Health and Safety Executive

Standardisation of the measurement of capture efficiency of on-gun extraction for welding

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Standardisation of the measurement of capture efficiency of on-gun extraction for welding

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The inhalation of welding fume is recognised as being a real threat to workers' health due to the development of occupational illnesses such as welding fume fever and asthma. Local exhaust ventilation (LEV) is an effective method to control worker exposure to welding fume and previous work has indicated the merit of the use of on-gun extraction systems.

The aim of the present study was to improve and refine the existing on-gun extraction methodology and has resulted in the development of two alternative methods for measuring the efficiency of on-gun fume extraction systems. There are distinct advantages and drawbacks to both methods of measuring on-gun capture efficiency, but a preferred method has been identified.

At the time of drafting this report, working group 4 of Standards committee CEN/TC 121/SC 9 has adopted this preferred method and is currently drafting a new standard for measuring the capture efficiency of on-gun fume extraction systems.

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WELDING TERMINOLOGY

Several terms are used throughout this report to refer to the orientation of welding operations being tested, these are defined below.

On-gun extraction torch or **integral torch extraction system** – A welding torch that incorporates air extraction into the torch design to extract welding fume as close to the arc as practical.

In the flat - Welding on a test piece that is lying flat on the traverse i.e. parallel to the ground.

In position - This refers to any welding where the test piece is on a vertical surface i.e. perpendicular to the ground.

Vertical - Welding in position where the torch moves vertically i.e. top to bottom or vice versa

Horizontal - Welding in position where the torch moves from side to side i.e. left to right or vice versa.

KEY MESSAGES

- Two test methods for measuring the efficiency of integral on-gun welding fume extraction systems have been devised and assessed. As a result, Method 1 has been selected and is currently being developed by technical committee CEN/TC 121/SC 9/WG 4 (Testing and marking of equipment for air filtration for welding and allied processes) with a view to drafting an EU Standard.

- On-gun extraction was found to be effective at removing welding fume when carrying out bead on plate welding. It was less effective during in the flat fillet welding.

- Improvements to the welding torch positioning and clamping system are required in order to obtain better repeatability of fume emission rates, especially during fillet welding, so that more accurate measurements of capture efficiency can be made.

- A reduction in on-gun air extraction flow rate resulted in a drop in fume capture efficiency and hence would likely increase worker exposure to welding fume. Therefore, the on-gun extract flow should be checked on a regular basis and if it drops significantly the reason(s) should be investigated,

- During testing it was noted that the extraction line connecting the torch extract to the extraction unit was leaking, particularly where the water cooling line passed through the tube wall. This resulted in a reduced flow rate at the torch extraction point which would likely depend upon manufacturer and model. Therefore it is important that the true measure of extraction flow rate is measured at the gun and not close to the extraction unit.

- Increasing the power of the fume extractor did not result in a large increase in extraction flow rate due to the high resistance to air flow inside the on-gun extraction hose. However, even a relatively small increase in extraction flow resulted in a noticeable increase in capture efficiency during in the flat fillet welding.

EXECUTIVE SUMMARY

The inhalation of welding fume is recognised as being a real threat to workers' health due to the development of occupational illnesses such as welding fume fever and asthma. Additionally exposure to welding fume may be linked to chronic obstructive pulmonary disease (COPD). The government scientific advisory committee WATCH (Working group on Action to Control Chemicals) has proposed that HSE adopt the position that *'whilst current evidence is suggestive, it is not sufficient to establish a causal link between exposure to welding fume and COPD'* [1]. Local exhaust ventilation (LEV) is an effective method to control worker exposure to welding fume and a previous study [2] has shown that on-gun extraction systems can potentially be used as an alternative to capturing hood based systems that are currently widely used. However, the study recommended that further work needed to be carried out to develop the methodology that is used to evaluate these systems. This was because varying fume emission rates when welding in different orientations (i.e. welding on vertical surfaces and welding in 90° fillets) created significant experimental errors, thereby making it difficult to accurately assess the effectiveness of the on-gun fume extraction system.

The aim of the present study was to improve on the previous methodology and so two alternative methods for measuring on-gun capture efficiency have been developed and assessed. In the first method (Method 1) the welding fume is collected and extracted by a canopy hood located just above the welding torch. The emitted fume is measured gravimetrically inside a sampling duct connected to the hood with and without the on-gun air extraction switched on. This method involves at least 2 consecutive tests and like the previous study relies on the repeatability of fume emission rate to ensure accurate results. The second method (Method 2) uses the same canopy hood to collect and extract fume not captured by the on-torch extraction, but at the same time measures the fume captured by the gun extraction inside a sampling duct positioned between the torch and extractor. This means that the capture efficiency can be measured in one test and is therefore relatively unaffected by changes in fume emission rate.

Measurements of on-gun fume capture efficiency carried out during the welding of bead on plate and fillet in the flat revealed the following:

- High capture efficiencies were measured when welding bead on plate regardless of the measurement method used, the type of welding unit used, the welding conditions and fume emission rate when the fume extractor was operated at its maximum flow. These were often in excess of 90% and compare well with the measurements made in the previous study [2].

- Lower measurements of capture efficiency were consistently observed using Method 2, the difference being greater during fillet welding.

- Measurements of capture efficiency using Method 1 and a direct-reading dust monitor to measure the fume concentration inside the canopy hood extract duct, repeatedly resulted in slightly lower values than those obtained during gravimetric sampling.

- A significant reduction in fume capture efficiency was found during bead on plate welding when the flow rate was reduced by about 50%. This would clearly be a problem as the fume extractor filtration system starts to clog and the air flow rate drops. This illustrates the need to regularly monitor the on-gun extract flow rate.

- Fume emission rate was reasonably repeatable during bead on plate welding for any given set of welding conditions. This could probably be improved further with better control over the gap between the welding tip and test piece.

- Fume emission rate during fillet in the flat welding showed poor repeatability for any given set of welding conditions, almost certainly because of poor control over the gap between the welding tip and test piece.

- Despite variable fume emission rate, the results have clearly shown that on-gun capture efficiency during fillet in the flat welding is considerably lower than during bead on plate.

- The use of a much more powerful fume extractor only resulted in an increase in on-gun extraction flow rate of about 14 %, although there is evidence to suggest that this resulted in a measureable increase in fume capture efficiency. However, it is difficult to quantify this accurately because of the large variations in fume emission rate.

- During the testing it was noted that the extraction line connecting the torch extract to the extraction unit was leaking, particularly where the water cooling line passed through the tube wall. This resulted in a reduced flow rate at the torch extraction point and would depend upon manufacturer and model. Therefore, it is important that the extraction flow rate is measured at the gun and not close to the extraction unit.

Both measurement methods were found to have distinct advantages and drawbacks. Method 1 is less likely to give systematic errors because measurements are made inside the same sampling line with and without the on-gun extraction switched on. However, if the fume emission rate changes between measurements then this can introduce large random errors. By improving the gun positioning and clamping system and carrying out enough repeat measurements then these errors should be greatly reduced. Method 2 is largely unaffected by changes in fume emission rate and a measurement of capture efficiency can be made in one test. However, it uses two different sampling lines operating at different pressures with different dimensions and different sampling probes, which may introduce systematic errors into the measurement of capture efficiency. Indeed, the consistently lower measurement of capture efficiency compared to Method 1 during bead on plate welding where the fume emission rate was reasonably constant would seem to confirm this. In addition, the effects of air leakage into the extraction system around where the cooling pipes enter the gun air exhaust pipe, on the measurement of capture efficiency are not completely understood. On balance, assuming that variations in fume emission rate can be reduced, then Method 1 would be the preferred method and it is this method that the Standards committee CEN/TC 121/SC 9/WG 4 have adopted. At the time of this report the committee is in the process of drafting a new standard for measuring the capture efficiency of on-gun fume extraction systems.

The use of a canopy hood located over the welding gun to intercept and contain fume during welding has been shown to be an effective method for determining on-gun capture efficiency. Improved clamping and positioning of the welding gun should resolve many of the issues found with variable fume emission rate.

Although not carried out as part of this work, measurements of on-gun capture efficiency during vertical welding of bar and fillets may be carried out by HSL at a later date or alternatively may be carried out by colleagues at INRS in France, who also sit on the CEN committee and are carrying out research in this area.

CONTENTS

1. INTRODUCTION

A large number of professional welders are at risk of potentially severe ill health effects, including welding fume fever and asthma, caused by inhalation of welding fume. Additionally exposure to welding fume may be linked to chronic obstructive pulmonary disease (COPD). The government scientific advisory committee WATCH (Working group on Action to Control Chemicals) has proposed that HSE adopt the position that *'whilst current evidence is suggestive, it is not sufficient to establish a causal link between exposure to welding fume and COPD'* [1]. LEV is one of the most common and effective available methods for controlling exposure to airborne contaminants, including welding fume, that cause such diseases.

HSE research project RR683 [2] (Effective control of gas shielded arc welding fume) investigated the effectiveness of different types of LEV to control exposure to welding fume, including integrated torch extraction (often referred to as 'on-gun' extraction) used on a gas-shielded arc welding machine. The report concluded that on-gun extraction was a suitable alternative to moveable capturing hood-based systems, but recommended that further work needed to be carried out to evaluate these systems. This was because varying fume emission rates when welding in different orientations (i.e. welding on vertical surfaces and welding in 90^o fillets) produced varying results. It was not clear whether variations in the calculated capture efficiency were due to variations in fume emission rates or increased experimental error, thus making it difficult to assess true control effectiveness.

Other EU countries now recognise on-gun extraction as an alternative method of controlling the emission of welding fume to traditional capturing hoods. However, their effectiveness has not been quantified and therefore a robust methodology for measuring the effectiveness/capture efficiency of on-gun welding systems is required. Capturing this methodology as a standard test fell to Technical committee CEN/TC 121/SC 9/WG 4 ("Testing and marking of equipment for air filtration for welding and allied processes") and at the time of this report were drafting an EU Standard. This is likely to be based on the methodology and recommendations described in HSE report RR683, but the Committee recognise that further development work is required.

This work aims to develop an improved methodology that can be used to quantify the effectiveness of on-gun extraction devices with a good degree of accuracy and repeatability. It will allow on-gun extraction systems to be assessed for different types of welding torches and various welding orientations. This would allow on-gun extraction torches to be classified based on their control effectiveness and this classification could, for example, be marked on the equipment thereby helping any purchaser of such equipment select the appropriate torch and also acting as a 'driver' that encourages industry to improve the design and control effectiveness of on-gun systems.

The results of the work will feed directly into HSE's target of identifying evidence of improved methods of engineering controls and will allow HSE to compare the performance of on-gun extraction to traditional mobile hoods and update existing guidance.

The work was jointly funded by HSE and Germany BG. The welding apparatus was provided by Abicor-Binzel and the portable fume extraction was provided by Nederman Ltd.

2. PREVIOUS HSL MEASUREMENTS OF ON-GUN CAPTURE EFFICIENCY

HSE report RR683 [2] describes a method for measuring the capture efficiency of on-gun extraction devices. The extraction system tested consisted of an Abicor-Binzel RAB 25 air-cooled, fume extracting welding torch with an integral extraction system, connected to a Nederman P30 extraction unit. Briefly, the experimental set-up consisted of a sampling system to measure the concentration of welding fume extracted by the welding torch. Extracted fume was passed into the sampling system, which comprised a length of circular duct into which was centrally-placed an isokinetic gravimetric sampling probe to measure the concentration of fume. This measurement was then compared with at least two measurements of 100% fume. Total (100%) capture was achieved by surrounding the welding torch with an enclosure so that any fume that escaped initial capture by the torch was also collected. Comparison of fume concentration inside the sampling system with and without the enclosure fitted allowed the capture efficiency to be determined. The results showed:

- The 100% fume concentrations measured in the sampling duct using 1mm diameter welding wire varied according to the welding position. Concentrations measured from highest to lowest with bead on plate were as follows: horizontal position>in the flat >vertically down>vertically up. For fillet welding the concentrations highest to lowest were as follows: in the flat>vertically down>vertically up.

- The optimum position for the extract nozzle that gave the highest capture efficiency was found to be 14 mm from the bottom of the gas shroud. The capture efficiency decreased if positioned nearer or further from the gas shroud, more so when further.

- Measured capture efficiency when welding fillets was lower than when welding bead on plate especially when carried out in the flat position as opposed to vertically, where it was estimated that around half of the fume escaped capture.

The report concludes by saying that there is still doubt as to the results from the fillet welds. The capture efficiency measured during flat fillet welding was 62% but video footage suggests a figure close to 100%. Indeed, previous measurements using a smaller fume enclosure had given a capture efficiency of 95% raising doubts as to the reliability of using this method of measuring fume capture for fillet welding.

3. APPROACH AND METHODOLOGY

3.1 GENERAL

Clearly from the previous study [2], the results of efficiency measured during in the flat fillet welding showed that there is a requirement to produce an improved and more repeatable method for collecting and measuring the fume that escapes capture by the on-gun extraction. Two methods are proposed both of which use a ventilated canopy hood positioned above the welding torch to intercept and contain the fume missed by the on-gun extraction system. The difference in the two methods lies in the way in which the 100% welding fume emission is measured and is described briefly as follows:

Method 1: Uses the canopy hood to collect 100% of the welding fume by switching off the on-gun extract airflow. The test is then repeated with the on-gun extract switched on. This relies on consistency of welding fume emission between tests to give accurate results.

Method 2: Passes the fume extracted by the welding gun through a sampling duct similar to that described in the previous study [2]. 100% emission is determined from the fume not collected by the on-gun extraction and hence collected by the canopy hood added to that measured inside the on-gun sampling duct. Consistency of welding fume emission is less of an issue since the capture efficiency is determined from one run. Both methods have their advantages and drawbacks which will be discussed later and based on these, a recommended test method will be proposed.

A Nederman P30 extractor was used initially to provide extraction to the welding torch; this was later replaced with a larger Nederman 3-phase P55 extractor to generate a higher volume flow rate.

Tests were carried out with the welding torch located inside a ventilated test cabin of dimensions 4 m x 4 m x 3 m high. This provided a physical safety barrier to the person operating the test apparatus remotely from outside the cabin. The cabin was ventilated using a large centrifugal fan which pulled air at a velocity of <0.1 m.s^{-1} through the cabin, so that it passed over the test system without disturbing the experimental airflows before being vented to the outside atmosphere. This ensured that in the event of the fume capture hood failing, any fume released into the cabin would be evacuated. The welding was performed using a bespoke automated traverse system and welding rig in an attempt to minimise variables, such as the contact tip to test piece distance and arc travel speed, so that a constant fume emission rate could be produced.

Welding test pieces comprised of 12.5 mm by 50 mm bright steel bar stock 500 mm long, which were clamped using two vices in order to minimise bar deformation during welding.

3.2 WELDING EQUIPMENT AND WELDING PARAMETERS

Water-cooled torches are generally recommended for welding at currents over 250A since they are more effective than air-cooled torches at lowering the operating temperature at such high currents. However, one potential problem with using water cooled torches that have on-gun fume extraction is that the two pipes (flow and return) containing the water pass through the air extraction hose and the torch handle and will therefore increase the resistance to air flow (particularly in the already constricted or congested torch handle). This can potentially result in a reduced air extraction rate at the torch nozzle and therefore a possible decrease in fume capture efficiency. The welding torch used in these tests was an Abicor-Binzel RAB Plus 501 water-cooled welding torch with an integral fume extraction system. This differs from the torch used in previous studies [2] (Abicor-Binzel RAB 25) which was air cooled. Water was supplied to the torch using an Abicor-Binzel coolant recirculator.

Initially trials were performed using HSL's Thermal Arc DC inverter which developed technical issues resulting in poor weld quality, see Fig. 1. After consultation with TWI a second inverter (ESAB 380A) was loaned for the remainder of the trial which gave better quality repeatable welds, see Fig 2.

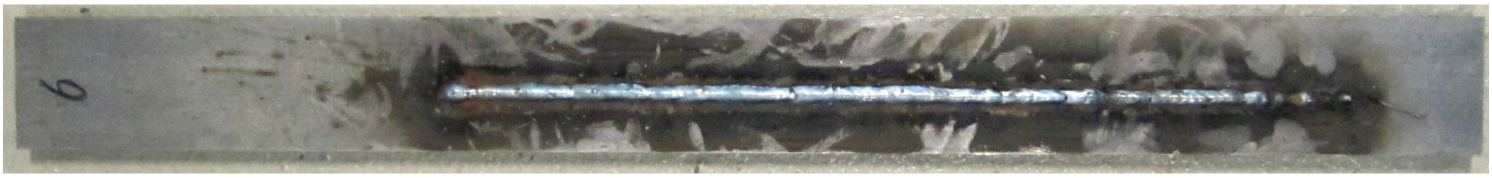

Fig 1. Weld carried out using HSL's Thermal Arc DC inverter

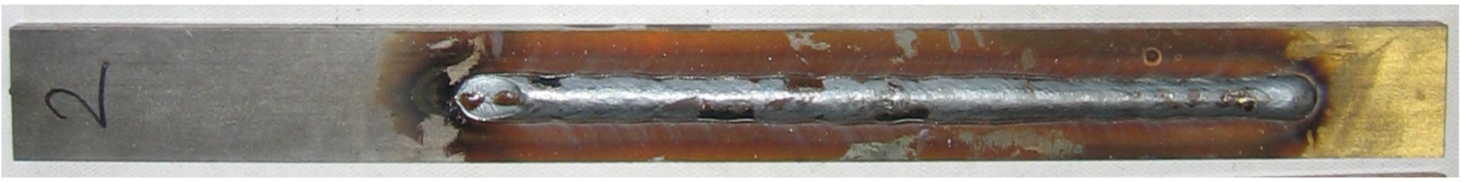

Fig 2. Weld carried out using TWI's ESAB 380A inverter

Initial tests carried out with the Thermal Arc DC inverter used 1mm diameter mild steel wire supplied by Murex Bostrand. The voltage and current settings were 20V and 130A respectively and were set by a member of the HSL workshops. The correct operating parameters for the ESAB 380A unit were determined by a welder from TWI and are shown in Table 1. In each case the weld parameters were set at a weld speed of 30 $cm.min^{-1}$ which was regarded as a typical speed at which a welder would weld.

The shielding gas used was Argoshield Universal (12% CO_2, 2% O_2, 86% Ar) and was set to a flow rate of 18 $l.min^{-1}$. The contact tip to workpiece distance (CTWD) was set to 15 mm for the Thermal Arc welder and 12 mm for the ESAB 380A welder on the advice of the welder operatives. This was checked before each test using a "spacer" that consisted of a suitable length of circular steel bar.

TABLE 1. Weld parameters obtained by a TWI welder for the ESAB 380A inverter (* this value was obtained at a later date at TWI's laboratory)

Weld Type	Wire diameter (mm)	Weld Current	Weld Voltage
Bar horizontal	1.0	200	32
Bar horizontal	1.2	300	32
Bar horizontal *	1.6	320	32
Fillet horizontal	1.0	195	27
Fillet horizontal	1.2	280	32
Bar moving up (torch down)	1.0	150	22
Bar moving up (torch down)	1.2	250	24
Bar moving down (torch up)	1.0	150	22
Fillet moving up (torch down)	1.0	150	22
Fillet moving up (torch down)	1.2	250	24
Fillet moving down (torch up)	1.0	150	22

Where possible the welding parameters were monitored using an AMV Weldcheck system, which monitors and records the inverter voltage and current during welding. Problems with the unit meant that it wasn't used for all of the tests.

Following advice from the welders, for tests conducted with bead on plate welding, the welding torch was set to an angle of 20° to the vertical. A similar angle was used for fillet welding but the torch had a lead-in angle of approximately 30° to the horizontal leg of the test piece. A pushing technique was employed in all cases.

3.3 AUTOMATED WELDING AND POSITIONING SYSTEM

Previous tests [2] had used an automated traverse and welding torch clamping system devised and provided on loan by TWI. Unfortunately, this was not available for these tests and so a bespoke system was devised. This was based on apparatus that had been used to automate the movement of hand-held power tools for a previous project [3]. It comprised a linear traverse, the speed of which could be adjusted using a speed controller module. This is shown in Fig 3, adapted for use in the current project.

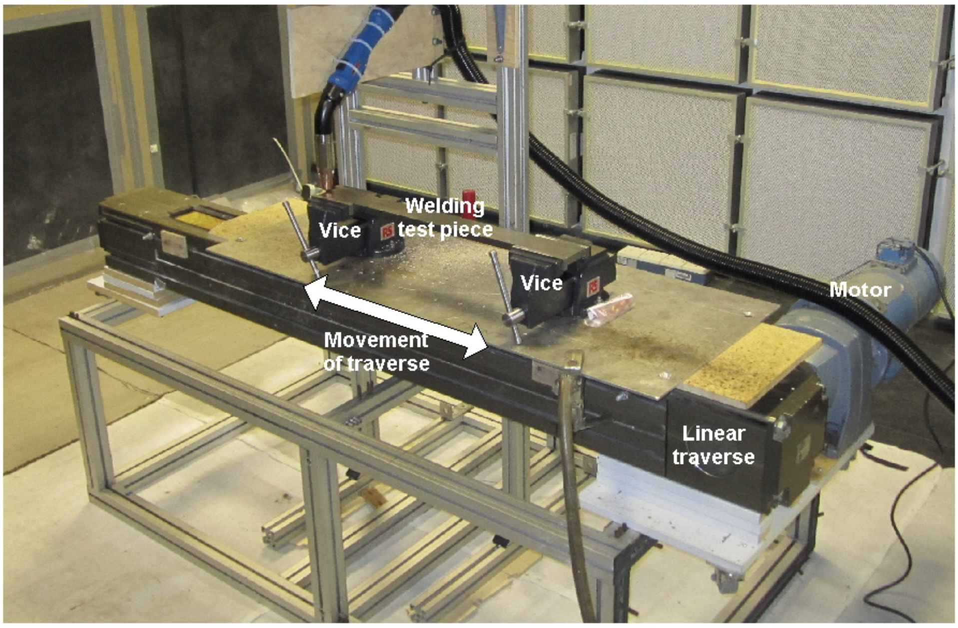

Fig 3. Linear traverse for carrying out automated welding

The welding test piece was clamped to the moving platform of the traverse using two vices, one at each end of the bar. The welding torch was attached to a 2-way traverse (not shown in Fig 3, but shown in Fig 4). This allowed reproducible vertical and horizontal positioning of the torch with millimetre precision, which was very important when setting the torch CTWD. The position of the welding torch was fixed and the test piece was moved beneath it. This was advantageous for two reasons: 1) it meant that the torch was always central inside the fume canopy hood so that all of the fume was collected and 2) the fume extract hose attached to the rear of the torch was stationary meaning that this did not pull on the torch which may have inadvertently altered the torch position during a test.

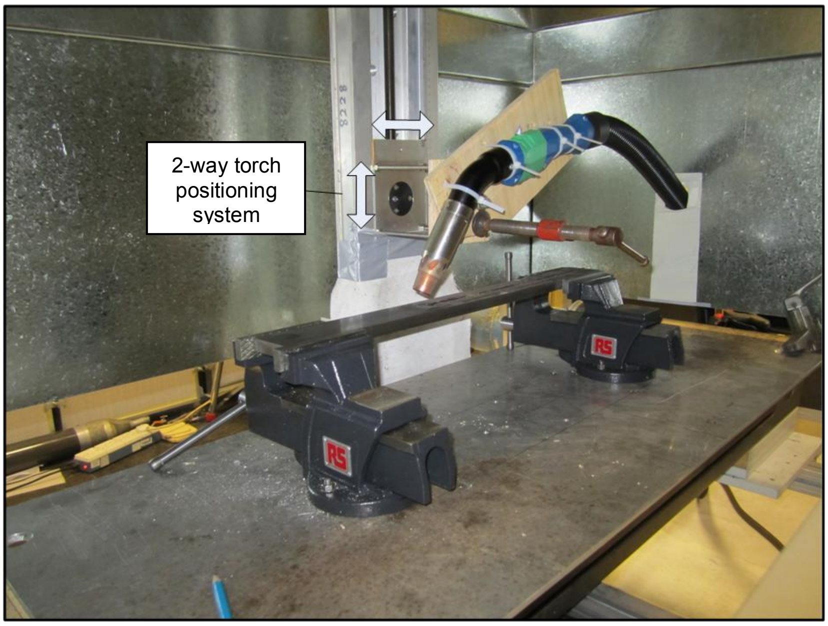

Fig 4. 2-way torch positioning system

The torch was securely attached using a series of cable ties to a rotating plate so that its angle could be adjusted and this was then locked into position using a bolt as shown in Fig 5.

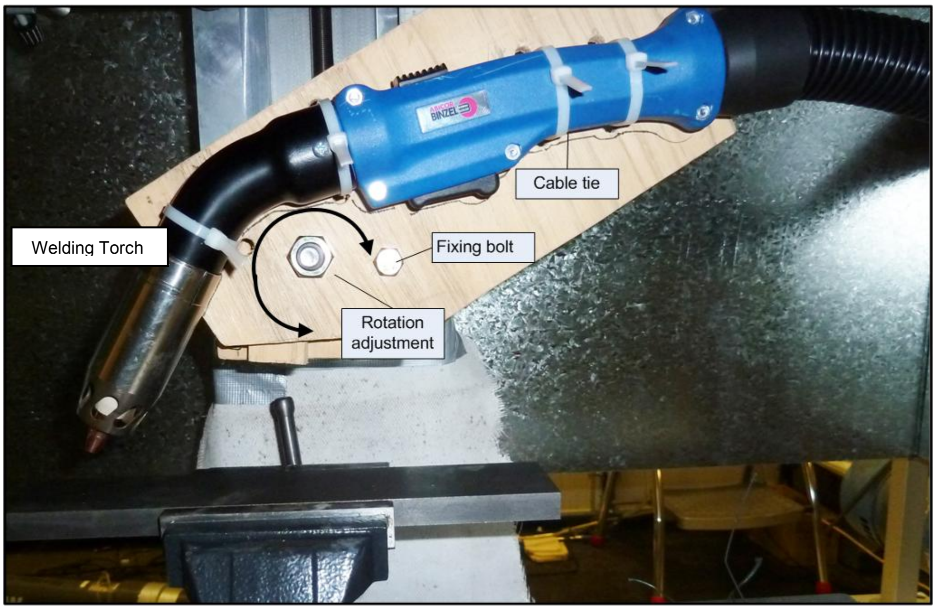

Fig 5. Method of torch attachment (bead on plate welding)

3.4 MEASUREMENT OF ON-GUN FUME CAPTURE EFFICIENCY METHOD 1: CANOPY HOOD

This method uses a canopy hood positioned directly above the welding torch (similar to that described in [4] and [5]) to collect and extract any fume escaping capture by the integral extraction on the welding torch. The capture efficiency of the on-gun extraction is determined by carrying out an additional measurement of 100% fume emission with the torch extract turned off (i.e. all the welding fume is collected by the canopy hood).

The hood was manufactured from galvanised steel and designed with inlet dimensions of 1.2 x 0.6 m and with a 0.4 m skirt so that the welding torch and test pieces were partially enclosed (see Fig 6). One side of the hood was attached using spring clamps so that it could be quickly removed to allow easy access to the welding torch and test piece.

Extract air was provided to the hood by a centrifugal fan and the flow rate was adjusted using an in-line diaphragm valve. The extract flow rate was adjusted to give an air velocity at the entrance to the hood of 0.1 $m.s^{-1}$. This was regarded as sufficiently high to collect and extract all of the rising fume but not so high that it created air movements within the hood that might affect the on-gun capture efficiency. The collected welding fume passed through a length of 160 mm diameter circular ducting through the wall of the test cabin to a further length of ducting.

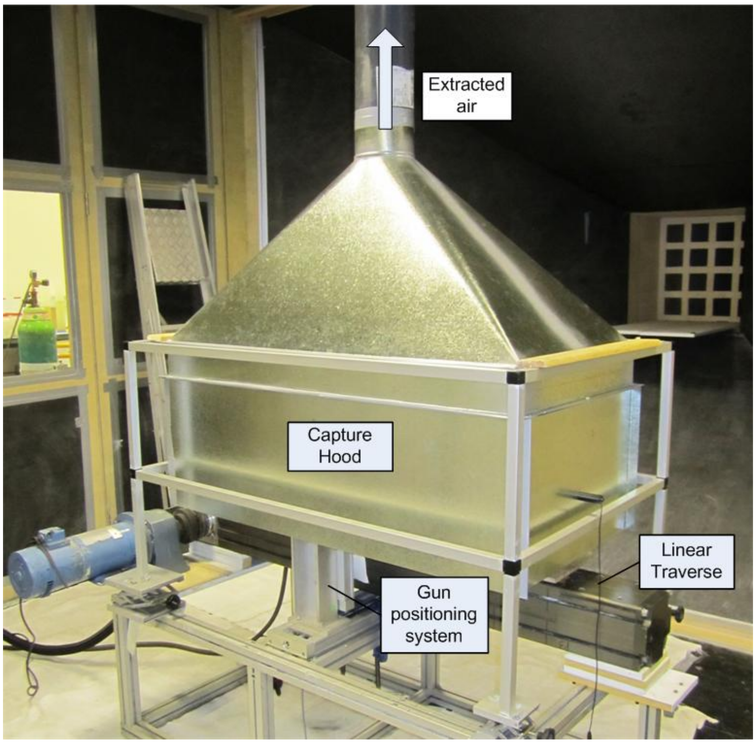

Fig 6. Fume canopy hood

Initial tests were carried out to see if an in-line filter could be used to capture all of the extracted fume. However, preliminary tests to see how much air could be pulled through a 24 cm diameter disk of GF/A glass microfiber filter material showed that even using a high pressure centrifugal fan, the flow rate produced was nowhere near adequate. Also, the flow rate would likely drop as the filter became loaded with welding fume. In order to increase the flow rate, a filter with a much larger surface area (and hence lower pressure drop) and/or a more powerful fan would be required. Neither of these options was practicable. For example, it was calculated that with the on-gun extract switched on and assuming a capture efficiency of 98 %, at a typical rate of fume emission, the filter would only collect around 12 mg of fume for a 1 minute test. This is a relatively small amount compared to the tare weight of the filter and could lead to weighing errors.

Therefore, an isokinetic gravimetric sampler was used inside the extract duct to measure the fume emission rate. This was similar and placed at the same position as that described in HSE research project RR683 [2], this was in a straight section of duct 10 diameters downstream from a 90° bend. See Fig 7 for sampler location. This ensured that the air flow was fully developed and the fume was thoroughly mixed so that the fume concentration measured at the central sampling position within the duct was representative of the average fume concentration within the duct. Figs 7 & 8 show the sampling duct and position of the isokinetic sampler.

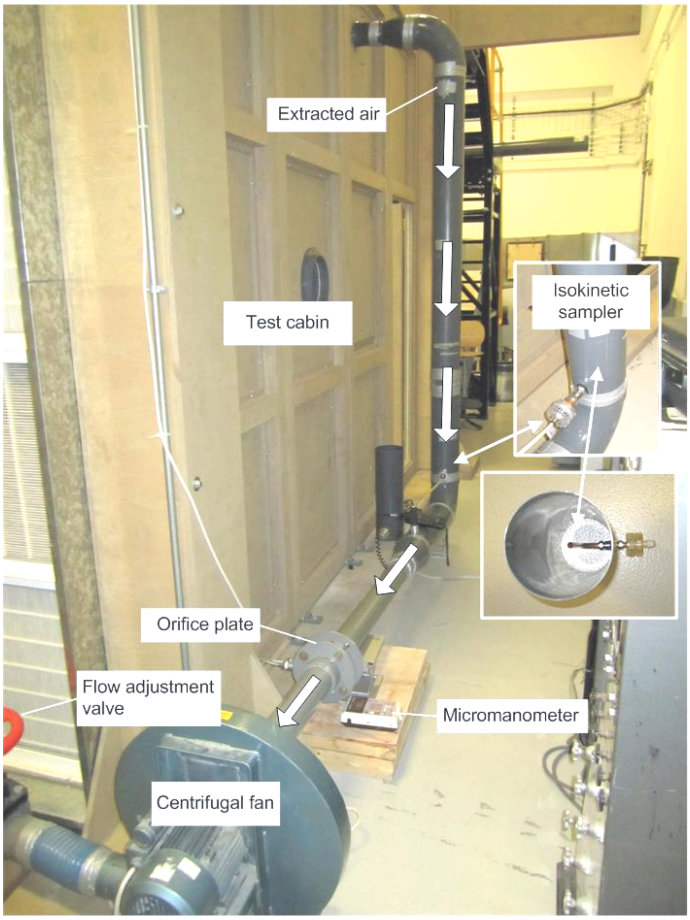

Fig 7. Canopy hood sampling line showing position of isokinetic sampler

The isokinetic sampler flow rate was adjusted so that the velocity into the probe matched the velocity through the sampling duct at the extract flow rate required to give a hood face velocity of 0.1 $m.s^{-1}$. For example, using a 13.6 mm diameter isokinetic probe and hood inlet dimensions of 1.2 x 0.6 m this equates to an extract flow rate through the duct of 260 $m^3.h^{-1}$ and an isokinetic sampler flow rate of 33.3 $l.min^{-1}$. The flow into the isokinetic sampler was provided by an Edwards E2M 3-phase pump and the flow rate was monitored using a Chell Instruments flow meter. The isokinetic sampling tube was manufactured from standard copper plumber's pipe (13.6 mm inside diameter) and was attached inside the sampling duct with the inlet facing into the air flow. The pipe inlet was sharpened to give a smooth air flow transition into the pipe in order to minimise particle losses during sampling. The pipe was bent through 90^o so that a modified 37 mm plastic filter cassette could be attached to the end of the copper pipe located outside the sampling duct. This was attached using a quick release connector so that the filters could be quickly and easily moved to and from the cassette. In addition, a direct-reading dust monitor (Microdust Pro, Casella Ltd) was positioned just downstream of the isokinetic sampler with its measuring probe inserted centrally inside the extract duct (see Fig 8). This has a concentration measurement range of 0.001 to 2500 mg m^{-3}. The dust monitor was used to see if real-time fume concentration measurements were a viable alternative method of measuring on-gun capture efficiency.

The filters used inside the isokinetic gravimetric samplers were 37mm GF/F glass microfiber. These were conditioned for at least 24 hours inside a temperature and humidity controlled balance room prior to weighing before and after exposure to welding fume. As an additional measure, blank control filters that remained unexposed to fume were used to correct for changes in mass caused by changes in environmental conditions. The extract flow was monitored using an in-line orifice plate, connected to a digital manometer located downstream of the sampling duct. The extracted fume was eventually vented to the outside using a length of flexible ducting. Fig 8 shows a schematic of the experimental set up.

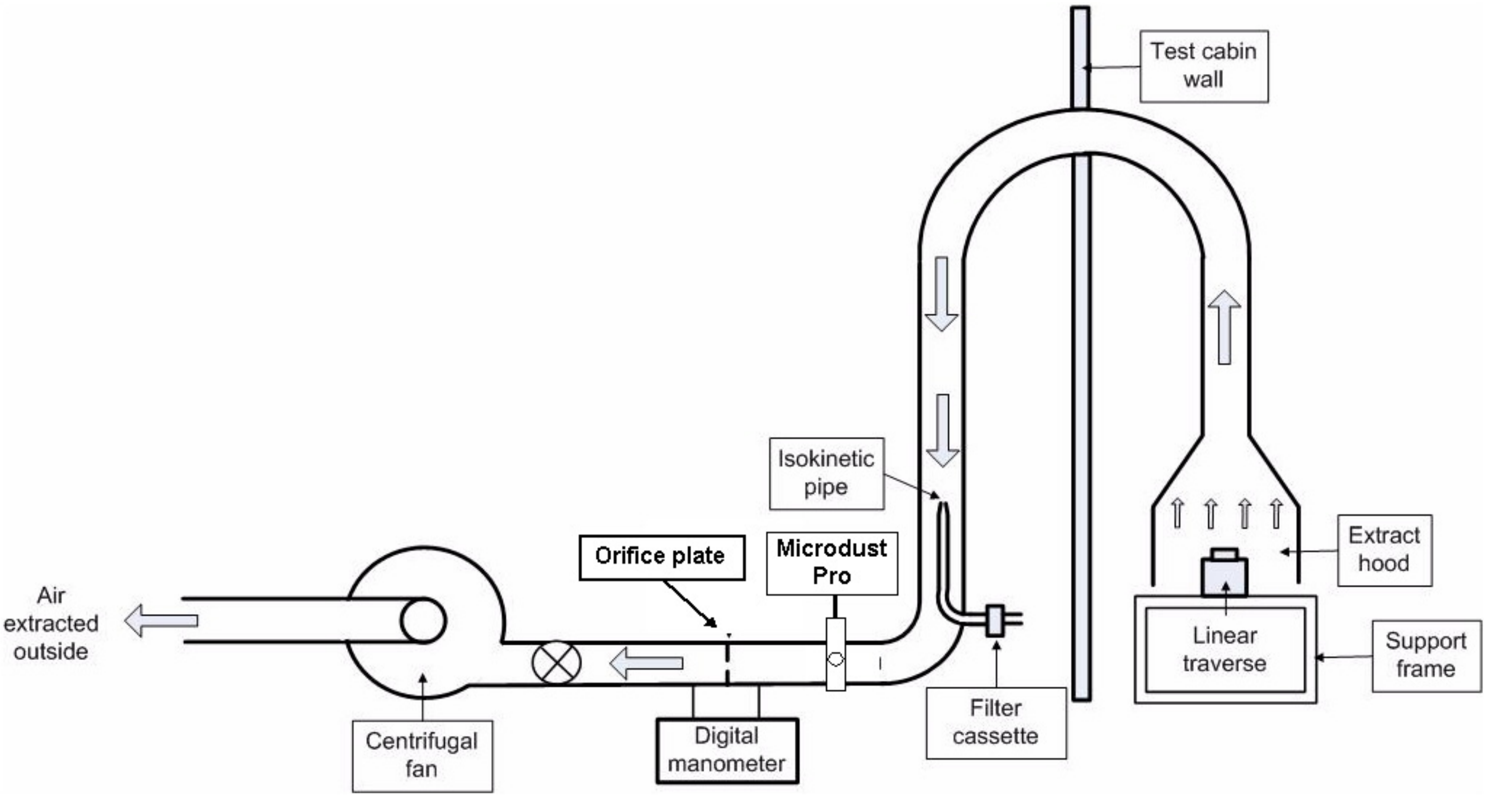

Fig 8. Schematic of canopy hood capture efficiency measurement method

3.5 MEASUREMENT OF ON-GUN FUME CAPTURE EFFICIENCY METHOD 2: MEASUREMENTS OF EXTRACTED FUME

Method 1 requires a minimum of 2 tests in order to measure the efficiency of the on-gun fume extraction system; one with the on-gun extraction switched on and one with it switched off. In reality several repeat measurements would be required to ensure that the fume emission rate does not change significantly. Method 2 measures the efficiency of the on-gun fume extraction system in a single test since it measures the quantity of fume captured and that which escapes (using Method 1, described in Section 3.4) at the same time.

To measure the fume captured by the on-gun extraction system, the sampling system shown in Figures 9 and 10 was used. This consisted of a 75 mm plastic diameter duct, connected to the welding torch extract ducting at one end and to the Nederman P30 fume extraction unit at the other. The outlet of the extraction hose was connected to the 75 mm ducting by a short length of 32 mm diameter flexible hose and an expansion piece. The extracted air passed through the hose connecting the torch to the inverter, and then into the sampling system. A gravimetric isokinetic sampling probe was placed centrally inside the ducting at a distance 2.8 m downstream of the expansion piece (as determined from the scoping trials in the previous study [2]). As in Method 1 (see Section 3.4) the volume flow rate of extracted air through the system was monitored using a digital manometer connected across an in-line orifice plate.

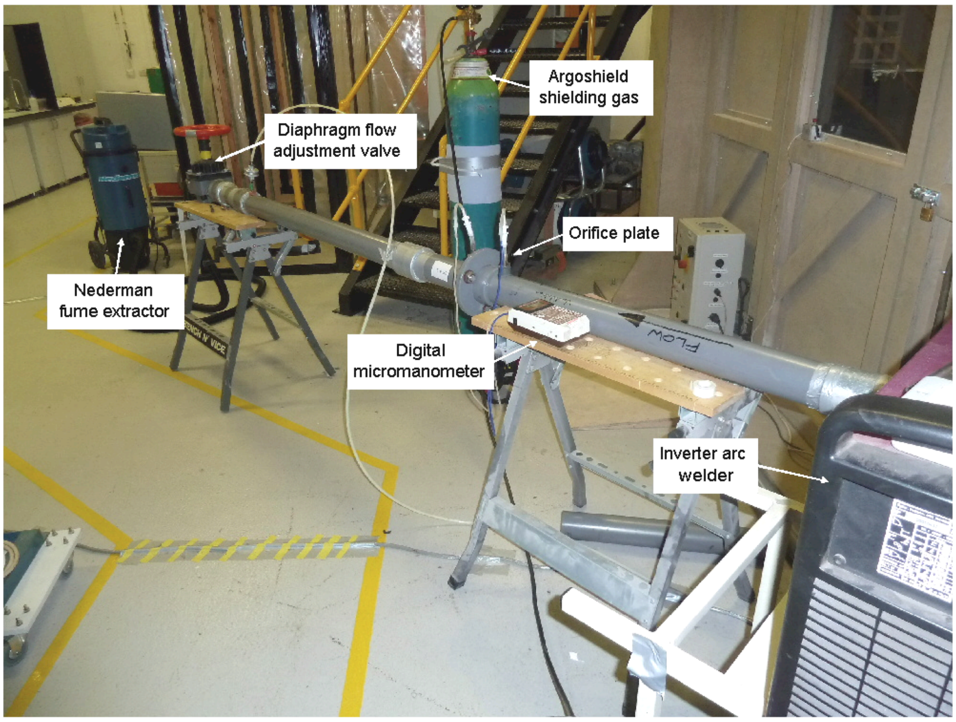

Fig 9. Photograph of experimental set up for sampling fume extracted by on-gun extraction

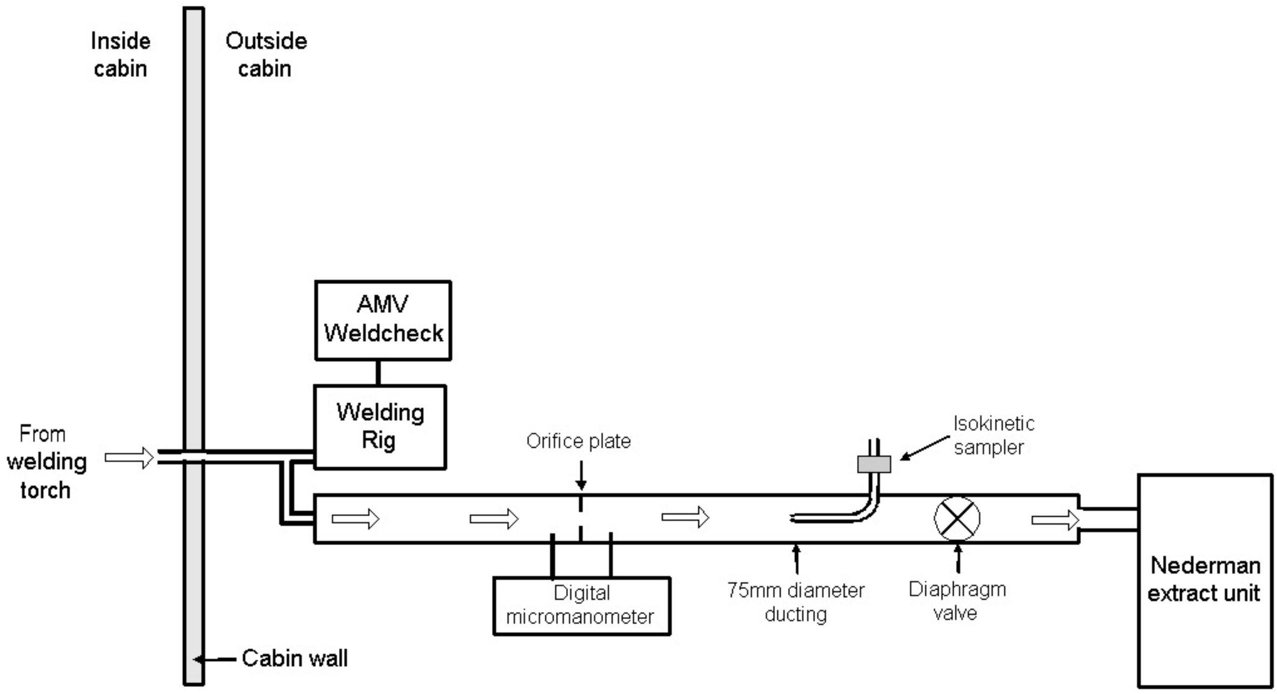

Fig 10. Schematic of experimental set up for sampling fume extracted by on-gun extraction

The isokinetic sampling tube was manufactured from stainless steel pipe with an inside diameter of 7 mm and was fastened inside the on-gun extract duct with the inlet facing the air flow. The same type of quick release filter cartridge was used as described in 3.4 to facilitate rapid loading and removal of the filters. Once again, the flow into the isokinetic sampler was provided by an Edwards E2M 3-phase pump and the flow rate was monitored using a Chell Instruments flow meter. The isokinetic sampler flow rate was adjusted so that the velocity into the probe matched the velocity through the sampling duct at the extract flow rate provided by the Nederman P30 fume extractor. For example, using a 7 mm diameter isokinetic probe and a torch extract flow rate measured inside the duct of 54 $m^3.h^{-1}$ equated to an isokinetic sampler flow rate of 7.2 $l.min^{-1}$. Unlike the extract flow through the canopy hood which was constant to maintain a hood face velocity of 0.1 m s^{-1}, the torch extract flow could vary depending on the type of extractor used and the condition of the filtration system. Therefore, a computer spreadsheet was devised to determine the isokinetic flow required at any particular extract flow.

Once again, conditioned 37 mm GF/F filters and blanks were used and were weighed before and after exposure to welding fume.

3.6 MEASUREMENT OF THE ON-GUN EXTRACT FLOW

Section 3.5 describes a method of measuring the on-gun extract flow by measuring the flow rate inside a length of circular duct connected to the torch extract. However, as an additional check the flow rate at the entry to the torch was determined by connecting the torch directly to a Wilson flow grid as shown in Fig 11.

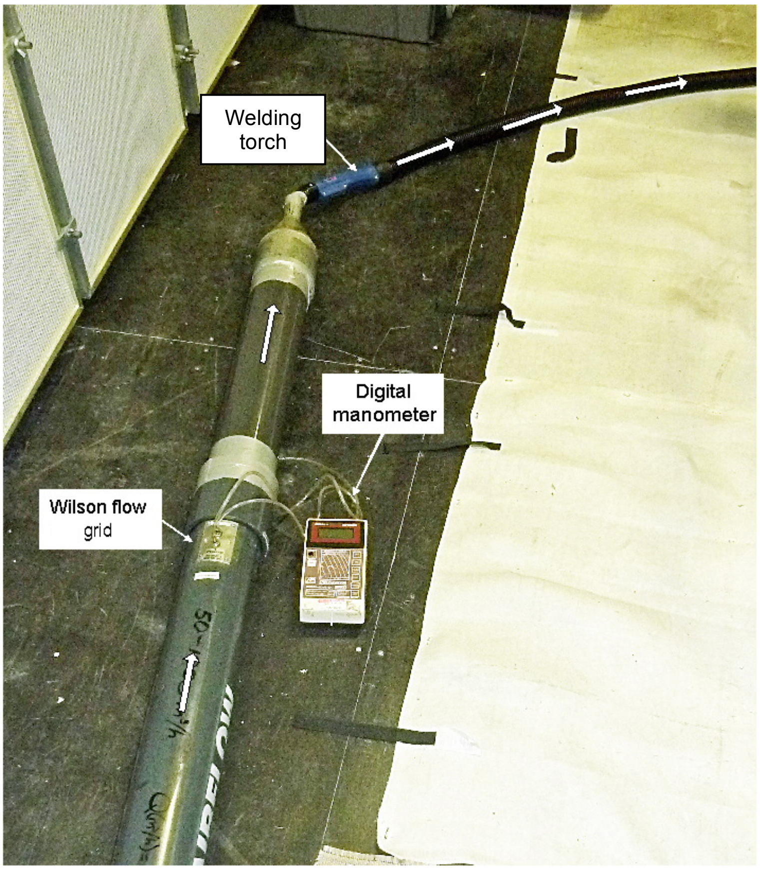

Fig 11. Measurement of flow rate into on-gun extraction inlet

The extract flow to the torch was provided by the Nederman P30 fume extractor and was controlled using the diaphragm valve positioned in the on-gun sampling duct described in Section 3.5 and shown in Figs 9 & 10. The flow rates measured inside the on-gun sampling duct and at the extraction inlet on the torch were determined for a range of values and are plotted in Fig 12. It was found that a power relationship gave the best fit to the data i.e. the lowest R^2 value.

It can be clearly seen that the flow rate measured at the on-gun extraction inlet is noticeably lower than that measured inside the on-gun sampling duct. It is thought that this was mostly due to inward leakage of air around where the water cooling pipes enter the “T” connector that attached the welding unit to the torch and fume extractor (See Fig 10). On closer investigation, air could be heard leaking at this point. Therefore, to obtain a true measure of the on-gun extract flow rate, it is important that it is measured at the entry to the on-gun system. In order to do this with the torch attached to the automated rig, a rubber adaptor was made that fitted over the welding torch forming an air-tight seal. This was then connected to the Wilson flow grid using a short length of flexible ducting.

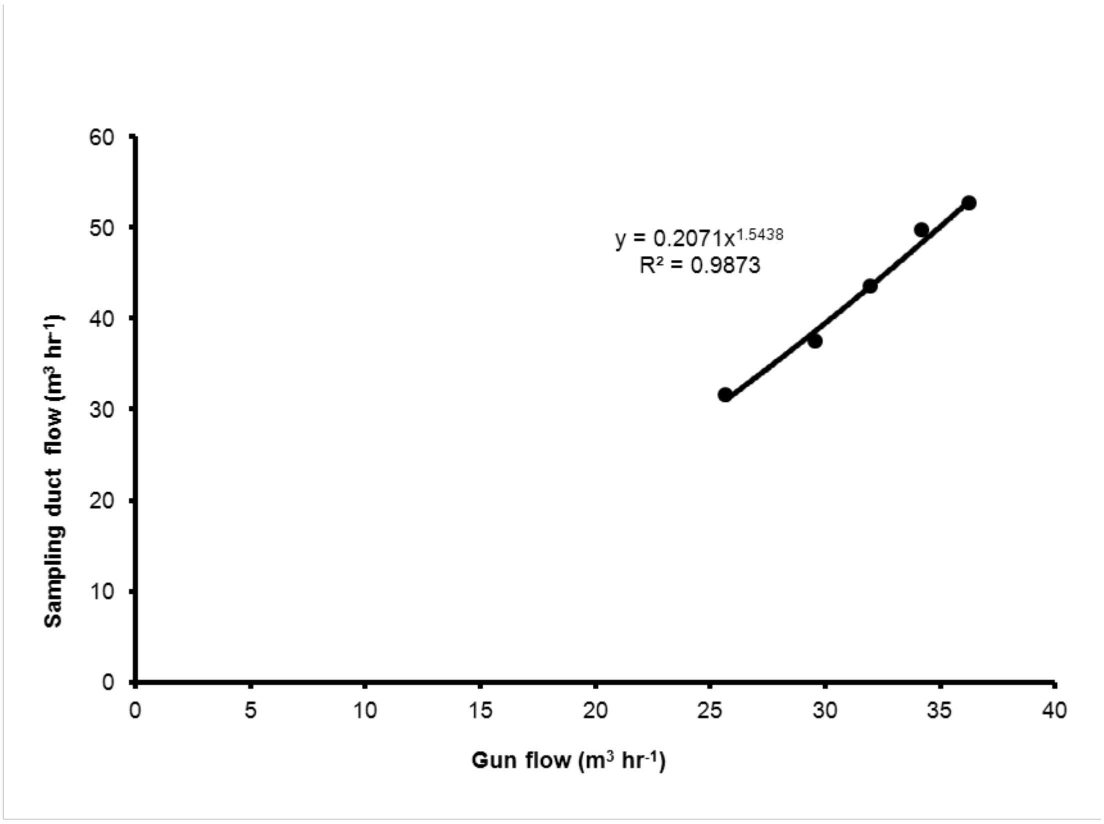

Fig 12. Measurement of extract flow at the entry to the on-gun extraction inlet and inside the on-gun fume sampling duct

3.7 TEST PROCEDURE

The mild steel test bars were supplied coated in oil to prevent corrosion and so prior to each test they were cleaned thoroughly using propan-2-ol to remove all traces of oil. Failure to do this would have resulted in a poor weld quality and any remaining oil would have been burnt off, both of which would have most likely resulted in increased and variable fume/smoke emission rates. The test pieces were of dimensions 500 x 50 x 12.5 mm (length x width x thickness) and in order to carry out fillet welding, two test pieces were tack welded at right angles to each other. The traverse speed was set to approximately 30 $cm.min^{-1}$ and was found to be very stable throughout the tests. For the first 12 tests, and with a weld duration of 1 minute, the average weld length was measured at 35.4 cm with a coefficient of variation (COV – defined as the quotient of standard deviation to mean expressed as a percentage) of 2.4%. Some tests were carried out for 1.5 minute in order to collect more welding fume onto the isokinetic sampler filters.

Initial tests were carried out by welding bead on flat bar using the Thermal Arc DC Inverter welding machine on loan from HSL's workshop. The welding parameters were set by a member of HSL's workshop and the welding was carried out using 1mm diameter wire. Problems with the wire feed mechanism meant that the weld quality began to deteriorate and so the Thermal Arc inverter was replaced with a ESAB 380A welder on loan from TWI and the welding parameters were set by a member of TWI staff (the welding parameters are detailed in Section 3.2). Bead on plate and fillet in the flat welding were carried out using 1.2 mm diameter wire. Limited fillet welding in the flat was also carried out using 1.6 mm diameter wire. It should be noted that although the welding parameters were also determined for in-position welding of fillet and bar using a vertical traverse system, time limitations meant that this work could not be performed. It may be the subject of future measurements.

Before each test the CTWD was checked using the metal spacer and, if necessary, adjusted using the torch positioning system. This was more problematical during fillet welding since it was difficult to measure from the torch tip to the corner of the fillet and so the torch was positioned such that the shielding gas shroud was just above the test piece in the vertical and horizontal direction. Maintaining the correct CTWD turned out to be more difficult during fillet welding and this will be discussed later. Fig 13 shows the position of the welding torch for bead on bar and fillet welding.

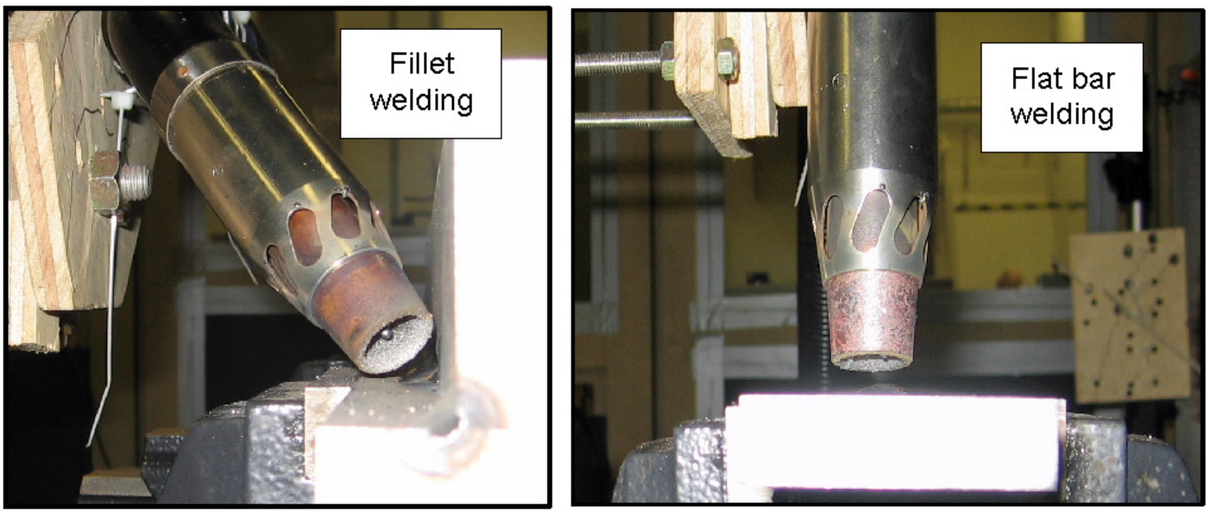

Fig 13. Position of welding torch tip relative to the test piece

Most of the tests were carried out using a Nederman P30 extractor operating at maximum flow rate. A few tests were also carried out at reduced flow rate to see how this affected the capture efficiency. Several tests were also carried out with a larger model P55 Nederman extractor to see by how much the extract flow could be increased and to see how this affected the capture efficiency.

An AMV Weldcheck (Tritonel Electronics Ltd) module was connected to the ESAB welder to monitor the operating arc voltage and welding current. However, problems with the unit meant that it wasn't used for all of the tests. Where used, it was programmed to record and print the voltage and current values every 4 seconds and to give an average value at the end of the test.

Throughout the tests the welding procedure was monitored using a small video camera located through the side of the canopy hood. This was connected to a laptop computer via an analogue to digital USB device so that the video could be recorded. This was useful to check that the welding unit was operating correctly throughout the tests. It also gave a visual indication and record of the effectiveness of the fume extraction system.

The test procedure was as follows:

1. Attach test piece securely in the two vices ensuring that the surface of the test piece was level with the top of the jaws of the vice.
2. Position the torch over the test piece using the metal spacer to set the CTWD.
3. Position the traverse so that the tip of the welding torch was about 2 cm in from the end of the test piece.
4. Switch on the dust monitor and calibrate as necessary according to the manufacturer's instructions.
5. Insert new pre-weighed filters into the isokinetic samplers
6. Switch on the on-gun extraction
7. Switch on the isokinetic samplers in the canopy hood sample duct and on-gun extraction lines and set the flow rates, noting that the flow rate through the on-gun sampling duct may vary depending on the type or condition of the fume extractor used.
8. Start the dust monitor logging
9. Turn on shielding gas
10. Switch traverse on
11. Switch welding power supply on
12. When weld strikes up start the timer
13. Weld for the allotted time
14. Stop the welder and the traverse at the same time
15. Allow sufficient time for the welding fume to clear estimated from the combined volume of the canopy hood and duct and the extract flow rate
16. Stop the dust monitor logging
17. Switch off the isokinetic samplers and remove the filters

18. Switch off the on-gun extraction

19. Allow the bar to cool before removing or use heat resistant gloves

The test was then repeated with the on-gun extract switched off and the 100% fume emission was determined by measuring the fume concentration in the canopy hood extract duct.

3.8 CALCULATION OF ON-GUN FUME CAPTURE EFFICIENCY

3.8.1 Method 1 – Measurements inside the canopy hood duct (with and without on-gun extraction)

$$E = \left(1 - \left[\frac{Cd}{C100\%}\right]\right) x100 \ldots\ldots\ldots\ldots(1)$$

Where E is the capture efficiency (%), Cd is the fume concentration ($mg.m^{-3}$) in the canopy hood duct with the on-gun extract switched on and C100% is the fume concentration in the duct under the same welding conditions with the on-gun extract switched off. To reduce errors that may be introduced by changes in fume emission Cd and C100% can be the average of several runs.

3.8.2 Method 2 – Simultaneous measurements inside the on-gun extract duct and the canopy hood duct

$$E = \left(\left[\frac{Rgd}{Rgd+Rch}\right] x100\right) \ldots\ldots\ldots\ldots(2)$$

Where Rgd is the rate of fume production ($mg.s^{-1}$) measured inside the on-gun extract duct and Rch is the rate of fume production measured inside the canopy hood extract duct. The rate of fume production R ($mg.s^{-1}$) is calculated as follows:

$$R = (CxQ)/3600 \ldots\ldots\ldots\ldots(3)$$

Where C is the concentration ($mg.m^{-3}$) inside the on-gun or canopy hood duct and Q is the flow rate ($m^3.h^{-1}$) through the duct. Equation 2 then becomes.

$$E = \left(\left[\frac{(CgdxQgd)}{(CgdxQgd)+(CchxQch)}\right] x100\right) \ldots\ldots\ldots\ldots(4)$$

Where Cgd is the concentration in the on-gun extraction duct, Cch is the concentration in the canopy hood duct, Qgd is the air flow rate through the on-gun extraction duct and Qch is the air flow rate through the canopy hood duct.

4. RESULTS

4.1 MEASUREMENTS OF FUME EMISSION RATES

Fume emission rates were determined from the 100% measurements made inside the canopy hood extract duct and were calculated from the product of the fume concentration inside the duct and the air flow rate through the duct using equation 3. Emission rates were determined for (a) bead on plate welding tests using the Thermal Arc DC Inverter welder and 1 mm diameter welding wire (b) bead on plate welding tests using the ESAB 380A welder and 1.2 mm diameter welding wire and (c) fillet in the flat welding tests using the ESAB 380A welder and 1.2 mm diameter welding wire. The results are shown in Fig 14.

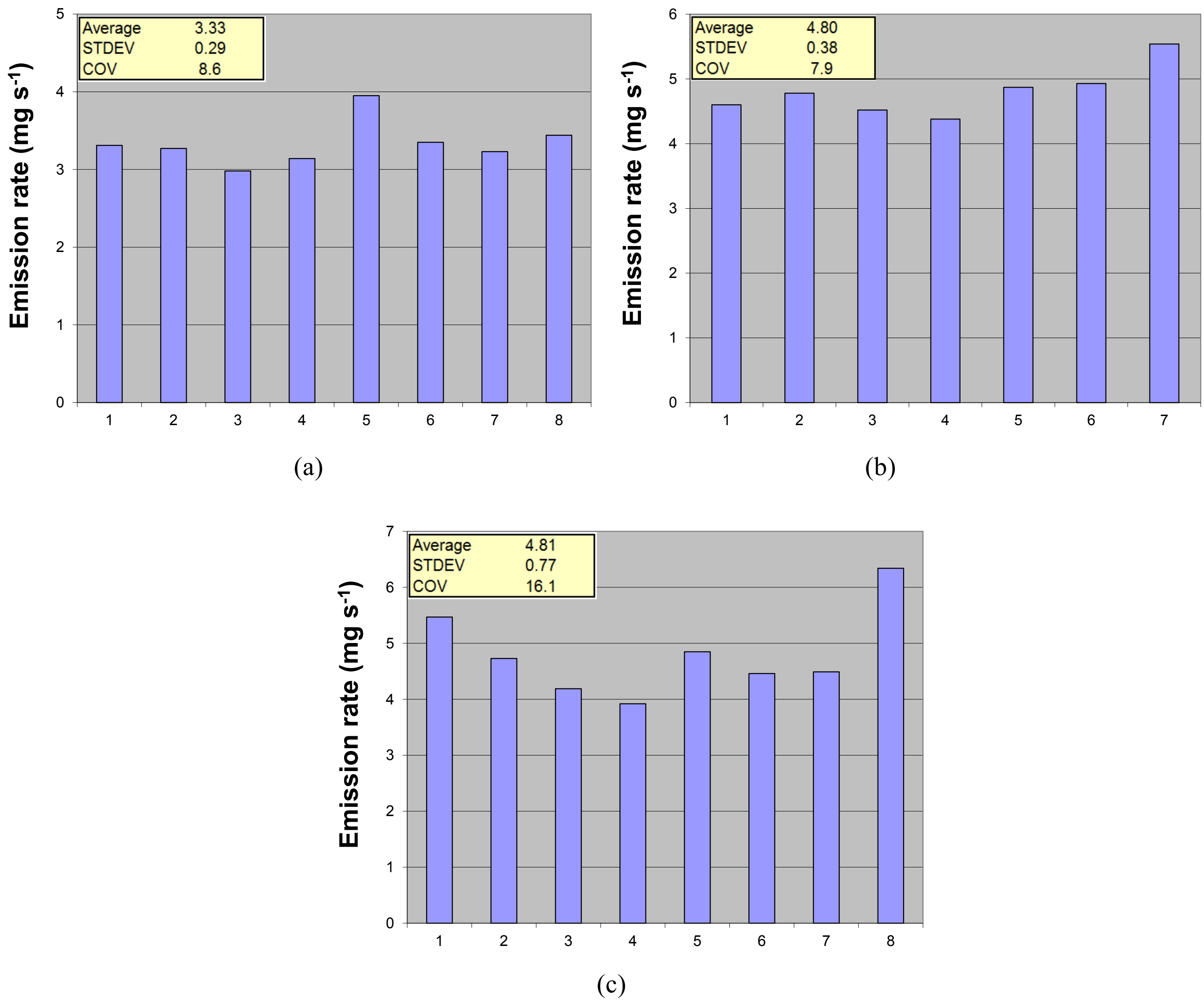

Fig 14. Results of fume emission rate measurements: (a) bead on plate, Thermal Arc DC Inverter welder, 1mm wire; (b) bead on plate, ESAB 380A welder, 1.2 mm wire; (c) fillet in the flat, ESAB 380A welder, 1.2 mm wire.

It can be seen from Fig 14 (a) and (b) that the fume emission rate for the bead on plate tests was fairly repeatable with a coefficient of variation (COV) of about 8-9% for any given welding unit, wire diameter and welding conditions. An overall increase in emission rate was observed as the wire diameter increased which was proportionate to the cross sectional area of the wire. The fume emission rates for the fillet in the flat welds were much more variable with a COV of 16%. These results are not surprising since, although it was relatively easy to clamp the torch securely in position for the bead on plate tests and maintain a constant CTWD throughout, the torch was more difficult to secure during the fillet tests and the CTWD had to be continuously readjusted between tests. On a couple of occasions, incorrect alignment resulted in the torch shroud impacting onto the test piece causing the traverse to stop. Interestingly, the fume emission rate was almost identical for bead on plate and fillet welding (see Fig 14(b) and 14(c)), which is not what was observed during the previous study [2] where the fume emission rate during fillet welding was found to be noticeably lower than during bead on plate. However, it is difficult to compare results from the two studies because of differences in experimental set-up and welding parameters.

4.2 MEASUREMENTS OF FUME CAPTURE EFFICIENCY – BEAD ON PLATE, THERMAL ARC DC INVERTER WELDER, 1 MM DIAMETER WIRE

4.2.1 Nederman P30 extractor set to maximum flow rate (approximately 33.2 $m^3.h^{-1}$ at the on-gun extraction inlet)

During these tests, the arc voltage was set to 20 V and the welding current was set to 130 A. The CTWD was set to 15 mm. The results are shown in Table 2.

TABLE 2. On-gun capture efficiency for bead on plate welding using the Thermal Arc DC Inverter welder and 1mm diameter wire

Sample line (G)un (H)ood	Extract flow rate (m^3 hr^{-1})	Gun flow rate (m^3 hr^{-1})	Gravimetric concentration (mg m^{-3})	Rate of fume (mg s^{-1})	Extraction efficiency Method 1 (Gravimetric)	Extraction efficiency Method 1 (Microdust)	Extraction efficiency Method 2
H	259		4.67	0.34			
G	54	29.1	150.0	2.25	89.8	82.1	87.0
H (100%)	259		45.96	3.31	89.9*		
H	259		4.43	0.32			
G	54	29.1	119.4	1.79	90.2	84.1	84.9
H (100%)	259		45.37	3.27	90.4*		
H	259		3.44	0.25			
G	53	37.17	107.2	1.57	92.3	84.2	86.4
H (100%)	259		44.90	3.23	92.6*		
H	259.2		2.59	0.19			
G	58	37.3	55.52	0.89	90.7		82.7
H	259.2		27.78	2.00			
				Averages	**90.8** **91***	**83.5**	**85.2**
				Standard Dev	**1.10**	**1.18**	**1.89**
				COV (%)	**1.2**	**1.4**	**2.2**

* extraction efficiency recalculated using average of 8 100% fume emission measurements

Table 2 shows that the measurement of fume capture efficiency during bead on plate welding using the Thermal Arc DC Inverter welder and 1 mm wire for the two methods was very repeatable with a COV of around 1.2 – 2.2 %. On average, method 2 gave capture efficiencies approximately 6% lower than Method 1. The measurement of capture efficiency made with the Microdust Pro direct-reading dust monitor was about 7% lower on average than that measured gravimetrically using the isokinetic sampler. The reason for this is not absolutely certain, but it may be because the response of this type of dust monitor depends on the size distribution of the particles that it measures. Therefore, if the particle size changes with and without the fume extractor switched on this could bias the results. For example, welding fume particles tend to agglomerate rapidly after generation to form larger particles. The rate of agglomeration would be expected to be greater at higher concentrations which would result in larger particles when the on-gun extraction was switched off than when it was switched on. In this situation, the dust monitor would overestimate the concentration of fume inside the canopy hood duct with the on-gun extraction switched on, resulting in a decrease in the measured capture efficiency, as was observed.

Overall, the capture efficiency was slightly lower than that found in the previous study [2], although the repeatability in the present study was considerably improved as shown by the low values of COV. A difference in capture efficiency is to be expected as a different welding torch was used for these tests. It should be noted that the last test in Table 2 was carried out with modified welding conditions (as reflected in the reduced fume emission rate) in an attempt to improve the weld quality, but this had little effect on the measured capture efficiency. In addition, the quality of the weld was not noticeably improved suggesting that there was a problem with the welding unit.

4.2.2 Nederman P30 extractor set to reduced flow rate (approximately 18 $m^3.hr^{-1}$)

During these tests, the arc voltage was again set to 20 V and the welding current was set to 130 A. The CTWD was set to 15 mm. The air flow through the on-gun extraction system was reduced to about half of its previous value by adjusting the in-line diaphragm valve (see Figs 9 & 10). The results are shown in Table 3.

TABLE 3. On-gun capture efficiency for bead on plate welding using the Thermal Arc DC Inverter welder and 1mm diameter wire – extraction flow reduced by approximately 50%

Sample line (G)un (H)ood	Extract flow rate (m^3 hr^{-1})	Gun flow rate (m^3 hr^{-1})	Gravimetric concentration (mg m^{-3})	Rate of fume (mg s^{-1})	Extraction efficiency Method 1 (Gravimetric)	(Microdust)	Method 2
H	259.2		16.95	1.22			
G	22.7	18	196.98	1.24	69.1	67.8	50.4
H (100%)	259.2		54.85	3.95	63.4*		
H	259.2		20.21	1.45			
G	22.7	18	242.97	1.53	56.5	44.6	51.3
H (100%)	259.2		46.48	3.35	56.4*		

* extraction efficiency recalculated using average of 8 100% fume emission measurements

Table 3 shows that there was a marked decrease in capture efficiency with reduced extraction flow rate. Once again the results for Method 2 were lower than for Method 1. The two results for Method 2 were very close, whereas there was a marked difference in the two results for Method 1 both for the gravimetric and real time measurement. This was clearly because of a change in the emission rate between the two tests as shown in Table 3 (3.95 and 3.35 $mg.s^{-1}$

respectively). Where the capture efficiency was recalculated using the average of 8 100% fume emission measurements, the discrepancy was not as great.

4.3 MEASUREMENTS OF FUME CAPTURE EFFICIENCY – BEAD ON PLATE, ESAB 380A WELDER, 1.2 MM DIAMETER WIRE

During these tests, the arc voltage was set to 32V and the welding current was set to 300A (see Table 1). On the advice of the TWI welder, the CTWD was set to 12 mm. Because of the consistency of the 100% fume measurements observed in the previous tests only Method 1 was used to determine the capture efficiencies during these tests. Table 4 shows the results from 3 separate tests. The number of measurements for each test varied depending on the amount of time available (6 for test 1 and 4 for tests 2 and 3). The average of the 100% emission rate measurements was used for each test.

TABLE 4. On-gun capture efficiency for bead on plate welding using the ESAB 380A welder and 1.2mm diameter wire

Test number	Gun extract flow	Extract flow rate (m^3 hr^{-1})	Gun flow rate (m^3 hr^{-1})	Grav Conc (mg m^{-3})	Rate of fume through canopy hood (mg s^{-1})	Extraction efficiency Method 1 Gravimetric	Microdust
1	Off	259.2		63.83	4.60		
	On	259.2	38.1	0.77	0.06	98.8 (98.8)	
	Off	259.2		66.39	4.78		
	On	259.2	37.3	2.60	0.19	96.0 (95.9)	
	Off	259.2		62.75	4.52		
	On	259.2	37.4	4.16	0.30	93.5 (93.4)	
2	Off	259.2		60.90	4.38		
	On	259.2	37.3	3.60	0.26	94.4 (94.3)	
	Off	259.2		67.65	4.87		
	On	259.2	37.2	4.18	0.30	93.5 (93.4)	
3	Off	259.2		45.99	3.31		
	On	259.2	37.1	3.34	0.24	94.6 (94.7)	
	On	259.2	37.2	4.73	0.34	92.3 (92.6)	
	Off	259.2		76.98	5.54		
					Average	94.7	
					Standard dev	2.1	
					COV (%)	2.2	

Extraction efficiencies in brackets recalculated using average of 7 100% fume emission measurements

Despite the change in welding unit, welding wire, weld conditions and CTWD the capture efficiencies were once again very high and consistent between tests as shown by the low COV of 2.2%. This is shown visually in Fig 15 in which still images were grabbed from videos taken inside the canopy hood. Where the capture efficiencies were recalculated using the average of all 7 100% fume emission measurements made during tests 1 – 3 (shown in brackets in Table 4), the results were almost identical.

(a) No extraction (b) With extraction

Fig 15. Still images taken from videos inside canopy hood (bead on plate)

4.4 MEASUREMENTS OF FUME CAPTURE EFFICIENCY – FILLET IN THE FLAT, ESAB 380A WELDER, 1.2 MM DIAMETER WIRE

During these tests, the arc voltage was set to 32V and the welding current was set to 280A (see Table 1). The CTWD was adjusted such that the welding torch shroud was positioned just above the test piece close to 45 degrees from the vertical (see Fig 13). In addition, the test piece was carefully adjusted in an attempt to maintain a constant CTWD to the vertical part of the test piece throughout a test. However, despite repeatedly repositioning the torch and test piece between tests, maintaining a constant CTWD during fillet welding proved particularly difficult. These issues could probably be resolved by designing a better torch clamping system and a system whereby the alignment of the fillet test piece could be adjusted e.g. mounting the test piece on an adjustable turntable.

Table 5 clearly identifies the problems found with the repeatability of capture efficiency measurement during in the flat fillet welding. This was mainly caused by changes in fume emission between tests because of the issues mentioned previously (and shown in Fig 14c). However, changes in CTWD may have affected the capture efficiency of the on-gun extraction system i.e. as the CTWD increased the capture efficiency of the on-gun system may have decreased.

TABLE 5. On-gun capture efficiency for fillet in the flat welding using the ESAB 380A welder and 1.2mm diameter wire

Gun extract flow	Extract flow rate (m^3 hr^{-1})	Gun flow rate (m^3 hr^{-1})	Grav Conc (mg m^{-3})	Rate of fume (mg s^{-1})	Extraction efficiency Method 1 (Gravimetric)
Off	259.2		75.94	5.47	
On	259.2	36.2	58.64	4.22	12.1
Off	259.2		65.68	4.73	
On	259.2	36.8	25.23	1.82	62.2
Off	259.2		58.19	4.19	
On	259.2	37.2	44.92	3.23	32.7
Off	259.2		54.39	3.92	
On	259.2	36.2	41.08	2.96	38.4
Off	259.2		67.39	4.85	
On	259.2	36.5	59.03	4.25	11.6
Off	259.2		61.89	4.46	
On	259.2	36.7	68.78	4.95	-3.1
Off	259.2		62.34	4.49	
Off	259.2		88.12	6.34	
				Average	**25.7**
				Standard dev	**23.5**
				COV (%)	**91.5**

Note that the capture efficiency was determined from the average of 8 100% fume emission measurements because of the large variation in emission rate between tests. Although highly variable, it is clear that the capture efficiency was much worse than during bead on plate welding. The fume capture is shown visually in Fig 16 in which still images were grabbed from videos taken inside the canopy hood. It confirms that the on-gun extraction performed poorly since there is clear evidence of fume escaping with the on-gun extraction turned on.

(a) No extraction

(b) With extraction

Fig 16. Still images taken from videos inside canopy hood (fillet in the flat)

4.5 MEASUREMENTS OF FUME CAPTURE EFFICIENCY – FILLET IN THE FLAT, ESAB 380A WELDER, 1.6 MM DIAMETER WIRE.

4.5.1 Nederman P30 extractor

During these tests, the arc voltage was set to 30V and the welding current was set to 330A).

Because of the problems encountered with maintaining a constant fume emission rate for in the flat fillet welding it was decided to revert back to using test Methods 1 and 2 to determine fume capture efficiency. Method 2 would eliminate any errors introduced by changes in emission rate, but the capture efficiency may still change between tests if the CTWD changes. Because of time restraints, only one measurement of on-gun capture efficiency was made using both methods. Method 1 used an average of two 100% fume emission measurements. The results are shown in Table 6 where it can be seen that both methods gave almost identical capture efficiency measurements of 30.5%, which is slightly higher than the average efficiency of 25.7% obtained using the thinner 1.2mm diameter wire in Section 4.4.

TABLE 6. On-gun capture efficiency for fillet in the flat welding using the ESAB 380A welder, 1.6mm diameter wire and the Nederman P30 extractor

Sample line (G)un (H)ood	Extract flow rate (m^3 hr^{-1})	Gun flow rate (m^3 hr^{-1})	Gravimetric concentration (mg m^{-3})	Rate of fume (mg s^{-1})	Extraction efficiency Method 1 (Gravimetric)	Method 2
H	259.2		91.07	6.56		
G	63.1	36.6	197.97	3.03	31.5	31.6
H (100%)	259.2		125.17	9.01		
H (100%)	259.2		140.62	10.12		

4.5.2 Nederman P55 extractor

In an attempt to increase the on-gun air flow rate (and hopefully the fume capture efficiency during in the flat fillet welding), the Nederman P30 extractor was replaced with the larger Nederman P55 which has a 50% higher nominal flow rate (240 $m^3.h^{-1}$ for the P30 and 360 $m^3.h^{-1}$ for the P55).

The average on-gun extraction flow measured previously using the Nederman P30 extractor was 35.4 $m^3.h^{-3}$. Replacing this with the Nederman P55 resulted in an increase in extraction flow rate on average to 41.2 $m^3.h^{-3}$ – an increase of only 14%. However, this did appear to result in a noticeable increase in the capture efficiency. For example using test Method 1, the average capture efficiency (taken from Tables 6 & 7) appears to have increased from 31.5% to 66.5% as the extraction flow rate increased. However, the results should be interpreted with care because of variability in the fume emission rate, as mentioned previously. There was a larger difference in the capture efficiency measured by the 2 methods compared to bead on plate welding, once again probably because of the variable fume emission rate. However, what is clear from these and the preceding results is that overall; on-gun capture efficiency is considerably poorer during in the flat fillet welding than bead on plate welding. This addresses one of the suggested research questions raised by the previous report [2].

TABLE 7. On-gun capture efficiency for fillet in the flat welding using the ESAB 380A welder, 1.6mm diameter wire and Nederman P55 fume extractor

Sample line (G)un (H)ood	Extract flow rate ($m^3 hr^{-1}$)	Gun flow rate ($m^3 hr^{-1}$)	Gravimetric concentration ($mg\ m^{-3}$)	Rate of fume ($mg\ s^{-1}$)	Extraction efficiency Method 1 (Gravimetric)	Extraction efficiency Method 2
H	259.2		56.20	4.05		
G	63.1	41.6	124.30	2.18	55.1	35.0
H (100%)	259.2		125.17	9.01	57.6*	
H	259.2		30.95	2.23		
G	62.1	40.9	106.43	1.84	78.0	45.2
H (100%)	259.2		140.62	10.12	76.7*	
H	259.2		47.82	3.44		
G	62.4	41.1	206.43	3.58		51.0
				Averages	66.5 67.1*	43.7
				Standard Dev		8.08
				COV(%)		18.5

* extraction efficiency recalculated using average of both 100% fume emission measurements

5. DISCUSSION AND CONCLUSIONS

A previous study to measure the effectiveness of on-gun extraction as a method of controlling welding fume emissions showed that the rate of fume generation needed to remain constant in order to get accurate and repeatable results. The rate of fume generation depends on the welding parameters used and also critically on the position of the welding tip in relation to the test piece. Failure to control the latter resulted in variability in the measurement of fume capture efficiency, especially when carrying out fillet welding. The method used a fume capture box that surrounded the welding torch to determine 100% fume emission, but there were some doubts as to the effectiveness of this method.

The aim of the present study was to improve on the previous methodology and has resulted in the development of two alternative methods for measuring the efficiency of on-gun fume extraction systems. In the first method the welding fume is collected and extracted by a canopy hood located above the welding torch. The emitted fume concentration is measured gravimetrically (or in real time using a dust monitor) inside a sampling duct connected to the hood with and without the on-gun extraction switched on. This method involves at least 2 independent tests and like the previous study relies on the repeatability of fume emission rate to ensure accurate results. The second method uses the same canopy hood to collect and extract fume not captured by the on-gun extraction system, but at the same time measures the fume captured by the on-gun extraction inside a sampling duct positioned between the torch and extractor. This means that the capture efficiency can be measured in one test and is therefore relatively unaffected by changes in fume emission rate.

Measurements of fume capture efficiency during the welding of bead on plate and fillet in the flat revealed the following:

- Welding bead on plate resulted in high fume capture efficiency (90% or greater) regardless of the measurement method used, the type of welding unit used, the welding conditions and fume emission rate when the fume extractor was operated at its maximum flow.

- Method 2 gave slightly lower measurements of capture efficiency during bead on plate welding. The difference was greater during fillet welding.

- Using a direct-reading dust monitor instead of an isokinetic gravimetric sampler to measure the fume concentration, for test Method 1, resulted in slightly lower measurements of capture efficiency.

- Reducing the extraction flow rate by about 50% resulted in a significant reduction in fume capture efficiency during bead on plate welding.

- Fume emission rate was very repeatable during bead on plate welding for any given set of welding conditions. This could probably be improved further with better control over the CTWD.

- Fume emission rates during fillet in the flat welding showed poor repeatability for any given set of welding conditions, almost certainly because of poor control over CTWD.

- Despite variable fume emission rate, the results have clearly shown that on-gun capture efficiency during fillet in the flat welding is considerably lower than during bead on plate welding.

- During the testing it was noted that the extraction line connecting the torch extract to the extraction unit was leaking, particularly where the water cooling line passed through the tube wall. This resulted in a reduced flow rate at the torch extraction point and would depend upon manufacturer and model. Therefore, it is important that the true measure of extraction flow rate should be measured at the gun and not close to the extraction unit.

- The use of a much larger fume extractor only resulted in an increase in on-gun extraction flow rate of about 14%, although there is evidence to suggest that this resulted in an increase in capture efficiency. However, it is difficult to accurately quantify this because of the variable fume emission rates.

There are distinct advantages and drawbacks to both methods of measuring on-gun capture efficiency. For example, the biggest advantage of using Method 1 is that the measurements are made inside the same sampling line with and without the on-gun extraction switched on and so there are no systematic errors introduced into the measurement. The biggest disadvantage is that if the fume emission rate changes between measurements then this can introduce large random errors. However, by improving the torch positioning and clamping system and carrying out enough repeat measurements, then these errors should be greatly reduced. Method 2 is largely unaffected by changes in fume emission rate and a measurement of capture efficiency can be made in one test. However, it uses two different sampling lines (at different system pressures) with different dimensions and different sampling probes which may introduce systematic errors into the measurement of capture efficiency. Indeed, the consistently lower measurement of capture efficiency compared to Method 1 during bead on plate welding where the fume emission rate was reasonably constant would seem to confirm this. In addition, the degree and the effects of air leakage into the extraction system around where the cooling pipes enter the torch extract line, on the measurement of capture efficiency are not completely understood. On balance, assuming that variations in fume emission rate can be reduced, then Method 1 would be the preferred method.

At the time of this report, working group 4 of Standards committee CEN/TC 121/SC 9 has adopted Method 1 and is currently drafting a new standard for measuring the capture efficiency of on-gun fume extraction systems.

Although not carried out as part of this project, the method can be applied to measuring on-gun capture efficiency during vertical “in position” welding using the same extraction hood and the welding conditions have been determined. This may be carried out later depending on the availability of funding, but also may be carried out by colleagues at INRS in France, who also sit on the CEN committee and are carrying out research in this area.

6. REFERENCES

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Standardisation of the measurement of capture efficiency of on-gun extraction for welding

The inhalation of welding fume is recognised as being a real threat to workers' health due to the development of occupational illnesses such as welding fume fever and asthma. Local exhaust ventilation (LEV) is an effective method to control worker exposure to welding fume and previous work has indicated the merit of the use of on-gun extraction systems.

The aim of the present study was to improve and refine the existing on-gun extraction methodology and has resulted in the development of two alternative methods for measuring the efficiency of on-gun fume extraction systems. There are distinct advantages and drawbacks to both methods of measuring on-gun capture efficiency, but a preferred method has been identified.

At the time of drafting this report, working group 4 of Standards committee CEN/TC 121/SC 9 has adopted this preferred method and is currently drafting a new standard for measuring the capture efficiency of on-gun fume extraction systems.

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