Strategies for Risk Assessment and Control in Welding: Challenges for Developing Countries

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Metal arc welding ranges from primitive (manual) to increasingly complex automated welding processes. Welding occupies 1% of the labour force in some industrialised countries and increasing knowledge of health risks, necessitating improved assessment strategies and controls have been identified by the International Institute of Welding (IIW), ILO, WHO and other authoritative bodies. Challenges for developing countries need to be addressed. For small scale production and repair work, predominantly by manual metal arc on mild steel, the focus in developing economies has correctly been on control of obvious physical and acute health affects.

Development introduces more sophisticated processes and hazards. Work pieces of stainless steel and consumables with chromium, nickel and manganese constituents are used with increasingly complex semi-manual or automated systems involving variety of fluxes or gasses. Uncritical adoption of new welding technologies by developing countries potentiates future health problems. Control should be integral at the design stage, otherwise substantive detriments and later costs can ensue. Developing countries need particular guidance on selection of the optimised welding consumables and processes to minimise such detriments.

The role of the IIW and the MFRU are described. Applications of occupational hygiene principals of prevention and control of welding fume at source by process modification are presented. © 2001 British Occupational Hygiene Society. Published by Elsevier Science Ltd. All rights reserved

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INTRODUCTION

Metal arc welding covers a range of processes involving different consumables such as rods or wires, various fluxes or shielding gases and hardware such as power sources and wire feeder systems. Manual metal arc (MMA), utilising a metal rod typically coated with a mixture of chemicals providing a flux to minimise oxidation and facilitate welding, is perhaps the simplest and most widely used process in developing countries, both for construction and especially repair work. Developed economies increasingly rely on semi-automatic or automatic processes such as metal inert gas (MIG) or similar, whereby a consumable wire electrode is used with a range of shielding gases. A common variant is to use wire with a core containing flux. Such flux-cored arc welding (FCAW) may also involve the use of shielding gases. Processes are selected primarily with regard to metallurgical, efficiency and economic criteria. The health hazards of particulates and gases emitted during such processes are well documented and are not rehearsed here (Hewitt, 1999a).

Traditionally, control of fumes and gases has been by enclosure and local exhaust ventilation (LEV); respiratory protective equipment (RPE) may also be necessary in certain circumstances, in particular in confined spaces. In accordance with good occupational hygiene practice, increasing attention has been paid to the investigation and development of consumables with minimum fume emissions and for the selection of process parameters which minimise emissions. Control at source by process modification has particular advantages in developing countries, where there are limitations on the health and safety infrastructure and on the availability of appropriate control technology compared to those in developed economies.
CHALLENGES FOR DEVELOPING COUNTRIES

The global economy and speed of technological innovation has minimised national boundaries. Improved communications, political factors and the economies especially of outsourcing have resulted in a shift of many manufacturing processes into formerly undeveloped areas. Attracted by low labour costs and in some cases different regulatory regimes, production units in light and heavy engineering are transferring from developed to developing countries. Specifically in relation to welding the ongoing and former repair work normally involving MMA has given way to volume manufacture with the emphasis on automated welding processes.

Not only the production processes themselves involving welding have been transferred but also the production of consumables in some cases. Constituents of welding consumables may include thorium, barium, manganese and other compounds. The production processes may give rise to emissions, for example, of fluorides and/or waste products which need careful environmental management. Good practice in consumable manufacture in terms of minimising environmental impact (as well as controlling risk to the workforce) is followed by responsible companies. As a focus for such companies and interested parties, the International Institute of Welding (IIW) has recently established an Environmental Group. Pollution exporting to developing countries is clearly unacceptable. Equally unacceptable is the uncritical imposition of sophisticated welding processes into a country without due consideration of the infrastructure in terms of management, health and safety awareness and organisation and the availability of at least minimal health surveillance.

Reflection on the potential efficacy of hardware and software control strategies is necessary. With a trained workforce and well established safety culture, attuned to adherence to prescriptive procedures, quality control and record keeping, greater reliance can be placed upon administrative or software control than where the workforce is untrained and unstructured, where the emphasis must be on engineering control. In the latter case, there is increased benefit in utilising the least hazardous consumables, even where these may carry initial financial and technical apparent constraints. These are more than offset by the risk reduction, so that less hardware control in the form of a containment and ventilation is necessary. As a corollary of the lack of safety structure and culture, risk assessment in developing economies may be inadequately carried out. Occupational health support, which in a developed economy would quickly identify shortfalls in the risk assessment or control, is often absent or deficient in developing countries. Of the many examples, the establishment of automobile manufacturing plants in new locations has been satisfactory only when there is a commitment to work-force education and training. Under these circumstances, in addition to technical training for the job function, workers may benefit from increased health and safety awareness and infrastructures. In other situations such benefits are not apparent.

The challenges for developing countries and for those countries which are exporting technologies into them, is to be aware of the cultural, economic and other differences, so that the workers’ health and environmental considerations are responsibly dealt with.

INTERNATIONAL INSTITUTE OF WELDING

The activities of the ILO and the WHO are addressed in other papers. The international organisation with particular interest in welding is the International Institute of Welding (IIW), which amongst its various commissions includes Commission VIII (Health and Safety of Welding). The IIW has an international role in respect of all aspects of welding and is made up of national delegates and experts from over 40 countries. Within Commission VIII many countries, including developing countries, are represented. Commission VIII monitors publications and national activities in relation to health and safety and publishes guidance as appropriate. Concerns such as respiratory problems, cancer risk, ergonomics as well as acute physical injuries are addressed. A useful forum therefore exists for comparison and for exchange of information pertaining to health and safety, with particular reference to assessment and control. Amongst the many publications is a series of fume information sheets highlighting the hazards and indicating control strategies for various types of welding processes. Other publications include statements on cancer risk in arc welding (IIW, 1992), on health aspects of the use of thoriated tungsten electrodes (IIW, 1993) etc.

Individual experts provide perspectives which can be valuable for developing countries — for example, Gorbacht et al. (1998) report that welders in Russian shipyards may use up to 40 tons of electrode per year and that welding may occupy 30–40% of the man hours involved in ship hull preparation. In the interests of improving worker protection, product and process modification can have significant effects. Changes in welding consumables and technology between 1960 and 1990 resulted in considerably reduced emissions. Understandably, the maximum emissions and worker exposure occurred from MMA welding, whilst increased automated processes and the incorporation of LEV result in dramatic reductions (Fig. 1). The lesson from this illustration is common to many processes involving welding, and it is that a systems approach, taking into account consumables, processes, containment and ventilation together with administrative factors, need to be used for optimisation.
In a thoughtful review, presented to the 1999 IIW Conference on The Human Factor and its Environment, Lyttle (1999) demonstrated, as the paper’s title implied that decreased fume increased productivity, and that optimised consumables selection led to an improved working environment and reduced welding costs. The original paper should be consulted for details; sufficient to say that, as described in the Russian shipbuilding report, serious attention to process modification can have economic benefits as well as providing greater protection for the welder.

OPTIMISATION BY PROCESS MODIFICATION

Research into the mechanism of fuel and gas formation is an essential prerequisite to proposals for process modification. The MFRU at the University of Bradford (UK) in cooperation with other research groups, including the Universities of Wollongong (Australia), have addressed these matters in many publications. In terms of fume, both the amount of total fume emitted per unit time (FFR) and the unit mass of consumable (FGR), and the composition of the fume, are important. Based upon fundamental research, models have been proposed and validated for the prediction of fume formation rate and of fume composition (Workman et al., 1997). The effects of process modifications can then be assessed.

Power input can influence the FFR and the composition of fumes and gases produced, but the relationships are complicated. In essence the welding mode changes with increasing voltage. Dip transfer or submerged arc occurs at low voltages and with minimal fume production. Higher voltages may be necessary for increased deposition rate, with a consequential increase in fume. Nevertheless, expedients such as utilising stabilised power sources can reduce spatter, producing improved weld quality as well as minimizing fume.

In relation to MMA and FCAW the mechanisms of flux in terms of fume emissions are not fully understood and are complex, with certain unstable fluxes exacerbating fume, whilst others minimise spatter, or bind up metals, producing slags. Sodium silicate, used historically in many MMA fluxes, can be replaced by lithium compounds, with the effect of minimising both fume emissions and hexavalent chromium compound emissions. Addition of less than 1% zinc to the flux in FCAW can have dramatic affects on hexavalent chromium and ozone emissions. (Dennis et al., 1996) Selection of optimum electrical parameters and variation in the flux concentration in the core can dramatically affect manganese loss. For example, in one series of tests producing constant weld composition and deposition rate, most fume occurred with metal core 40 V electrode negative FCAW; but reduced to a third of the fume when cored wire of 8% flux and 29 V electrode positive welding were used (Hewitt, 1999b). The shielding gas used for MIG may be helium or argon, or mixtures of these with, for example, carbon dioxide. Reducing the oxygen content of the shielding gas and/or variation of the CO2 content (with minimum emission at 5% CO2) allow a selection of the shield gas which produces minimum emissions compatible with attaining the desirable metallurgical end point.

A systems approach, combining of attention to consumable, the equipment and control systems in a particular situation is necessary for optimisation of process modification for control (Hewitt, 1994). Details are presented in copious publications of the MFRU and some process modifications options are presented in Table 1.

CONCLUSION

Developing countries are increasingly being drawn within the global economy. Transfer of technologies such as welding from developed economies into those which do not have similar infrastructures in terms of health and safety may be disastrous. On the basis of established occupational hygiene good practice, reliance should not be placed upon add-on controls. Rather, a systems approach should be adopted whereby the least hazardous consumables and power
Table 1. Process control options for minimising fume

**MIG**
- Select welding mode (voltage) to minimise spatter
- Select shield gas to facilitate smooth metal transfer
- Use modern power sources allowing good control of electrical parameters
- High purity wires including surface (avoid Na lubricants)
- Optimise oxygen in primary shield gas
- Minimise oxygen in macro environments
- Optimise gas flow rate
- Minimise u.v. and hence ozone and Cr6
- Have essential toxic volatile metals in workpiece not electrode

**MMA**
- Take note of modifications of principles above
- Adjust power sources and parameters to minimise spatter
- Use minimum practicable current and voltage
- Select fluxes which ensure minimum oxygen in micro and macro environments
- Use stable fluxes of low toxicity (eliminate Ba, F etc.)
- Eliminate Na from flux. Use other cations in binders.
- Note enhanced fume and Cr6 with Na sources are selected. By this strategy, which is particularly appropriate for developing countries, the deficiencies in terms of infrastructure and available hardware controls can be compensated for. The benefits of such an approach can be economic but more particularly, in the context of this paper, can provide inherently safer processes to an otherwise vulnerable workforce.

Technology transfer into developing countries must be done with a sensitivity to the social and economic constraints therein. Developing countries need particular guidance on selection and optimised welding consumables and processes to minimise detriments. Process modification in welding has demonstrable benefits. It minimises reliance on administrative contr-ols and on costly hardware solutions later. It does not reduce the necessity for suitable and sufficient risk assessment but it undoubtedly simplifies this. The benefits of process modification are increasingly recognised and with improved communications should allow safer technology transfer.

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