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**Controlling Gas Shielded Arc Welding Fume
Using an On-Gun Extraction System**

ECM/07/04

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FOREWORD

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

In the flat - Welding on a test piece that is laying 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

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EXECUTIVE SUMMARY

Objectives

The objectives of this project were;

1. To determine the optimum position for the extraction nozzle for maximum capture efficiency without compromising weld metal integrity
2. Measure the capture efficiency of the Nederman Abicor Binzel on-gun extraction system in various positions (i.e. welding in the flat, vertically up and down and welding in fillet joints)
3. To compare these to conventional captor hood based local exhaust ventilation (LEV) systems to determine whether the on-gun system was able to sufficiently control exposure to welding fume without compromising weld metal integrity
4. Investigate the effect of fume emission rate on the capture efficiency of the system

Main Findings

It was easy to determine the optimum position for the extraction nozzle, and was found to be 14 mm from the bottom of the shielding gas shroud. For butt welding the system provided adequate control and provided a suitable replacement for hood based LEV except when welding in the horizontal position when capture efficiency was 74 %. In general for welding in a fillet the control provided by the on-gun system was sufficient to provide an alternative for hood based LEV in most positions. There are still ambiguities regarding the effect of fume emission rate on capture efficiency when welding in fillets in the flat, making it difficult to fully quantify capture efficiencies when welding fillets. Fume emission rate was found to have no effect on capture efficiency when welding bead on plate in the flat. Tests with 1.0 mm and 1.2 mm welding wire that gave different fume emission rates produced comparable capture efficiencies.

Weld metal integrity was only compromised when the extraction nozzle was placed flush with the bottom of the gas shroud. In all other tests the weld metal integrity was unaffected by visual porosity. None of the samples submitted for radiographic examination showed any evidence of sub-surface porosity.

Recommendations

It is recommended that for butt welding in all positions except horizontally the Nederman on-gun extraction system provides a high enough capture efficiency to adequately control the emission of welding fume at source and prevent exposing the operator. For optimum performance, the extraction nozzle should be placed approximately 14 mm above the bottom of the shielding gas shroud. Placing the extraction nozzle closer than this may cause impairment of the weld metal integrity.

Because of the nature of this project, all welding was carried out remotely using an automatic traversing system. This means that no assessment was made of the torch's ergonomic suitability or its operability. For this, further work using a human welder would have to be undertaken.

Further work is required to fully assess the on-gun system when welding fillets and the effects of increased fume emission rate on capture efficiency.

1 INTRODUCTION

Welding generates fume and gases, which, if inhaled, can be harmful to health[1]. Consequently, fume control is often required to maintain exposures at acceptable levels. Control is frequently achieved using local exhaust ventilation (LEV), in the form of moveable hoods, to capture the fume close to its source, before it enters the welder's breathing zone[2, 3]. Efficient capture can only be achieved when the hood is positioned close to the generation point and is repositioned at frequent intervals, to ensure that the fume generated is always within its capture zone[4]. This is sometimes difficult to achieve and does not always occur, leaving the welder and potentially other workers over exposed to welding fume.

For continuous wire welding processes, a possible solution to this problem is to use on-gun extraction systems to control the fume. These have the advantage that the extraction point is always close to the fume source but they have been reported to be ergonomically unsuitable because of the weight of the gun and the dragging effect of the extraction ducting, whilst the presence of the extract nozzle can obscure the welder's sight of the weld in tight situations. HSE guidance for inspectors [5] states that *on-gun systems work efficiently whilst welding in butt joints, in the flat, and with the torch in a very upright orientation, but that they are less efficient when welding in position, or in horizontal/vertical fillets*. Furthermore, efficient fume capture cannot be achieved without the risk of compromising weld metal integrity, arising from shielding gas removal by the high velocity of the extracted air[6, 7]. This guidance is also available on the internet.

Manufacturers of on-gun extraction systems now claim that improvements in design have made them both capable of efficient fume capture without compromising weld metal integrity, and to be acceptable ergonomically, whilst their reduced size allows improved vision of the work[5]. However, no information was available to substantiate the claims regarding extraction efficiency and maintenance of weld metal integrity, so Nederman and Abicor Binzel commissioned this project, using an on-gun extraction system that they market.

2 APPROACH

Welding was performed using a specifically designed welding torch incorporating an on-gun extraction system. The concentration of fume in the extraction ducting of the torch was measured using an isokinetic sampling technique. The extraction efficiency was taken to be the ratio between the fume concentration in the extraction duct, measured during testing under specific test parameters, to the fume concentration measured under the same test conditions but with total fume capture (100% extract tests). Total capture for a given set of test conditions was achieved by positioning, either, a funnel, or a box shaped enclosure of similar volume, around the torch. This arrangement ensured that any fume initially escaping the extraction system would be trapped in the enclosure and ultimately captured. In general, three determinations were made under each specific set of conditions and were accompanied by three 100% extract determinations under exactly the same conditions. This approach ensured that any changes in fume emission rate stemming from the different welding conditions were taken into account. Using this technique, the capture efficiency of the on-gun system was measured over a range of welding parameters and conditions to establish the following;

- The levels of capture efficiency to be expected for on-gun systems without compromising weld metal integrity
- The effects of extract nozzle position
- The effects of welding position, i.e. in the flat, vertically up, vertically down and horizontally
- Welding in a fillet compared to butt welding
- Differences in fume emission rate

Butt welding was simulated by welding bead on plate. Weld metal integrity was assessed by examining the weld metal deposited in each test for porosity, this being the most significant defect to occur in carbon manganese weld metal. Initially, the assessment was made visually but any deposits where the weld bead appearance indicated that sub surface porosity might be present were subjected to radiographic examination.

3 EXPERIMENTAL DETAILS

3.1 ON-GUN EXTRACTION SYSTEM

The on-gun extraction system consisted of an Abicor-Binzel RAB 25, air cooled, fume extracting welding torch, connected to a Nederman P30 extraction unit (Figures 3.1 and 3.3). The welding torch is shown schematically in Figure 3.2. The maximum recommended flow rate of the extracted air was $100 \text{ m}^3\text{h}^{-1}$ and the static pressure within the duct was 15 kPa, these values are standard for use in industry[5].



Figure 3.1: Abicor-Binzel RAB 25 air cooled fume extracting welding torch

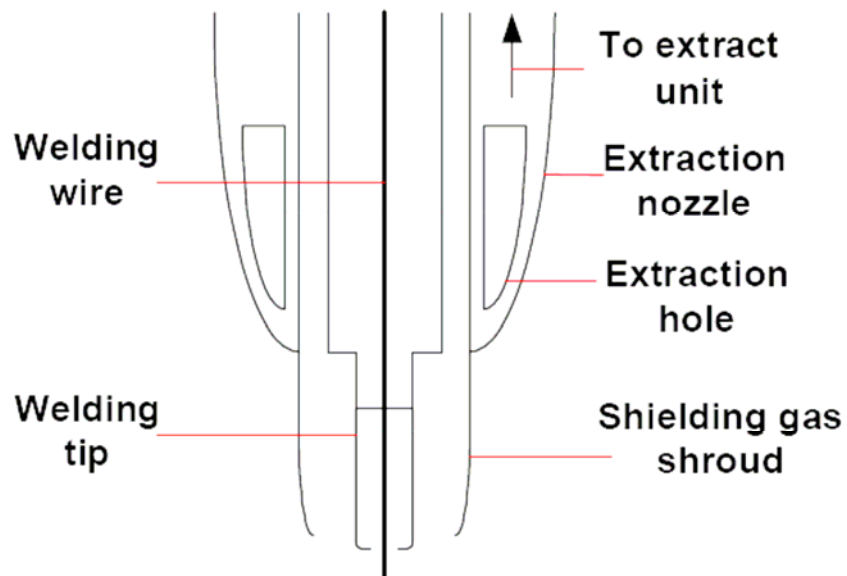


Figure 3.2: Schematic diagram of Abicor Binzel fume extracting welding torch



Figure 3.3: Nederman P30 portable high vacuum fume extraction unit

3.2 TEST PIECES

Welding was performed on test pieces made from lengths of 50 mm by 12.5 mm bright mild steel bar stock. For bead on plate welding, they were 500 mm long. For fillet welding, horizontal/vertical fillets were made by tacking together two 500 mm lengths in the appropriate configuration.

3.3 ENCLOSURES

The enclosures used in the 100 % capture tests are shown in Figures 3.4 and 3.5. The funnel, which fitted closely around the handle of the welding torch, was approximately 300 mm in diameter. The box, which also fitted closely around the torch, was an approximate cube with dimensions of 150 mm.

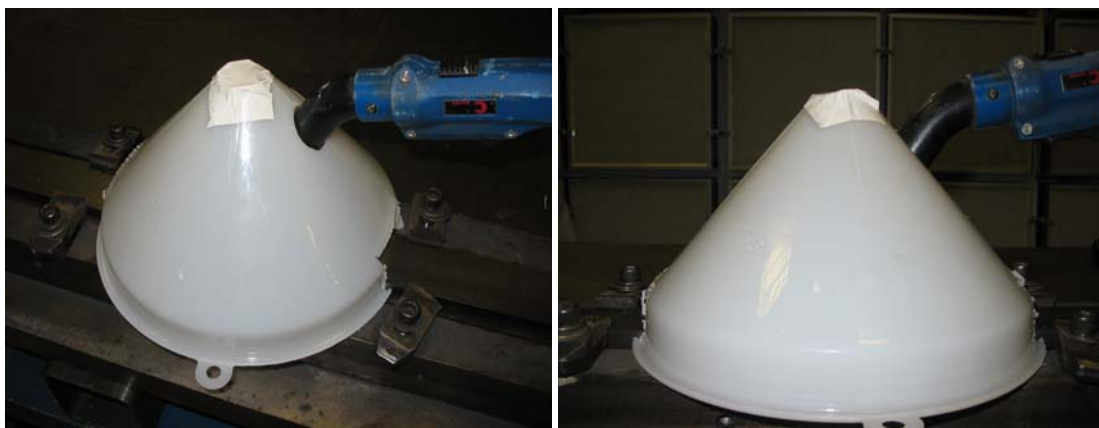


Figure 3.4: Funnel enclosure in position and from the side

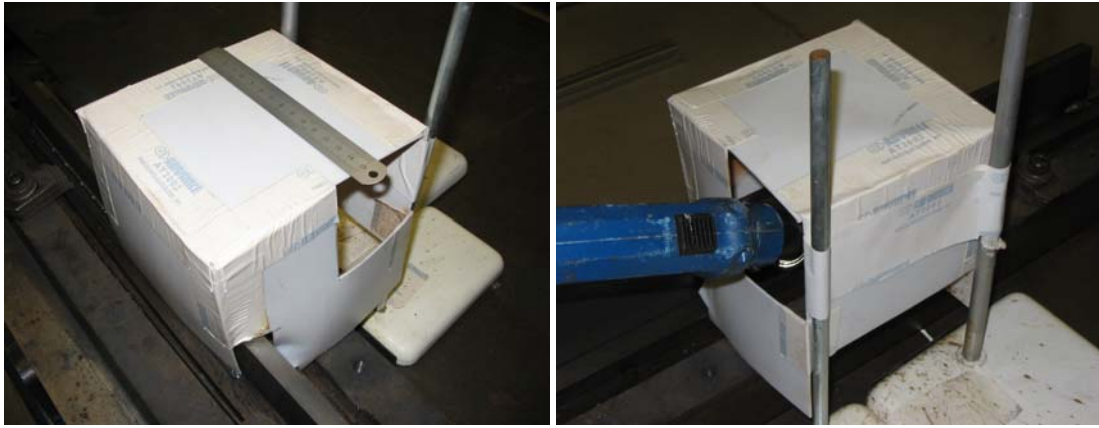


Figure 3.5: Box enclosure with scale and in position

3.4 WELDING

The power source was an ESAB AristoMiG 500 inverter, fitted with an ESAB AristoFeed 48 wire feed unit. Although connected to the fume extracting torch inside the test cabin, the power source was positioned and operated from outside the cabin. Welding parameters (e.g. voltage, current, wire feed speed etc.) were monitored using the AMV Weldcheck system. Welding was carried out automatically on test pieces secured to a traversing system that was operated remotely, from outside the test cabin. Tests performed in the flat were carried out on a horizontal traverse with the welding torch traversing a stationary test piece. Positional welding was carried out on a vertical traverse with a stationary torch and a traversing test piece. A pushing technique was employed in all cases except when welding vertically downwards and horizontally. For tests conducted with bead on plate welding, the welding torch was at an angle of 70° to the test piece. 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.

Welding was performed using two different diameters of welding wire and associated welding conditions. These were selected on the basis of their common use making the results applicable to a wide range of users. Condition 1 employed a 1.0 mm diameter, double de-oxidised, mild steel wire and welding parameters that were suitable both for welding in the flat and in position, i.e. vertically up, vertically down and horizontally. Condition 2 employed a 1.2 mm diameter wire of similar composition but was suitable only for welding in the flat. The contact tip to work distances (CTWDs) was 12.5 mm and 20 mm for Conditions 1 and 2 respectively. Shielding gas flow rate was 15 lmin^{-1} for condition 1 and 18 lmin^{-1} for condition 2, typical of current welding practice with normal welding torches. The welding conditions are given in Table 3.1.

Table 3.1: Welding conditions for Condition 1 and Condition 2

Welding condition	Wire	Diameter	Current	Voltage	Wire feed speed	Shielding gas flow rate	Traverse speed	CTWD
		mm	A	V	mmmin^{-1}	lmin^{-1}	mmmin^{-1}	mm
1	Bostrand LWI	1.0	130	19	4.5	15	240	12.5
2	Bostrand LW1	1.2	260	32	8.5	18	240	20

3.5 SAMPLING SYSTEM

The sampling system is shown in Figure 3.6, the system is an adapted method of the sampling strategy used in previous studies of LEV efficiency for use in arc welding processes[8]. It

consisted of a 75 mm diameter plastic duct, connected to the welding torch extract ducting at one end and to the extraction unit at the other. The flow rate of extracted air through the system was maintained at a constant level of $80 \text{ m}^3\text{h}^{-1}$ using a diaphragm valve and was monitored using a micromanometer connected to an orifice plate. Although less than the maximum recommended air flow for the system, $80 \text{ m}^3\text{h}^{-1}$ allowed some latitude for adjusting air flow rate, should the filters on the extraction system become partially blocked. In addition to this the sampling system (incorporating an orifice plate and a valve) added an extra resistance to the system which would not be found in industry. An isokinetic sampling probe was positioned centrally within the duct, the velocity of air entering the probe being matched to that in the extraction duct using an adjustable sampling pump and rotameter.

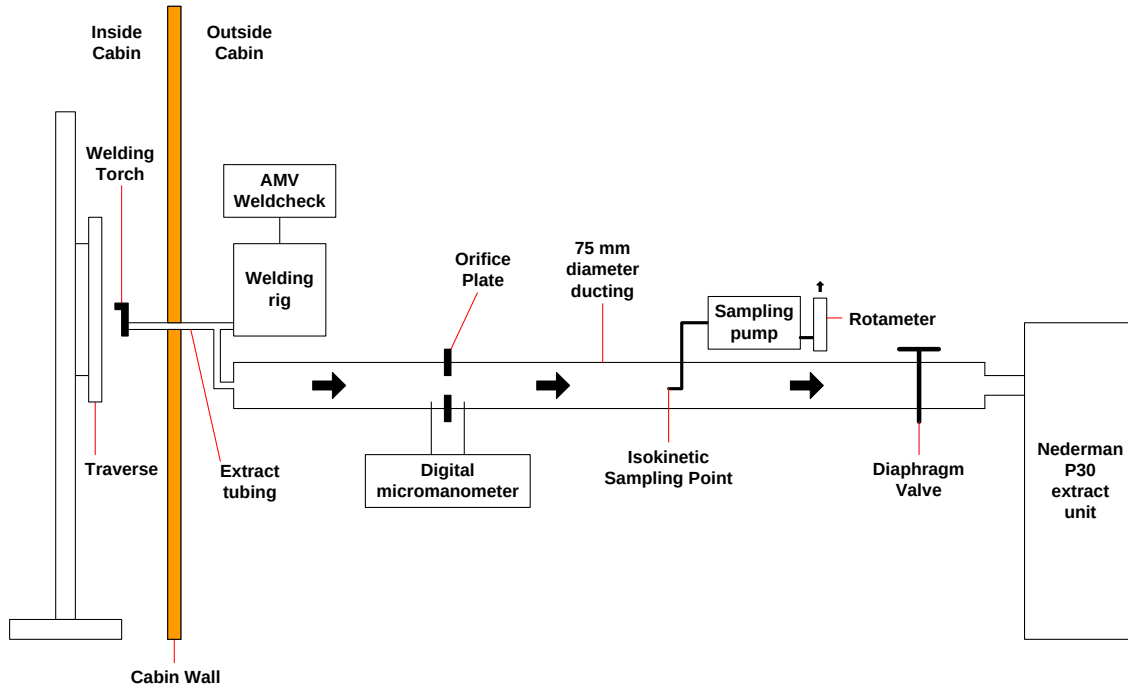


Figure 3.6: Schematic diagram of on-gun extraction system and sampling set up

The weight of fume (mg) collected by the probe was obtained from the difference in weight of the sample filter in the isokinetic probe, weighed before and after each test. The filters were conditioned for 24 hours before being pre weighed and conditioned for a further 24 hours after being exposed to fume before being weighed again. The filters were conditioned and kept in a climatically controlled room at a constant temperature and humidity. Every ten filters were accompanied by three control filters, these were kept with the test filters at all times and placed in the filter cassettes once to account for any environmentally induced changes in mass. Together, these measurements allowed the concentration of fume (mgm^{-3}) in the duct to be calculated from the weight of fume collected and the volume of air sampled.

3.6 TEST CABIN

Welding was carried out inside a test cabin, to provide a controlled environment. The floor area enclosed measured approximately 4 m by 4 m and the cabin was 3 m high. Welding was carried out centrally within the cabin. A uniform flow of air, with a velocity of 0.1 ms^{-1} , passed through the cabin at right angles to the welding direction. Any fume escaping extraction was removed from the enclosure between tests.

4 WORK PROGRAM

The programme of work was as follows;

- Using Condition 1, extraction efficiency was measured, during bead on plate welding, in the flat, with the extract nozzle in various positions, to optimise the position for fume capture (Tests 1 to 9). Subsequent tests were all performed with the extract nozzle in the optimum position.
- Tests were performed bead on plate, in the flat (Tests 10 to 14).
- Vertically up (Tests 15 to 20).
- Vertically down (Tests 21 to 26).
- Horizontally (Tests 27 to 32) to evaluate the effect of welding position on capture efficiency.
- Further tests, performed in a horizontal/vertical fillet, in the flat (Tests 33 to 38).
- Vertically down (Tests 39 to 44).
- Vertically up (Tests 45 to 50) these were also used to evaluate the effects of welding position but were used, additionally, to examine the effect of welding in a fillet.

Tests 1 and 2, which were subsequently shown to provide the optimum extraction nozzle position in tests 3 to 9, were used as 100% extract checks for tests 3 to 9 and for tests 10 to 14, which examined efficiency during bead on plate welding in the flat.

- Using Condition 2, welds were deposited bead on plate, in the flat (Tests 51 to 56).
- In a horizontal/vertical fillet, in the flat (Tests 57 to 62) the results of these tests were again used to examine whether capture efficiency was different for fillet welding when compared to bead on plate, but also provided an indication of whether higher fume emission rates affected extraction efficiency.

5 RESULTS

5.1 GENERAL

The majority of capture efficiencies measured during testing during bead on plate welding were more than 90 %, with only one result obtained whilst welding horizontally being significantly lower. Results obtained with fillet welding proved to be difficult to interpret. Initial experiments to determine the capture efficiency when welding in a fillet in the flat were performed using a large enclosure, cuboid in shape measuring approximately 600 mm long, 300 mm wide by 400 mm high to provide 100 % capture measurements. These tests showed capture efficiency of ~90 % using a 1.0 mm wire and ~50 % when using a 1.2 mm wire. To determine the capture efficiency for welding fillets in position we initially used 100 % capture values from welding bead on plate in position. On analysis of these data it became apparent that the fume emission rate from fillets was significantly different to that from welding bead on plate. As a result of this, capture efficiency measurements were repeated for welding fillets vertically up and down. These results are given in full in Appendix A. At the same time capture efficiency measurements for welding fillets in the flat with both the 1.0 and 1.2 mm wires were repeated using the smaller cube shown in Figure 3.5. Along with these four sets of repeated tests, capture efficiency measurements for bead on plate welding in the flat with Condition 1 were repeated.

In these repeated tests, the results for welding bead on plate in the flat were essentially the same changing from 89 % to 93 %. The results for welding fillets vertically upwards and downwards changed but this was to be expected as correct 100 % capture values from welding fillets were used in the repeated tests. Only the results of the repeated tests are given in Table 10.1. For welding a fillet in the flat with the 1.2 mm wire capture efficiency changed from 46 % to 55 % but for the 1.0 mm wire from 95 % to 62 %, this is discussed later in section 5 and in section 6.

The fume concentrations in the extract duct, measured in the 100 % capture tests with a 1.0 mm diameter wire, were rather different, depending upon the welding position, although the welding parameters had been maintained at as constant a level as possible. Highest concentrations, at 289 mgm^{-3} , were measured when welding bead on plate in the horizontal position. Concentrations when welding bead on plate, in the flat were 226 mgm^{-3} , 193 mgm^{-3} bead on plate, vertically down and 130 mgm^{-3} when welding bead on plate, vertically up. Similarly, there were differences in concentration between the various positions when welding with the 1.0 mm wire in a horizontal/vertical fillet, although the differences were smaller. Testing was not carried out in the horizontal position, leaving the highest value at 128 mgm^{-3} for welding in the flat, 122 mgm^{-3} for welding vertically down and 101 mgm^{-3} for welding vertically up. Thus, the results were lower than for bead on plate welding but the order had been retained.

Table 5.1: Maximum fume concentrations from 100 % capture tests

Description	Fume concentration (mgm^{-3})
Bead on plate, horizontal.	289
Bead on plate, in the flat.	226
Bead on plate, vertically down.	193
Bead on plate, vertically up.	130
Fillet, in the flat.	159
Fillet, vertically down.	141
Fillet, vertically up.	103

None of the samples submitted for radiographic examination showed the presence of sub surface porosity. Results for all tests of the on-gun system are shown in Appendix A.

5.2 EFFECT OF EXTRACT NOZZLE POSITION ON CAPTURE EFFICIENCY

The concentration of fume in the extraction duct when the extract nozzle was positioned flush with the gas shroud of the gun (Test 3) was higher than the average concentration measured in the 100% checks (Tests 1 and 2). However, positioning the nozzle in this way caused a reduction in weld metal integrity, as shown by visual porosity, making this nozzle position unusable practically. Numerically this actually gave capture efficiency substantially higher than 100 % at 120 %, which may be due to an increased fume emission rate caused by the removal of the shielding gas leading to compromised weld metal integrity. Highest capture efficiency was measured when the extract nozzle was 14 mm from the bottom of the gas shroud, making this the optimum position. The capture efficiency, at around 90 %, was somewhat lower when the extract nozzle was slightly nearer than the optimum position to the weld and lower still (78%) when it was further away. There were no visual indications of porosity in the welds deposited with the extraction nozzle 7, 14 and 21mm from the bottom of the gas shroud.

Table 5.2: Capture efficiencies of varying extract nozzle positions

Nozzle distance from gas shroud mm	Capture efficiency %
0	120
7	93
14	107
21	78

5.3 EFFECT OF WELDING POSITION ON CAPTURE EFFICIENCY

5.3.1 Bead on Plate Welding

The average capture efficiency when welding bead on plate in the flat with the 1.0 mm wire (Tests 10 to 14), was 94 %. Thus, almost all the fume generated was captured. The results ranged from 84 % to 101 % giving an indication of the reproducibility of the method. Extraction efficiency obtained with the 1.2 mm wire, at 93 %, was almost identical.

The average capture efficiency when welding bead on plate, vertically up (Tests 15 to 20), was 107 %. Thus, slightly more fume was measured in the evaluation tests than in the 100 % check tests, although the difference was probably within the range of experimental error. Nevertheless, it is important to note that, for vertically up welding, all fume was captured.

The average capture efficiency when welding bead on plate, vertically down (Tests 21 to 26), was 90 %. Whilst the efficiency was not quite as high as when welding vertically up, almost all the fume was captured and the result was again similar to that obtained when welding in the flat.

The average capture efficiency when welding horizontally (Tests 27 to 32), at 74 %, was somewhat lower than for bead on plate welding in the flat, vertically up and down positions.

Table 5.3: Capture efficiency of bead on plate welding in the flat and in position

Test description	Capture efficiency (%)
In the flat, 1.0 mm wire	94
In the flat, 1.2 mm wire	93
Vertically up	107
Vertically down	90
Horizontally	74

5.3.2 Fillet Welding

The average capture efficiency when welding a horizontal/vertical fillet, in the flat in the original tests (Tests 33a to 36a), with the 1.0 mm diameter wire was 95 %. However when repeated using the smaller cube (used for the 100 % extract tests) (Tests 33b to 38b) capture efficiency was 62 %. When welding with the 1.2 mm diameter wire in the original tests (Tests 57a to 62a) the average efficiency was 46 %. When repeated with the smaller cube (Tests 57b to 62b) capture efficiency was 55 %. In all tests welding fillets in the flat with the exception of the first measurements made with the 1.0 mm wire in the large enclosure were lower than for welding bead on plate.

The average capture efficiency when welding a horizontal/vertical fillet, vertically down (Tests 39 to 44), with the 1.0 mm diameter wire was 82 %. In this case, the capture efficiency approached that achieved during bead on plate welding but was, nevertheless somewhat lower.

The average capture efficiency when welding a horizontal/vertical fillet, vertically up (Tests 45 to 50) with a 1.0 mm wire was 81 %, i.e. the same as for welding vertically down but again lower than for bead on plate welding.

Table 5.4: Capture efficiency of fillet welding in the flat and in position

Test description	Capture efficiency (%)
In the flat, 1.0 mm wire	95/62
In the flat, 1.2 mm wire	46/55
Vertically down	82
Vertically up	81

5.4 EFFECT OF WELDING FILLETS OR BEAD ON PLATE ON CAPTURE EFFICIENCY

Capture efficiency was 94 and 93 % respectively when welding bead on plate, in the flat, with 1.0 mm and 1.2 mm wires. When welding a fillet in the flat, it was substantially lower, at ~50 % with the 1.2 mm wire but capture efficiency for the 1.0 mm wire remains unclear. Welding vertically down, bead on plate, gave a capture efficiency of 90 % and the efficiency was 107 % when welding vertically up. The results obtained for welding vertically down and up in a fillet were 82 and 81 % respectively. Although the numerical values for the positional bead on plate tests are rather different, the results could be regarded as similar, in that both results indicate that the vast majority of the fume was collected. Overall, it appeared that fume capture during fillet welding was less efficient than during bead on plate welding.

Table 5.5: *Capture efficiency of bead on plate welding and fillet welding*

Test description	Capture efficiency (%)
Bead on plate, in the flat, 1.0 mm wire	94
Bead on plate, in the flat, 1.2 mm wire	93
Fillet, in the flat, 1.0 mm wire	95/62
Fillet, in the flat, 1.2 mm wire	46/55
Bead on plate, vertically down	90
Fillet, vertically down	82
Bead on plate, vertically up	107
Fillet, vertically up	81

5.5 EFFECT OF FUME EMISSION RATE ON CAPTURE EFFICIENCY

The fume concentrations measured in 100 % extract checks demonstrate that welding with the 1.2 mm diameter wire generated more fume than with the 1.0 mm wire, as much as four times in some cases. Comparative tests performed with both diameters of wire, bead on plate and in a fillet, provided similar capture efficiency data, with the exception of the anomaly regarding fillet welding in the flat with a 1.0 mm wire. This demonstrates that in most cases the on-gun extraction system tested works equally well with different fume emission rates under the conditions in which the tests were performed.

Table 5.6: *Capture efficiency of welding with 1.0 and 1.2 mm wires*

Test description	Capture efficiency (%)
Bead on plate, 1.0 mm wire	94
Bead on plate, 1.2 mm wire	93

6 DISCUSSION

The work has shown that, contrary to popular belief, the on-gun fume extraction system evaluated will, with limited exceptions, provide satisfactory fume capture, without compromising weld metal integrity. However, the eventual consideration is whether on-gun extraction can approach the efficiency of conventional, captor hood based, local exhaust ventilation, which, when used properly should provide capture efficiencies approaching 100 %. Therefore, the value of 90 % capture efficiency selected here was considered to be a necessary criteria for on-gun extraction to be considered a viable alternative to captor hood based LEV. On this basis on-gun extraction provided satisfactory fume capture for the configurations tested. Welding overhead may result in unsatisfactory fume capture efficiency, but this configuration was outside of the scope of the present study.

At the work planning stage, consideration had been given to performing a single group of tests, under the welding parameters selected for testing, to determine the 100 % extract value. The average of these results would then be used for all tests performed with those welding parameters; i.e. all tests performed with Condition 1 would use the results from a single group of 100 % extract checks. It was apparent, from the fume concentrations measured during testing to determine 100 % extract efficiency, that the emission rate of the fume varied depending on the welding position, even though the welding parameters were essentially the same, confirming the necessity to perform 100 % checks alongside each determination of capture efficiency.

Not all of the differences in fume concentrations measured in 100 % checks were unexpected. For example, it is well known that welding in a fillet in the flat provides a lower fume emission rate than welding bead on plate. However, no data were available previously to suggest that welding in different positions generated different quantities of fume.

The results have shown that positioning the extract nozzle, in order to achieve efficient capture, whilst maintaining weld metal integrity, is not a difficult task. Weld metal integrity, as shown by porosity, was only compromised in an extreme position where the extraction nozzle was flush with the bottom of the gas shroud. None of the other positions examined resulted in any indication of weld metal porosity. Only when using a nozzle position at the other extreme, furthest from the weld, resulted in any reduction in capture efficiency. Thus, it should be very easy for a welder to adjust the nozzle position satisfactorily.

The capture efficiency when welding in position was essentially equal to that of welding in the flat. Capture efficiency from welding vertically down was essentially the same as welding vertically up. However, slightly lower capture efficiency was obtained when welding horizontally. The reason for this lower value is unknown. A possible explanation concerns the weld, once the bead has been laid down it continues to emit fume, once given off this fume rises. When welding vertically it is possible that this fume is subsequently recaptured as it passes the torch but when welding horizontally the torch has moved laterally and this fume is unlikely to be captured. Nevertheless, the results indicated that positional welding with the on-gun system evaluated, will, with the possible exception of horizontal welding, provide a high level of fume capture.

The results obtained for welding fillets in the flat are difficult to interpret and the true capture efficiency is still unknown. Following the completion of testing we filmed welding a fillet in the flat using 1.0 mm wire with and without extraction and bead on plate in the flat and in position with and without extraction. Close inspection of these images shows that for bead on plate welding both in the flat and in position almost no fume is seen to escape. The video of welding a fillet in the flat shows very little fume escaping capture suggesting that the capture efficiency

is closer to the 95 % value than the 62 % value. The images of fillet welding in position also seems to corroborate the capture efficiency measurements with the large majority of fume captured. These images should be treated with a slight degree of scepticism due to the high degree of illumination cast by the arc. This illumination tends to exaggerate the amount of fume in the immediate vicinity of the arc whilst making any fume further away that has escaped capture harder to see. Consequently, it is difficult to recommend on-gun extraction for fillet welding without further work.

The video footage of fillet and bead on plate welding without extraction provides some valuable insight into the way in which fume is emitted from the two processes. Figure 6.1 below is a still image taken from the video of bead on plate welding in the flat without extraction.



Figure 6.1: Still image of bead on plate welding without extraction using 1.0 mm wire

The welding was performed using a pushing technique and as can be seen the fume is emitted in a unidirectional manner in front of the torch as the weld is laid down. Figure 6.2 below shows a still from the video of fillet welding in the flat without extraction. As can be seen the fume appears to channel along the intersection of the plates formed by the fillet and is emitted at the ends of the fillet in both directions at a greater velocity. If we then consider the apparent discrepancy in capture efficiencies of fillet welding with the 1.0 and 1.2 mm wire, whilst remembering that the 1.2 mm wire produces two to three times the mass of fume, the manner in which the fume is emitted may become important for fillet welding where it is less of a factor in bead on plate welding. It may be that the combined factors of an increased mass of fume moving in two directions is too energetic a process for the on gun system to adequately control when the 1.2 mm wire is used. It should again be noted here, that during testing the extraction system was operated at a volume flow rate of $80 \text{ m}^3\text{h}^{-1}$, whereas the nominal operating flow rate

recommended by the manufacturers was $100 \text{ m}^3\text{h}^{-1}$. This could be a possible explanation for the apparent lower capture efficiency with the 1.2 mm wire compared to the 1.0 mm. However, this is speculation only and further work would be required to prove it quantitatively.



Figure 6.2: Still image of fillet welding without extraction using 1.0 mm wire

When welding bead on plate in the flat capture efficiency was unchanged with increased fume emission rate, i.e. using 1.2 mm diameter wires. However, as discussed above, the geometry involved when welding fillets complicates the situation. It is recognised that this statement can only be made for the consumables and welding parameters examined but since the consumables were selected on the basis of common use the statement should be applicable in a large number of cases.

7 PRACTICAL IMPLICATIONS

This work demonstrates that, used properly, the Nederman Abicor Binzel on-gun extraction system for welding fume will supply satisfactory fume control during butt welding in the flat and in position and during fillet welding in position. However, some ambiguities remain regarding the capture efficiencies achievable during fillet welding in the flat until further work can be carried out. The work conducted made no assessment of its suitability in other areas, e.g. ergonomically or in terms of providing sufficient visual access.

In addition the extraction volume flow rate of $80 \text{ m}^3\text{h}^{-1}$ was selected for the reasons discussed in section 3.5. Increasing the extraction flow rate to $100 \text{ m}^3\text{h}^{-1}$, which is recommended by the manufacturers, should increase the capture efficiencies.

8 CONCLUSIONS

The capture efficiency of an on-gun fume extraction system marketed by Nederman and Abicor Binzel was assessed by comparing the concentration of fume captured whilst welding under a given set of parameters with the total fume concentration emitted under the same conditions. Following initial tests to optimise equipment parameters, capture efficiency was measured during bead on plate welding in the flat and in position. Welding parameters and consumables were chosen on the basis of common usage, to make the results widely applicable. An extract rate of $80\text{m}^3\text{h}^{-1}$ was selected, which is 20 % lower than the maximum rate recommended by Nederman. Tests were also conducted whilst welding horizontal/vertical fillets. In addition to evaluating capture efficiency in a number of welding configurations, the work programme made it possible to evaluate the effects of extract nozzle position and welding position. At the same time, weld metal was examined for porosity to ensure that extracting the fume had not compromised its integrity. Other factors such as ergonomics and operability were not assessed. From the results, it was possible to draw the following conclusions:

1. Adjusting the extract nozzle to a position that would provide efficient fume extraction without compromising weld metal integrity was not a difficult operation.
2. For butt welding, the on-gun extraction system tested provided a suitable alternative to the more common captor hood based, local exhaust ventilation, as far as capture efficiency and weld metal integrity were concerned.
3. For fillet welding, the on-gun system tested can be recommended as a suitable alternative to captor hood based LEV for positional welding, but in the flat results were less clear. Further work is required to properly evaluate its effectiveness.
4. The only situations where weld metal integrity was compromised was when the extract nozzle was positioned flush with the end of the gas shroud. However this was an extreme test and the system is unlikely to be used in this manner in a real setting.
5. Optimum capture efficiency was obtained with the extract nozzle approximately 14 mm from the end of the gas shroud.
6. The capture efficiency of the on-gun system tested was generally 90 % or above when welding bead on plate, whether welding was performed in the flat, vertically up or vertically down. The capture efficiency was 74 % when welding horizontally.
7. The capture efficiency when welding in horizontal/vertical fillets was lower than when welding bead on plate. The capture efficiency was 82 and 81 % respectively when welding vertically up and vertically down. When welding in the flat the capture efficiency was approximately 60 %.
8. The on-gun system has a distinct advantage over traditional mobile captor hood based LEV systems. This is because the traditional LEV system has to be constantly repositioned, whilst for the on-gun system the extract is always close to the arc.

9 REFERENCES

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Table 10.1: Table of results for all tests

Test No	Test description	Welding condition	Current	Voltage	Fume concentration	Capture efficiency	Average
			A	V	mgm ⁻³	%	%
1	100 % extract check bead on plate inside funnel	1	133	19.4	226.85	100 % Test	
2	100 % extract check bead on plate inside funnel	1	128	19.4	219.63	100 % Test	
3	Bead on plate, in the flat, extract nozzle flush with bottom of gas shroud	1	135	19.3	267.81	120	120
4	Bead on plate, in the flat, extract nozzle 7mm from bottom of gas shroud	1	139	19.3	217.59	97	93
5	Bead on plate, in the flat, extract nozzle 7mm from bottom of gas shroud	1	138	19.3	192.04	86	
6	Bead on plate, in the flat, extract nozzle 14mm from bottom of gas shroud	1	128	19.3	240.37	108	107
7	Bead on plate, in the flat, extract nozzle 14mm from bottom of gas shroud	1	130	19.3	234.81	105	
8	Bead on plate, in the flat, extract nozzle 21mm from bottom of gas shroud	1	128	19.3	173.15	78	78
9	Bead on plate, in the flat, extract nozzle 21mm from bottom of gas shroud	1	127	19.3	171.48	77	
10	Bead on plate, in the flat	1	137	19.4	206.67	93	94
11	Bead on plate, in the flat	1	138	19.4	215.00	96	
12	Bead on plate, in the flat	1	140	19.3	225.00	101	
13	Bead on plate, in the flat	1	139	19.3	188.33	84	
14	Bead on plate, in the flat	1	128	19.4	211.9	95	
15	Bead on plate, vertically up	1	126	19.4	117.59	90	107
16	Bead on plate, vertically up	1	128	19.3	149.26	114	
17	Bead on plate, vertically up	1	128	19.3	153.15	117	
18	100% extract check, bead on plate, vertically up, inside funnel	1	128	19.4	130.74	100 % Test	
19	100% extract check, bead on plate, vertically up, inside funnel	1	128	19.4	130.84	100 % Test	
20	100% extract check, bead on plate, vertically up, inside funnel	1	127	19.4	129.93	100 % Test	

Test No	Test description	Welding condition	Current	Voltage	Fume concentration	Capture efficiency	Average
			A	V	mgm ⁻³	%	%
21	100% extract check, bead on plate, vertically down, inside funnel	1	139	19.3	193.06	100 % Test	
22	100% extract check, bead on plate, vertically down, inside funnel	1	128	19.3	176.39	100 % Test	
23	100% extract check, bead on plate, vertically down, inside funnel	1	128	19.3	185.56	100 % Test	
24	Bead on plate, vertically down	1	127	19.3	171.48	93	90
25	Bead on plate, vertically down	1	127	19.3	153.15	83	
26	Bead on plate, vertically down	1	128	19.3	171.48	93	
27	Bead on plate, horizontal	1	128	19.4	225.77	78	74
28	Bead on plate, horizontal	1	128	19.4	219.51	76	
29	Bead on plate, horizontal	1	129	19.4	197.58	68	
30	100% extract check, bead on plate, horizontal, inside funnel	1	125	19.4	289.26	100 % Test	
31	100% extract check, bead on plate, horizontal, inside funnel	1	128	19.4	277.04	100 % Test	
32	100% extract check, bead on plate, horizontal, inside funnel	1	126	19.4	301.48	100 % Test	
33a	Fillet, in the flat	1	115	19.3	145.37	94	95
34a	Fillet, in the flat	1	115	19.3	147.04	95	
35a	100 % Extract check, fillet, in the flat inside large enclosure	1	115	19.3	149.72	100 % Test	
36a	100 % Extract check, fillet, in the flat inside large enclosure	1	115	19.3	159.89	100 % Test	
33b	100% extract check, fillet, in the flat, inside funnel	1	113	19.3	121	100 % Test	
34b	100% extract check, fillet, in the flat, inside funnel	1	113	19.3	145	100 % Test	
35b	100% extract check, fillet, in the flat, inside funnel	1	113	19.3	119	100 % Test	
36b	Fillet, in the flat	1	113	19.3	72	56	62
37b	Fillet, in the flat	1	113	19.3	80	62	
38b	Fillet, in the flat	1	113	19.3	88	69	

Test No	Test description	Welding condition	Current	Voltage	Fume concentration	Capture efficiency	Average
			A	V	mgm ⁻³	%	%
39	100% extract check, fillet, vertically down, inside funnel	1	120	19.3	141	100 % Test	
40	100% extract check, fillet, vertically down, inside funnel	1	120	19.3	112	100 % Test	
41	100% extract check, fillet, vertically down, inside funnel	1	120	19.3	113	100 % Test	
42	Fillet, vertically down	1	120	19.3	103	84	82
43	Fillet, vertically down	1	120	19.3	100	82	
44	Fillet, vertically down	1	120	19.3	96	79	
45	100% extract check, fillet, vertically up, inside funnel	1	120	19.3	98	100 % Test	
46	100% extract check, fillet, vertically up, inside funnel	1	114	19.3	102	100 % Test	
47	100% extract check, fillet, vertically up, inside funnel	1	120	19.3	103	100 % Test	
48	Fillet, vertically up	1	120	19.3	85	84	81
49	Fillet, vertically up	1	120	19.3	81	80	
50	Fillet, vertically up	1	120	19.3	81	80	
51	100% extract check, bead on plate, in the flat, inside box	2	277	33.5	436	100 % Test	
52	100% extract check, bead on plate, in the flat, inside box	2	275	33.5	412	100 % Test	
53	100% extract check, bead on plate, in the flat, inside box	2	275	33.5	439	100 % Test	
54	Bead on plate, in the flat	2	275	33.5	386	90	93
55	Bead on plate, in the flat	2	275	33.5	416	97	
56	Bead on plate, in the flat	2	275	33.5	398	93	

Test No	Test description	Welding condition	Current	Voltage	Fume concentration	Capture efficiency	Average
			A	V	mgm ⁻³	%	%
57a	Fillet, in the flat	2	273	33.5	254.17	50	46
58a	Fillet, in the flat	2	273	33.5	211.09	41	
59a	Fillet, in the flat	2	274	33.5	301.67	59	
60a	Fillet, in the flat	2	273	33.5	181.98	35	
61a	100 % extract check, fillet, in the flat, inside large enclosure	2	273	33.5	537.78	100 % Test	
62a	100 % extract check, fillet, in the flat, inside large enclosure	2	273	33.5	487.78	100 % Test	
57b	100 % extract check, fillet, in the flat, inside box	2	275	33.5	494	100 % Test	
58b	100 % extract check, fillet, in the flat, inside box	2	275	33.5	452	100 % Test	
59b	100 % extract check, fillet, in the flat, inside box	2	275	33.5	375	100 % Test	
60b	Fillet, in the flat	2	274	33.5	275	62	55
61b	Fillet, in the flat	2	275	33.5	208	47	
62b	Fillet, in the flat	2	275	33.5	249	57	