2011

The influence of copper content of welding wires on the fume formation rates in gas metal arc welding of steel

N Bothma
University of Wollongong, ncb873@uow.edu.au

B J. Monaghan
University of Wollongong, monaghan@uow.edu.au

J Norrish
University of Wollongong, johnn@uow.edu.au

Publication Details
Bothma, N., Monaghan, B. J. & Norrish, J. (2011). The influence of copper content of welding wires on the fume formation rates in gas metal arc welding of steel. 6th Asian Pacific IIW International Congress and 56th WTIA Annual Conference (p. S401).

THE INFLUENCE OF COPPER CONTENT OF WELDING WIRES ON THE FUME FORMATION RATES IN GAS METAL ARC WELDING OF STEEL

Bothma N, Monaghan BJ, and Norrish J

ABSTRACT

Increases in Fume Formation Rates (FFR) of welding wires have been attributed to the fact that wires are copper coated. Instability during the welding process can have an influence on the FFR. The University of Wollongong has developed an auto control mechanism that will minimise the influence of the instability and this could be applied to more accurately determine the FFR of welding wires in the "drop-spray" mode of transfer.

KEYWORDS

Gas Metal Arc Welding, Welding Wire, Welding Fume, Fume Formation Rates, Drop Spray Transfer, Copper

AUTHOR DETAILS

Nicolaas Bothma is with BOC Australia.
Prof Brian Monaghan and Prof John Norrish are with the University of Wollongong, Australia

THE INFLUENCE OF COPPER CONTENT OF WELDING WIRES ON THE FUME FORMATION RATES IN GAS METAL ARC WELDING OF STEEL

1. INTRODUCTION

One of the most widely used welding processes for the fabrication of structural steel is Gas Metal Arc Welding (GMAW). Like most fusion welding processes GMAW generates particulate fume. This particulate fume originates either from the base material or the welding consumable [1, 2, 3, 4, 5].

In the case of GMAW the consumable is a continuously fed filler wire and it' s melting and vaporisation in the welding arc is thought to be the major contributor to the total particulate fume [6]. This filler wire is often coated with copper and may also contain traces of organic oil or drawing lubricants.

Several researchers has studied the differences in the Fume Formation Rates (FFR) of copper coated and 'uncoated' filler wires and have claimed that the FFR of the copper coated wire was substantially higher than the uncoated wire [7,8,9].

In previous studies a fixed set of welding parameters and a common shielding gas were used. Wires were however selected on the basis of diameter of the wire, whether they are coated or uncoated, or on their total copper content. In many of the reported investigations the consumables are from different manufactures and there is little information on the core wire composition or surface treatment during production. The copper content reported in the analysis of welding wire is usually a reflection of the total copper content of the wire and includes the amount of copper in the base material as well as the copper contained in the surface coating of the wire [10,11].

Another potential source of error in previous work is batch to batch variation of copper content of the filler material. An initial review of existing analytical data on the variation in copper content of a single consumable over a 1 year period was obtained. This represents 1500 tonne of welding wire. The wide variance in the copper content of the wire can be seen in Figure 1 [20]

The variation in copper content of the wire was between 0.005% and 0.094% and in fact the total copper content of coated wires can be lower than that of some of the uncoated wires commercially available.

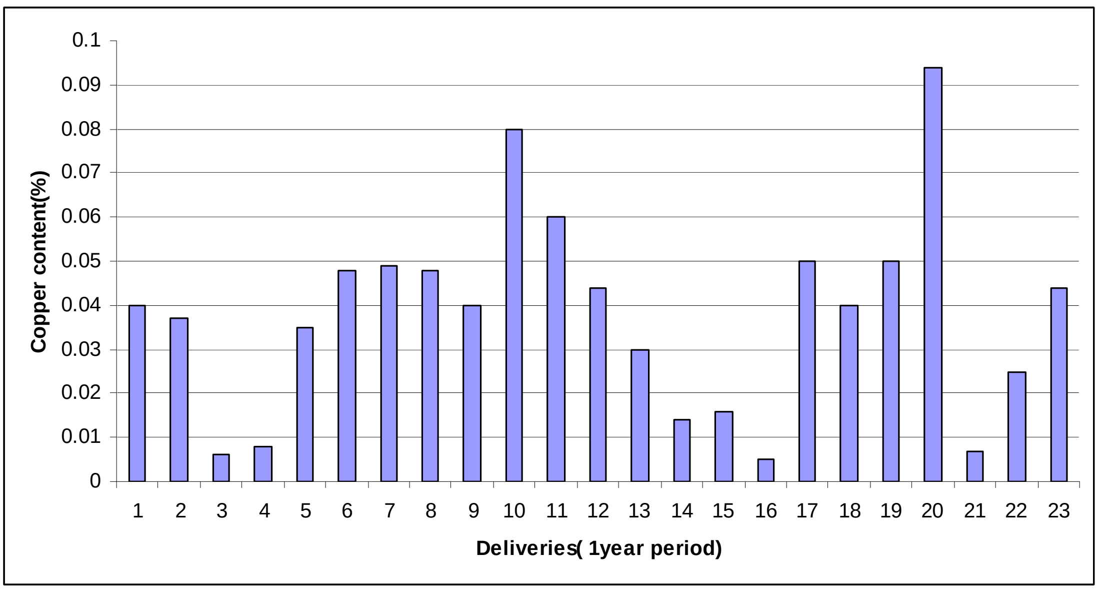


Figure1 Variation in copper content (% Cu) of welding wires delivered in 23 shipments over a 1 year period.[20]

The present investigation set out to explore the fume generation rate variations using a single cast of core wire with a variety of surface treatments under very carefully controlled experimental conditions

2. EXPERIMENTAL METHOD

Unlike these previous investigations the work reported in the following study used wires from the same cast of base material and known primary manufacturing route in an attempt to determine the influence of differences in copper coating on the FFR. However an 'uncontrolled group of welding wires, similar to those used in previous studies were also studied to illustrate the points made above.

Two sets of experimental trials were undertaken:

1) Samples from 6 different suppliers of welding wire were selected for the initial testing. This included both copper coated and non coated wires of two different diameters. The base material chemical compositions of these wires were not the same although all wires conformed to the AWS specification (A5.18-2001 Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding) [21] for welding wires. These trials are referred to as the "Uncontrolled sample group"

2) Three samples of the same diameter wire from the same manufacturer, the same base material composition and known processing route were obtained for the second series of testing. These trials are referred to as the "Controlled sample group"
In these second trials the processing route of the wires was exactly the same, with the only difference being in the final coating of the wire. Two samples were copper coated and the third left uncoated. One of the copper coated wires was polished after coating to reduce the coating thickness.

Both sets of wires were chemically analysed.

A fixed 'target' set of welding parameters (voltage, wire feed speed, arc length) was selected to compare all wires (Table 1)

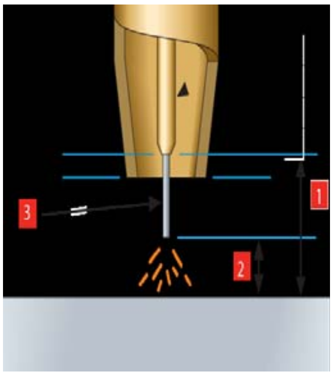
Table 1: Welding parameters used for all wires

	0.9mm	1.2mm
Wire Feed speed (WFS) m/min	11	8
Voltage (V)	31.6	31.5
Current (A)		
Contact tip to work distance (CTWD) mm	20	20
Shielding gas	Ar/18 CO_2	Ar/18 CO_2

Gas metal arc welding (GMAW) was performed using a Fronius Trans Synergic 4000 power source coupled to a Cigweld Trans Robot WS 0550 welding robot. (see fig 1)

The welding robot was programmed to produce a constant contact tip to work distance of 20mm and the welding parameters were selected to be as close as possible to the "drop-spray" transfer mode region. The drop-spray mode of metal transfer, occurs in the transition region between globular and spray transfer modes and a minimum in FFR at this transition has been widely observed [5].

Welding was carried out in a modified fume box on a ground C-Mn steel plate and the bead length was equal to 225 mm. (This bead length equated to 20 seconds of welding.)



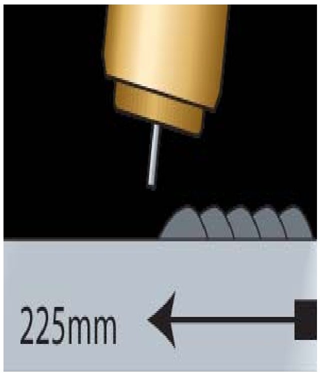


Figure 2a Figure 2b Figure 2c

Figure 2a shows the experimental setup with the torch in position and the fume hood removed.
Figure 2b illustrates the setup of the Mig torch {1 Contact tip to work distance 25mm}
{2 Arc length 5mm}
{3 Consumable electrode}
Figure 2c illustrates the direction of travel and the weld bead length obtained in 20seconds of welding

Fume was collected on a Pall A/E glass filter with minimum pore size of 1µm. Each filter was weighed before and after welding on a Sartorius balance (with an accuracy of 0.000g). Each measurement was repeated three times and the average Fume Formation Rate reported.

The chemical analysis of the “Uncontrolled sample group” is given in Table 3.From this table it can be seen that there are significant differences in the chemical analysis of the welding wires and in particular the copper content.

Table 2; Chemical analysis of the “Controlled group” of welding wires. The difference in Copper content is as a result of the surface coating

	AWS SPECIFICATION	**“C” 70S-6 COPPER COAT #1**	**“C” 70S-6 COPPER COAT #2**	**“C” 70S-6 COPPER FREE**
C*	0.06-0.15	0.07	0.07	0.07
S*	0.035 max	0.008	0.008	0.008
P	0.025 max	0.012	0.012	0.012
Mn	1.40-1.85	1.55	1.56	1.55
Si	0.8-1.15	0.84	0.85	0.84
Ni	0.15max	0.006	0.006	0.006
Cr	0.15 max	0.018	0.019	0.018
Mo	0.15 max	0.001	0.001	0.001
Cu	0.5 max	0.083	0.13	0.001
Al		0.003	0.003	0.002
Sn		<0.001	<0.001	<0.001
Nb		0.001	0.001	0.001
Ti		0.015	0.016	0.015
V	0.03 max	0.004	0.004	0.004

These wires were obtained from a single supplier and from the same cast of steel rod as confirmed by the chemical analysis. The different results in the copper content are a result of the surface treatment of the wire

Table 3 Chemical analysis of the “Uncontrolled sample group”. Large variances in the copper content can be observed whilst elements such as the C, Mn and Si levels are much closer controlled [12]

	AWS SPECIFICATION ER 70S-6; A5.18-90	A SM-70	B ARISTOROD	C 70S-6 COPPER COAT	D COPPER COAT	E LW1 COPPER COAT	C 70S-6 COPPER COAT	F UNCOATED
Diameter		1.2mm	1.2mm	1.2mm	0.9mm	0.9mm	0.9mm	0.9mm
C*	0.06-0.15	0.07	0.07	0.07	0.06	0.07	0.06	0.07
S*	0.035 max	0.016	0.015	0.008	0.02	0.007	0.024	0.014
O$^{\#}$		0.015	0.009		0.008	0.004	0.018	0.018
N$^{\#}$		0.006	0.003		0.007	0.008	0.01	0.005
P	0.025 max	0.011	0.012	0.005	0.009	0.015	0.015	0.015
Mn	1.40-1.85	1.49	1.46	1.48	1.43	1.44	1.42	1.45
Si	0.8-1.15	0.85	0.87	0.94	0.77	0.84	0.81	0.85
Ni	0.15max	0.012	0.023	0.013	0.044	0.053	0.046	0.019
Cr	0.15 max	0.053	0.045	0.016	0.024	0.061	0.027	0.042
Mo	0.15 max	0.001	0.008	0.015	0.007	0.008	0.007	0.005
Cu	0.5 max	0.011	0.043	0.11	0.34	0.28	0.13	0.033
Al		0.004	0.001	0.003	0.001	0.004	0.004	0.002
Sn		<0.001	0.002	<0.001	0.007	0.01	0.002	0.002
Nb		<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001
Ti		0.004	0.001	0.015	0.002	0.001	0.001	0.001
V	0.03 max	0.001	0.001	0.005	0.002	<0.001	<0.001	<0.002

3. RESULTS

The Fume Formation Rate of the “uncontrolled sample group” was determined using the technique described above and the results are given in Table 4

Table 4: Fume formation rate of “Uncontrolled sample group” of welding wire.

Wire Sample/ Wire diameter	Surface coating	Mass of fume collected in 20 sec welding (ave of 3 measurements (g)	Fume Formation Rate (g/min)
“A” SM-70 1.2mm	Copper Free	0.093	0.279
“B” 12.5 1.2mm	Copper Free	0.118	0.354
“C” 70S-6 1.2mm	Copper coated	0.129	0.387
“D” 70S-6 0.9mm	Copper coated	0.083	0.249
“E” LW1-5 0.9mm	Copper coated	0.086	0.258
“C” 70S-6 0.9mm	Copper coated	0.075	0.225
“D” 0.9mm	Copper Free	0.062	0.186

From Table 4 it can be seen that the FFR rate of the copper coated wires in both diameters were higher than the FFR of the uncoated wire. In the case of the 1.2mm wire the FFR of the “B” copper coated wire was 38% higher and for the 0.9mm wire the FFR of the “E “copper coated wire was 34% higher than the equivalent copper free wires from the same manufacturer. It should be noted that fume measurements are for total particulate fume not just the copper fraction.

The FFR of the “Controlled group” of welding wires were determined in the same manner as the trials conducted on the uncontrolled group and fume generation results are given in Table 5.

Table 5 FFR of “Controlled group” welding wires.

Wire Sample/ Wire diameter	Surface coating	Mass of fume collected in 20 sec welding (ave of 3 measurements (g)	Fume Formation Rate (g/min)
“C” 70S-6 1.2mm	Copper Free	0.129	0.387
“C” 70S-6 (1) 1.2	Copper Coated	0.153	0.459
“C” 70S-6 (2) 1.2mm	Copper coated	0.179	0.537

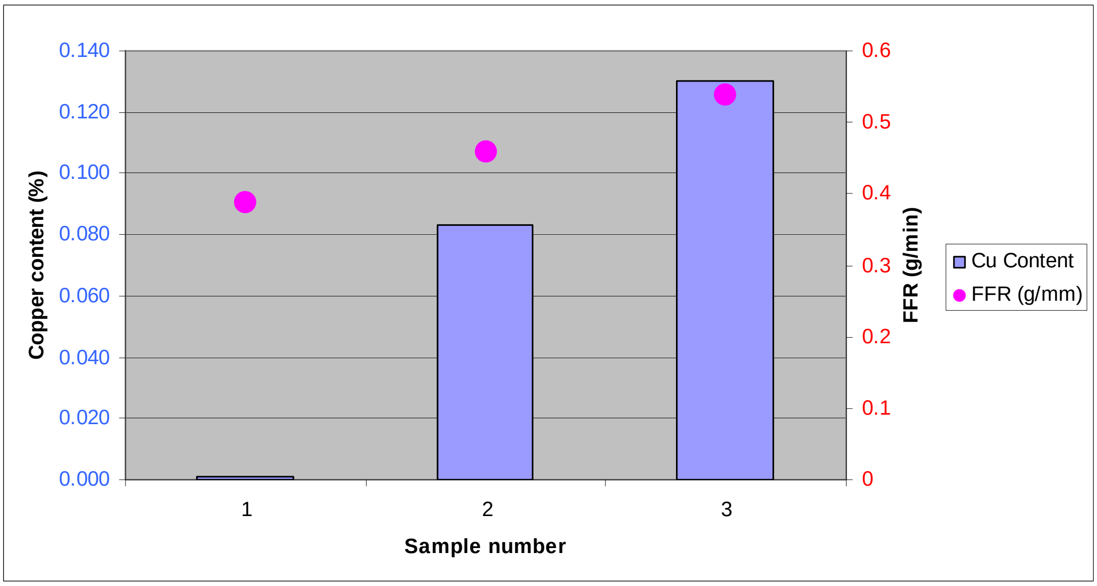


Fig 3 Fume formation Rate results versus copper content of sample wire

From Figure 3 it can be seen that, again the FFR of both the copper coated wires were higher than that of the uncoated wire, in this case by 18.6% and 38.8 %.

5. DISCUSSION

5.1 Transfer mode instability

A fixed set of welding parameters (refer Table 1) were used for all of the FFR determination of all wire samples. The parameter set depended only on the wire diameter. These welding parameters were chosen to approach the “drop-spray” mode of metal transfer. This mode of transfer is a transition between globular and spray transfer and represents an area of minimum FFR [13,14,15,16]

During testing of the wires some instability in the metal transfer was noticed. In practice this would have been overcome by experienced welder manipulating the arc length. This instability would be expected to lead to a change in the FFR as the arc voltage changes have an influence on the mode of metal transfer, which is associated with the FFR.[17,18]. Currently most published FFR research uses a fixed set of welding parameters and has this limitation. It is intended to use the approach developed by Carpenter et al [17] to assess FFR under optimum (non-fixed welding parameters) in a future study.

5.2 Effect of copper on the FFR of welding wires.

Copper is present in all C-Mn welding wires and most of the International standards only specify a total copper content [19] in welding wires this copper value is a combination of the copper in the base material and copper that is added by the electrolytic copper plating process that is performed on all copper coated wires.

As shown in this study the copper content of copper coated wires may vary significantly from one batch to another. In previous research work into the determination of FFR of different welding wires no consideration was given to the differences in base material of welding wires and in particularly the copper content and the conclusion that ’copper coated’ wires produced up to 30% more total particulate fume than uncoated wires was based solely on the application of the copper coating.

The results of the “Uncontrolled sample group” confirmed the fact that coated wires produce more fume than uncoated wires. Although in this sample group the total copper content of all wires were known the contribution of the copper coating to the total copper value is unknown. The base metal chemistry also varies in several other aspects. Based on this the increase in FFR cannot conclusively be attributed to the copper coating alone.

In the determination of the FFR results of the “controlled sample group” the increase in copper content can be accurately determined as the base metal copper value and the overall chemistry known to be identical. Using these trials it can be seen that:

The FFR of the two copper coated wires are higher than the uncoated wire, however the increase in FFR is not directly proportional to the increase in copper content.(Table 6)

Table 6 % Increase in Fume Formation rate of wire measured against the copper free wire for the ‘controlled ‘ group of wires

Sample	% Copper	FFR g/min	Increase in copper content (as measured against the copper free sample	Increase in FFR(as measured against the copper free sample)
“C” 70S-6 Uncoated	0.001	0.387		
“C” 70S-6 Copper Coated #1	0.083	0.459	0.082 8200%	0.072 18.6%
“C” 70S-6 Copper Coated #2	0.13	0.537	0.129 12900%	0.15 38.8%

6. CONCLUSION

Increases in FFR of welding wires have been attributed to the fact that wires were copper coated. This study has proven that although an increase in the FFR of copper coated welding wires do occur this increase is not directly proportional to the increased copper content of the wire.

Further research is needed to determine the effect that copper has on the mechanisms that lead to fume formation during welding.

Instability during the welding process can have an influence on the mode of transfer, which in turn will have a influence on the FFR. The University of Wollongong has developed a Auto control mechanism [8] that will minimise the influence of the instability and this could be applied to further research to more accurately determine the FFR of welding wires in the “drop-spray” mode of transfer

7. REFERENCES

[1]. Investigation of fume formation mechanisms in GMAW by R Deam, I Haidar, J Lowke, J Norrish, J Tyagi and A Workman 1997 Proceedings of the Technological Developments and Advances for Australian Industry, International Welding and Joining Research conference

[2]. Particulate fume generation during gas metal arc welding by M Thorton and I Stares

[3]. An investigation of particulate weld fume generated from the GMAW of plain carbon steel by Z Sterjovski, J Brossier, E de Thoisy, D Cuiuri, J Norrish and B J Monaghan

[4]. Effects of welding process parameters on fume emission in gas metal arc welding by K Yamazaki, E Yamamoto, K Suzuki and F Koshiishi of the Kobe steel Welding company

[5]. n-Situ measurement of metal droplet temperature in gas metal arc welding by two-color pyrometry by K Yamazaki, E Yamamoto, K Suzuki and F Koshiishi of the Kobe steel Welding company

[6]. Effect of arc welding electrode temperature on Vapour and fume composition by N T Jenkins, P F Mendez and T W Eager

[7]. Estimation of exposure to arc welding fume by G J Carter

[8]. SE wire: A high performance, non-copper-coated solid wire for MAG welding published by The Kobelco wire company

[9]. The influence of small variations of wire characteristics on gas metal arc welding process stability by P J Modenesi and R C de Avelar

[10]. Copper levels in welding wire published in Welding in the world vol25, No ¾, pp 60-62

[11]. Systems approach to the control of welding fumes at source by P J Hewitt and A A Hirst

[12]. AWS A5.18 – 2001 Specification for Carbon steel Electrodes and Rods for Gas Shielded Arc Welding

[13]. Fume characteristics – the effects of arc welding practice by Graham Carter a TWI Technology briefing 736 – 2002

[14]. Particulate fume plume distribution and breathing zone exposure in gas metal arc welding by J Norrish, G Slater, P Cooper November 2005 University of Wollongong

[15]. Material transfer in MIG welding with CO_2/Argon shielding gases by Gerd Huismann,HSU, University of Federal Armed Forces, Hamburg Germany IIW document Doc.212-1156-09

[16]. The mechanism and significance of drop spray transfer in GMAW by I Richardson, J Norrish and M Hermans

[17]. Optmising the Welding conditions to determine the influence of shielding gas on Fume formation rate and particle size distribution for gas metal arc welding by K R Carpenter, B J Monaghan, A Nicholson, D Cuiuri and J Norrish

[18]. Influence of shielding gas on fume size morphology and particle composition for gas metal arc welding by K R Carpenter, B J Monaghan and J Norrish

[19]. 19) A Model for prediction of fume formation rate in Gas Metal Arc Welding (GMAW), Globular and Spray modes, DC electrode positive by J.H. Dennis, P.J. Hewitt, C.A.J.Redding and A.D. Workman

[20]. Manufacturer' batch certificates, C-Mn welding wire, BOC archives

[21]. AWS specification AWS A5.18-2001 Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding, published by the AWS organisation