the reproducibility of FER measurements from the participant results;
- estimate the repeatability of fume composition data from HSL analysis of TWI fume samples; and
- demonstrate that prEN ISO 15011-4 test results are fit-for-purpose.

4.3 Instructions to participants

The round robin participants were given detailed instructions on what was expected of them prior to commencement of the exercise. They were asked to:

- read the copy of prEN ISO/DIS 15011-4 supplied to them;
- refer to EN ISO 15011-1 for the basic methodology for determination of FER;
- adhere strictly to detailed test protocol given in the accompanying paperwork;
- carry out preliminary work to establish optimised conditions under which to carry out the tests, and in particular to have an experienced welder determine the optimum operating voltage, decide on an appropriate welding speed and gas flow, and select an appropriate arc time;
- carry out 10 tests on each consumable under repeatability conditions (i.e. with the same welder carrying out the tests one after another on the same day, using the same equipment), using mechanised welding for continuous wire processes; and
- report the results in detail using the supplied spreadsheets.

4.4 Test protocol

The detailed test protocol that was provided to the round robin participants in the paperwork that accompanied the test samples is set out in Table 4.

The objective of supplying such detailed information to the participants was to make it as easy as possible for them to both comply fully with the requirements of EN ISO 15011-1 and prEN ISO/DIS 15011-4 and adhere to the small number of additional prescriptions that resulted from the findings of the robustness tests. Compiling the test protocol involved obtaining trade literature, extracting from it manufacturers' recommended current ranges and gas types etc, and then determining test conditions that were in line with the requirements of prEN ISO/DIS 15011-4 (90 % current, most oxidising gas mixture, etc).

Table 4: *Round robin test protocol*

Parameter	Consumable type					
	MMA	**MAG**	**Rutile FCAW**	**Basic FCAW**	**MCAW**	**SSFCAW**
Current (A)	120	240	315	225	306	153
Polarity	dc+	dc+	dc+	dc-	dc+	dc-
Power Source	Ripple free inverter	Ripple free inverter	Ripple free inverter	Ripple free inverter	Ripple free inverter	Ripple free inverter
Test piece	Unalloyed	Unalloyed	Unalloyed	Unalloyed	Unalloyed	Unalloyed
CTWD (mm)	-	18	20	20	20	14
Gas	-	Ar / 2 % O_2	CO_2	CO_2	75 % Ar / 25 % CO_2	-
Gas flow rate	-	Adequate within range 15-20 l/min	Adequate within range 15-20 l/min	Adequate within range 15-20 l/min	Adequate within range 15-20 l/min	-
Torch	-	Water cooled / 90º	Water cooled / 90º	Water cooled / 90º	Water cooled / 90º	No shroud
Voltage	Optimised	Optimised	Optimised	Optimised	Optimised	Optimised
Travel speed	Optimised	Optimised	Optimised	Optimised	Optimised	Optimised

4.5 Test results

The test results reported by round-robin participants are summarised in Table 5.

Table 5: *Round robin test results*

	Laboratory									Average	SD (mg/s)	RSD (%)
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**			
MMA												
FER (mg/s)	3.6	3.4	5.1	5.4	4.3	4.7	5.5	*6.0*	4.8	4.8	0.9	18
SD (mg/s)	0.3	0.2	0.4	0.2	0.4	0.5	0.1	*0.3*	0.4	0.3		
RSD (%)	8.8	4.9	7.9	3.2	8.2	10	2.5	*4.2*	8.4	6.5		
MAG												
FER (mg/s)	0.47	*4.0*	*1.9*	*0.96*	*4.3*	0.53	*1.7*	*3.9*	*0.56*	2.0	1.6	79
SD (mg/s)	0.05	*0.5*	*0.2*	*0.4*	*1.8*	0.03	*0.2*	*0.2*	*0.08*	0.4		
RSD (%)	10	*12*	*11*	*44*	*42*	5	*13*	*5*	*15*	17		
Rutile FCAW												
FER (mg/s)	19.0	*17.5*	*(13.0)*	19.8	19.5	18.6	*17.3*	19.8	*18.4*	18.7	1.0	5.2
SD (mg/s)	0.5	*2.0*	*(0.3)*	0.5	1.6	0.5	*0.5*	0.5	*1.1*	0.9		
RSD (%)	2.7	*11.3*	*(2.3)*	2.3	8.9	2.6	*2.6*	2.7	*5.7*	4.8		
Basic FCAW												
FER (mg/s)	27.7	*17.3*	17.5	30.3	26.5	22.1	-	25.0	*21.8*	23.5	4.7	20
SD (mg/s)	0.7	*0.7*	0.6	2.2	1.2	0.8	-	1.3	*0.7*	1.1		
RSD (%)	2.7	*4.2*	3.1	7.3	4.4	3.6	-	5.0	*3.2*	4.3		
MCAW												
FER (mg/s)	18.6	*5.7*	11.9	*11.6*	*22.4*	11.4	*14.2*	10.5	*22.2*	14.3	5.7	40
SD (mg/s)	0.9	*0.4*	0.7	*1.0*	*2.2*	0.6	*0.43*	0.5	*1.8*	1.0		
RSD (%)	4.9	*7.7*	5.8	*9.0*	*10*	5.0	*3.0*	4.8	*8.2*	6.3		
SSFCAW												
FER (mg/s)	*12.2*	*11.3*	*9.1*	*11.6*	*8.0*	10.3	*10.1*	*7.0*	*11.6*	10.1	1.8	18
SD (mg/s)	*0.4*	*0.2*	*0.5*	*0.6*	*0.4*	0.4	*1.1*	*0.2*	*0.2*	0.5		
RSD (%)	*3.5*	*1.7*	*6.0*	*5.1*	*4.9*	3.8	*11.0*	*2.6*	*1.4*	4.8		

Data in italics is where there were potentially significant deviations from the prescribed test conditions

FER data and associated standard deviations and RSDs are given in Table 5 for each of the round robin participants. It should be noted that the reported data has been randomised and the order in which it appears in Table 5 does not correspond to the order in which the round robin participants are listed in 4.1. The table is subdivided into six blocks giving the results for each of the six processes examined in the round robin (MMA, MAG, rutile FCAW, basic FCAW and SSFCAW. The average RSD at the bottom right-hand corner of each block represents the repeatability of the FER measurements for the process concerned, and the RSD of the average FER in the top right-hand corner of each table gives a measure of reproducibility.

In interpreting the data in Table 5 it is important to be aware that all but one of the round robin participants failed to adhere fully to the test protocol for one or more of the processes examined. Where there were potentially significant deviations from the prescribed test conditions the results concerned are shown in italics. Furthermore, in the case of rutile FCAW, laboratory C used an abnormally low current, reporting that the test could not be carried out under the specified conditions. Consequently, the result concerned, which is in parentheses in Table 5, was considered to be invalid and was excluded when the data was processed. The nature of other deviations from the test protocol varied, but they included collection of too little fume, incorrect CTWD or failure to control CTWD due to the use of manual rather than mechanised welding, use of the wrong shielding gas, use of an incorrect torch angle and incidence of suspect results due to reporting abnormalities.

4.6 Repeatability of FER measurements

Repeatability data for FER measurement results reported by round-robin participants are summarised in Table 6.

Table 6: *FER repeatability data*

Process	Mean FER (mg/s)	Mean repeatability (%)	Repeatability range (%)
MMA	4.8	6.5	2.5 – 10.1
MAG	2.0	17	5 – 44
Rutile FCAW	18.7	4.8	2.3 – 11.3
Basic FCAW	23.5	4.2	2.7 – 7.3
MCAW	14.3	6.3	3.0 – 10.0
SSFCAW	10.1	4.8	1.7 – 11.0

The repeatability of FER measurements made in the round robin was good for all processes except MAG. For MMA, rutile and basic FCAW, MCAW and SSFCAW the repeatability ranged from 1.7 – 11.3 % and averaged 5.3 %. For MAG the repeatability was poorer, ranging from 5 – 44 % and averaging 17 %. This could be due to the high dependence of FER on voltage for this technique, as mentioned in section 3.4, but the power source should compensate for any changes in CTWD by adjusting the current to maintain a constant voltage. One of the two participants who reported poor FER repeatability for MAG used an incorrect shielding gas (Ar/2% CO_2), which gives a rather unstable arc, and this could account for the results they obtained. Another factor that might have adversely affected the repeatability of FER results for MAG welding is the low amount of fume collected, especially for those round robin participants who failed to adhere to the minimum of 100 mg prescribed in

EN ISO 15011-1.

4.7 Reproducibility of FER measurements

The reproducibility of FER measurement results reported by round-robin participants are summarised in Table 7, in which the right-hand column gives the 95 % confidence limits, calculated as 1.96 times the standard deviation of the participant mean.

Table 7: *FER reproducibility data*

Process	Mean FER (mg/s)	Reproducibility (%)	95 % confidence limits
MMA	4.8	18	± 35 %
MAG	2.0	79	± 155 %
Rutile FCAW	18.7	5.2	± 10 %
Basic FCAW	23.5	20	± 39 %
MCAW	14.3	40	± 78 %
SSFCAW	10.1	18	± 34 %

The results are also presented graphically as box and whisker diagram in Figure 2.

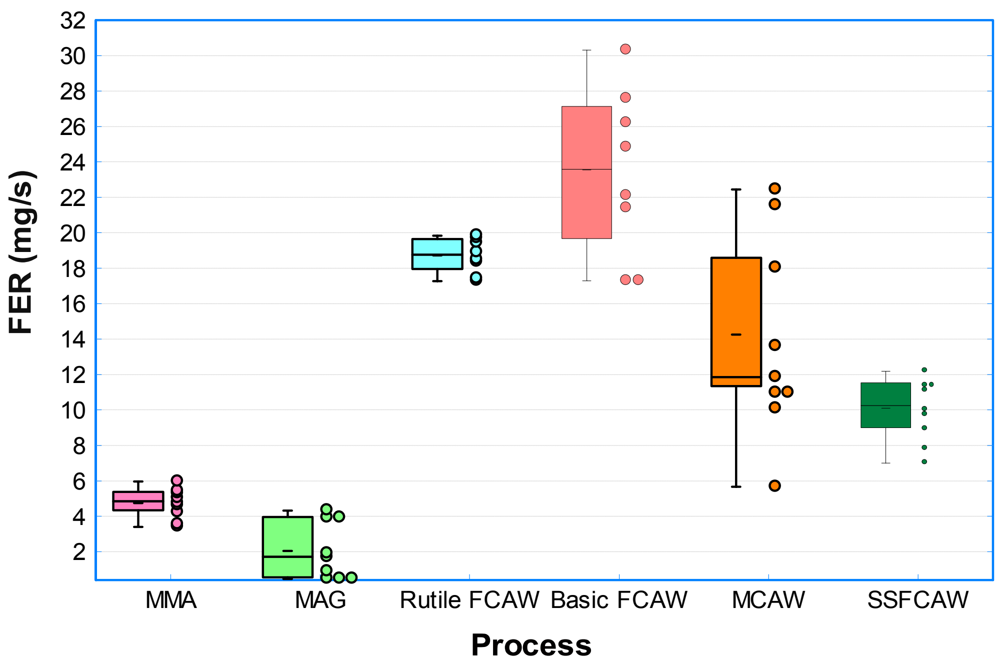

Figure 2: *FER data box and whisker diagram*

For four of the processes examined (MMA, rutile FCAW, basic FCAW and SSFCAW), the 95 % confidence limits for FER measurements carried out in accordance with prEN ISO/DIS 15011-4 were in the range 10-40%. This was considered to be acceptable, being comparable, for example, with the requirements specified by CEN for the performance of procedures for the measurement of chemical agents in workplace air [7], in which the overall uncertainty of the method has to be < 30 % or < 50 %.

The poor reproducibility for MAG was considered to be of no great concern because of the low FER of the tested consumable. Inaccuracy in the determined FER is therefore unlikely to have a significant bearing on the outcome of a risk assessment in which the data are used, nor on the classification of a wire using the welding consumable classification system described in prEN ISO/DIS 15011-4. However, it is worth noting that the reproducibility of the method might have been significantly better if the round robin participants had used the test conditions exactly as prescribed. It can be seen from Table 5 that only two participants adhered strictly to the test protocol and they reported very similar FERs (0.47 and 0.53 mg/s).

The relatively poor reproducibility for MCAW is also due in part to deviation from the prescribed test conditions, but variation in welder-optimised test parameters, and in particular arc voltage, appears to be a major factor influencing the performance of the method. Different welding processes exhibit different degrees of dependence of FER on voltage and the plots of FER v voltage given in figures 3, 4 and 5 for rutile FCAW, basic FCAW and MCAW, respectively, illustrate this point.

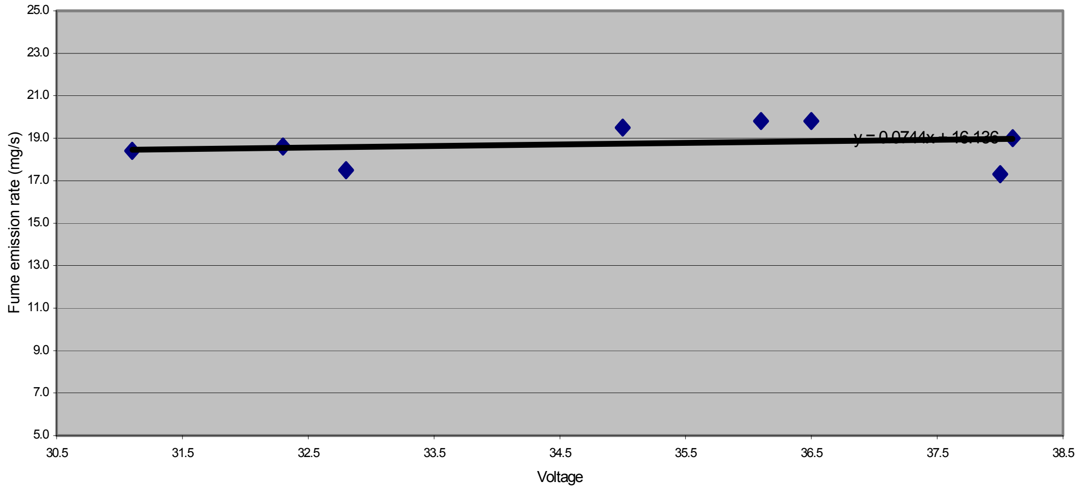

Figure 3: *FER v voltage for rutile FCAW*

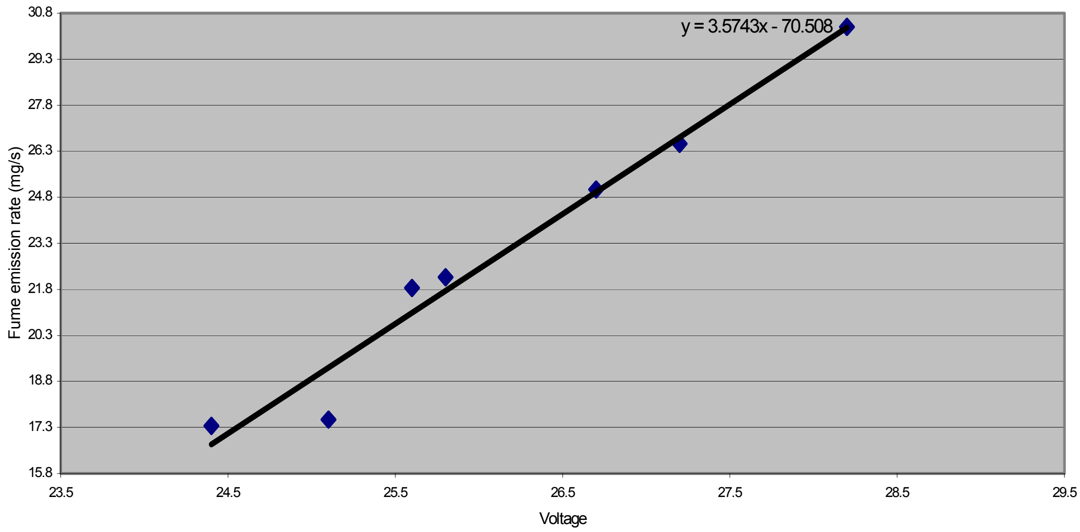

Figure 4: FER v voltage for basic FCAW

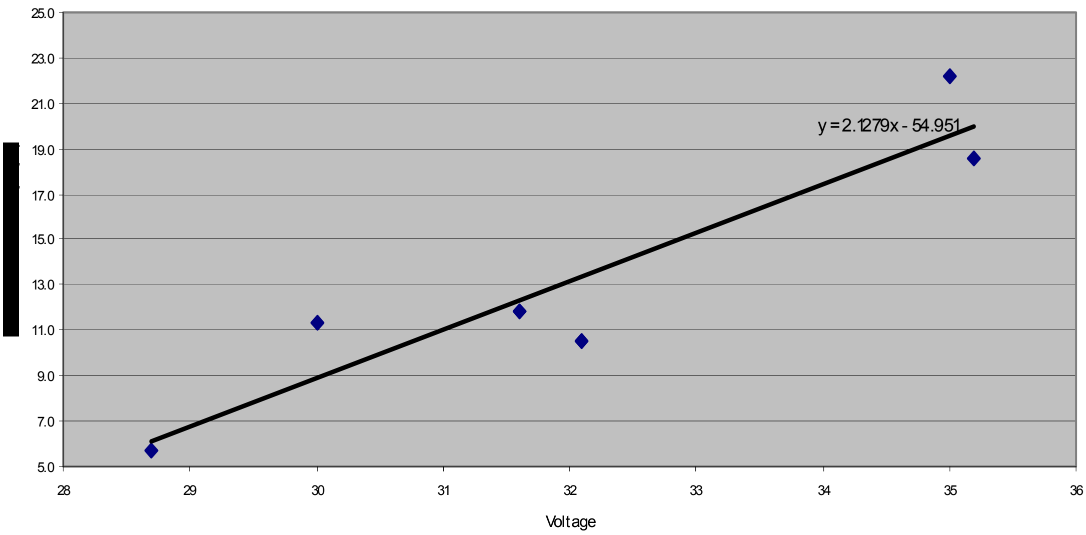

Figure 5: FER v voltage for MCAW

Figure 3 shows that, for rutile FCAW, FER does not vary much across the range voltages used by round robin participants; whilst figures 4 and 5 show that there is a much greater dependence of FER on voltage for basic FCAW and MCAW. This largely accounts for the poorer reproducibility for these two processes.

5 Measures to improve FER reproducibility

A number of measures were identified that could improve FER reproducibility:

1) It is very important that the prEN ISO 15011-4 protocol is strictly followed and that test conditions are properly reported. There are perhaps no direct measures that can be taken to promote such good practice, but it is much more likely that the requirements of the standard will be met when it has been published and FER measurements are performed by organisations that operate a quality system.

2) Results will be improved if the arc voltage is set more reproducibly. Steps have been taken to address this by amending the draft standard by adding a recommendation that the optimum operating voltage is determined by a number of experienced welders and the average of the resulting values is used when making FER measurements.

3) The CTWD was set incorrectly by one participant in the round robin and there was a lack of clarity about the means by which the CTWD was set by a number of others. The reproducibility of FER measurements will therefore be improved if the CTWD is set more precisely. This needs to be addressed in EN ISO 15011-1 when the standard is revised

4) The method of measurement of current and voltage also needs to be prescribed more precisely in EN ISO 15011-1 when it is revised, since such measurements need to be made accurately and in the same manner by all users of the test method for maximum reproducibility.

5) It is important that arcing time is measured accurately when this is of short duration. Once again, this needs to be stressed in EN ISO 15011-1 when it is revised.

6 Repeatability of fume composition data

The repeatability of fume composition data was determined at HSL by the analysis of fume samples collected at TWI during the round robin. The ten welding fume samples generated for each consumable in the round robin tests carried out at TWI were analysed by a method based on that described for the analysis of workplace air samples in ISO 15202 [8]. In each case, the welding fume was removed from the filter on which it was collected by careful brushing, as prescribed in EN ISO 15011-1. Unfortunately, this was not possible for the MAG welding samples because of the small quantity of fume collected, so the fume generated by this process could not be analysed. For the other five processes, milligram quantities of welding fume were dissolved using nitric, hydrochloric and hydrofluoric acids in a closed vessel microwave digestion system and analysed by inductively coupled plasma atomic emission spectrometry (ICP-AES). The resulting data is presented in Table 8.

***Table 8**: Fume composition repeatability data*

Process	Element	Mean composition (% m/m)	Repeatability (%)
MMA	Cr	4.4	8.5
	Fe	5.5	8.7
	Mn	4.9	6.4
	Ni	0.3	8.8
	Pb	0.4	4.0
	V	2.2	7.2
Rutile FCAW	Fe	36.9	3.7
	Mn	8.8	4.9
	Cu	0.2	4.0
	In	0.2	6.2
	Mg	4.1	7.4
Basic FCAW	Fe	56.9	4.6
	Mn	6.9	5.0
	In	0.3	4.7
	Mg	1.4	4.8
	V	0.3	10.5
MCAW	Fe	64.3	5.8
	Mn	5.9	9.4
	In	0.2	8.8
SSFCAW	Fe	34.9	5.2
	Mn	1.6	8.0
	Ba	16.6	7.1
	Li	0.6	7.9
	Mg	10.5	10.0
	V	5.3	7.9

The ICP-AES results show that it is possible to obtain fume composition data with good repeatability using the method for collected of welding fume prescribed in prEN ISO 15011-4. The determined repeatability was typically in the range 5-10 % for major constituents of the fume.

7 Conclusions

The repeatability of FER measurements made using the test method prescribed in prEN ISO 15011-4:2004 is good, typically in the range 2-10 %.

The reproducibility of FER measurements is such that the test method prescribed in prEN ISO 15011-4:2004 is considered to be fit-for-purpose for most of the processes examined, with 95 % confidence limits in the range ± 10 % to ± 40 % for MMA, rutile FCAW, basic FCAW and SSFCAW.

Recommendations have been made for improving the reproducibility of FER measurements and it seems reasonable to expect that the reproducibility of FER measurements will be fit-for-purpose for all processes when these recommendations have been acted upon. A repeat round robin could demonstrate this.

The repeatability of fume composition measurements has also been shown to be good, being typically in the range 5-10 % for major constituents of the fume.

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