Welding research and development in Australia

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ABSTRACT

The role of the WTIA as the premier welding organisation in Australia is outlined. In 1992, Australia introduced a unique concept for cooperation in research and development. Over 60 Cooperative Research Centres (CRCs) were established covering a wide range of technologies and industries. The objective was to link key research centres, working in a collaborative manner on research projects to meet the needs of industry. The CRC for materials welding and joining was formed in 1992 and a new application for a further 7 years of funding for an expanded CRC for Welded Structures is presently being made to Federal Government. This paper highlights key research strategies and projects undertaken by the group as well as a unique network of technology support centres providing technology transfer to industry, particulary small and medium enterprises. Examples of research outputs will illustrate the success of this collaborative strategy in which Federal Government provides a $2.2m grant p.a., which needs to be matched by industry contributions as well as in-kind contributions from the core partners. Industry sectors deeply involved in research projects include pipelines, power generation, petro-chemical, steel production and automotive. The CSIRO also undertakes a significant amount of research work in its own right.

Key words : *WTIA, CRC for materials welding & joining, CSIRO.*

INTRODUCTION

The objective of this paper is not to give a comprehensive review of the welding industry and welding technology in Australia but an insight into some of the activities that are taking place in relation to research and development.

The main organisation covering the widest range of welding related activities in Australia is the WTIA. It has approximately 400 company members and 1400 personal members and all other welding related organisations are somehow connected with it.

In July 1995, the WTIA completed its 5 year business plan 91/1/96 - 31/12/00 after involving 55 people from 26 different organisations in its strategic planning; what has been achieved so far is way beyond anyone's expectations.

In October 1995, an extensive welding industry needs analysis [1] was undertaken and this confirmed the role of WTIA as being :

- ❑ Provision of Technical Services
- ❑ Certification of Personnel
- ❑ Technology Transfer
- ❑ Education and Training
- ❑ Development of Standards and Procedures
- ❑ Technical Consultation and Referral
- ❑ Development of Industry Research Needs
- ❑ International liaision

Australia is an island continent the size of the United States with vast open spaces, and only 18 million people settled mostly on the coastal fringe, particularly to the south. So how can one ensure that all those people involved in the welding industry, wherever they may be located, have access to the latest technology and thus the opportunity to build a world class business ? This has called for unique solutions.

Cooperative welding research [2]

In 1992, the Australian Federal Government introduced a new concept for collaborative research amongst the relevant organisations in Australia. Known as the Cooperative Research Centre (CRC) programme, more than 70 CRCs have been established covering a wide range of industries and technologies.

One of these was the CRC for Materials Welding and Joining which is just completing its 7 year period of Government financial support. Its cooperative partners are :

ANSTO in addition to its skills and resources in materials and non-destructive testing has substantial capabilities in structural mechanics, life assessment, and risk management.

BHP is a world leader in steel metallurgy including welding metallurgy with interests in oil, gas and mining as well as steel;

WTIA has deeply rooted linkages into industry and provides an ideal technology transfer agency. As part of its dynamic growth, WTIA has recently established a Technology

Support Centres network which adds considerably to its capabilities to interact with the broad base of Australian industry;

CSIRO has extensive facilities and skills across the whole field of welding metallurgy and processes as well as strong groups covering the fields of polymer science and corrosion;

The University of Adelaide has considerable strength in metallography, higher education and specialised competence in non-fusion welding processes;

The University of Wollongong has excellent educational competence, engineering and welding processes expertise. A broad range of capabilities exist in the Departments of Materials, Mechanical, Electrical and Civil Engineering;

The CRC incorporates a strategy for developing international linkages with companies and research organisations that could provide substantial benefit to Australia.

It already has international linkages with 14 universities, organisations and companies involved with welding and joining in 8 of the world's major industrialised nations. These connections include visits and secondments both by staff and students, contributions to research projects, and annual visiting Professorships to Australia by world authorities on welded structures.

The linkages include TWI in the UK, University of Ghent in Belgium, Nippon Steel and University of Osaka in Japan, KAIST in Korea, Harbin in China, NOVA in Canada and Colorado School of Mines in the US.

A new application for a CRC for Welded Structures is presently under consideration by the Federal Government. This new CRC will deal with research and development of welded components at all stages, from conceptual design through to decommissioning. New industry sectors becoming involved include offshore oil and gas, defence and welding equipment. This expanded CRC will involve 7 new partners. These are :

Pacific Power has modern facilities and expertise at their Advanced Technology Centre for work in the area of life assessment of welded structures operating at high temperatures and brings direct access to the power generation industry;

The University of Sydney has world class facilities for the static and dynamic testing of large scale structural components. It will also bring complementary expertise in the areas of arc weld metal transfer and welding monitoring and control systems.

The involvement of APIA helps to secure the continuation of the existing level of research undertaken for the pipeline industry, and provides a platform for growth because of that industry's demonstrated need for research activities in areas beyond welding and joining;

The centre for Oil and Gas Engineering (COGE) at the University of Western Australia provides opportunities for access to the oil and gas industry sector and will in addition provide a base for interaction with other user groups in Western Australia;

DSTO provides linkages to companies working on the construction of major defence platforms for Army, Navy and Air Force, as well as the through life refits and upgrades necessary to keep these platforms operational, eg COLLINS submarines, ANZAC frigates, Minehunters Inshore, Infantry Mobility Vehicles and Light Armoured Vehicles;

The addition of CIGWELD provides opportunities for quick-to-market commercial exploitation of significant welding equipment related IP developments. CIGWELD is an exceptionally well managed organisation which is expanding rapidly around the world since it became part of Thermadyne. It is especially active in the Asia Pacific region.

Industry sectors

The various industry sectors that interest the CRC are identified below.

Pipelines industry sector : The Pipelines research program of the existing CRC was independently assessed as providing returns in excess of $113 million based upon a conservative evaluation of the benefits. The new program has been assessed by the same independent process and the returns are expected to considerably exceed $130 million. A substantial proportion of these savings are expected to accrue from a project concerned with the provision of data which will quantify the risk of external interference. This will lower the cost of new pipelines by allowing the pipeline to be designed for the identified threat. For existing pipelines that are affected by increased operational risk from increased urban development along the pipeline route, the research is expected to significantly reduce cost and significantly increase safety, by providing the appropriate safety enhancements at the correct location. These savings will increase with time because urban growth continues to impact upon more pipelines.

Joining equipment industry sector : The Australian arc welding equipment market is estimated to be worth $80 million per annum. The total turnover of Australian businesses that use welding is $46 billion, and the value attributed to welding is $5 billion in 5,500 establishments employing some 280,000 people. Worldwide the estimated sales of arc welding equipment are $8 billion.

The Joining Equipment Industry Sector research program has identified the prospect of developing specific new and improved volume selling products that are within the product line responsibility of CIGWELD, which is the Australian welding equipment manufacturing and exporting arm of the US company Thermadyne. Thermadyne operates on a worldwide basis.

The involvement of CIGWELD as a Core Partner in the CRC for Welded Structures will contribute to the quality of management and the industrial relevance of the research program. It will also provide quick worldwide market opportunities for already identified items of product technology. Under this structure the research will be market led with realistic commercial constraints, and has strong prospects of adding jobs in the elaborately transformed manufactures sector of the Australian export economy.

Power generation and petrochemical plant industry sector : Deregulation of the Power industry in Australia has resulted in greater uncertainty in the reliability of high temperature plant due to increasing trends to thermally cycle critical equipment to meet the commercial requirements of the market place. This, along with the need to increase the life of existing assets, establishes a clear need for R&D to validate accurately the parameters that are used to estimate damage accumulation and predict accurately the remaining life of critical components.

Currently, expenditure of $1.2 million per year in Australia is directed towards R&D into life assessment and life management of critical power plant. The provision of increased R&D funding into this area would have significant cost benefits with potential savings of up to 10% of production costs for a typical power producer as a result of an increase in the reliability of power plant and an extension in the life of existing assets. Through the application of this research, savings of the order of $150 million per year could be achieved for the Power industry and the Petrochemical industry, which would also be a major beneficiary of additional R&D funding into the life management of plant operating at high temperatures and pressures.

Transport industry sector : The Transport Industry Sector research program is highly diverse and contains a number of markets in which there are clearly demonstrable research opportunities, but which for various reasons have traditionally been difficult to penetrate.

A good example of the opportunity is the aluminium shipbuilding industry which has an annual production value of some $600 million. A typical large fast ferry costs approximately $80 million and contains some 22 tonnes of weld metal of which some 30% might be in excess of the design requirements. In addition to this, the shape of the welds is in many cases sub-optimal and slight improvements could be shown to provide major improvements in fatigue performance and hence vessel life and sea-keeping qualities.

Mining industry sector : Australia is a major producer and exporter of coal, alumina, iron ore and other minerals. The maintenance costs associated with these activities are extremely large, and can be gauged by the fact that in the coal mining industry the total maintenance costs are of the order of $10 per tonne of coal produced, which is about 20% of the selling price of the product. The machinery maintenance costs constitute about half of this figure and involve substantial welding activities in the repair of fatigue cracking and in replacement of worn surfaces.

This is reflected in the fact that Australia is the world's largest per capita user of welded hardfacing consumables. The CRC has already produced major benefits from group sponsored research into the optimisation of welding procedures for the deposition of hardfacing.

A reduction in maintenance costs of 5% or $0.50/tonne would lead to savings of around $1.5 million per mine in the coal mining industry alone. On this basis the prediction of annual savings of more than $10 million per annum across the mining industry from CRC-WS activities is a very conservative estimate, and even allowing for risk and discounted future returns would have an economic benefit of at least $60 million over the life of the CRC.

Building industry sector : There is currently a strong push throughout the world for the adoption of higher strength structural steel sections in the building industry. The industry is highly competitive, and this competition is particularly intense between different materials e.g. between reinforced concrete and steel.

The limited research which has been performed so far on the welding of the very leanly alloyed cold formed high strength steels which are beginning to be used, has shown the potential for fracture in the heat-affected-zone of welded connections.

These fractures pose risks to the structural integrity of welded cold-formed structures. The research in this area will therefore be directed at overcoming the problems of welding of the cold-formed sections to ensure that ductile behaviour always occurs.

An assessment of the savings which can be realised from the successful implementation of these high strength steels into welded structures shows that the economic benefits are very large. Similarly, the costs of problems which can arise are huge, as has been seen in the Californian and Kobe earthquake experiences.

The economic benefits of research in this sector have been assessed to be $100 million for the next 7 years. These benefits can be seen to be very conservative in the light of the fact that building structural steel costs can be reduced by 20% by the use of the high strength steels. The assessment is based upon the Australian market of about 400,000 tonnes of welded cold formed tubular sections with a value of approximately $1200/tonne.

Welding health and safety industry sector : Due to the adoption of the Hazardous Substances Regulations (HSR) (essentially adopted in every state and territory of Australia), employers must comply with limiting, if not avoiding, exposure of operators to fume generated by welding and cutting processess. There are currently no authoritative guidelines in place which provide the means to demonstrate HSR cmpliance of welding operations generating fume exposure. In the absence of these guidelines there will be a need for individual workplace monitoring of all processes and the myriad of associated variables (consumable, joint type, position, etc.)

It has been estimated that there are 100,000 workplaces in Australia which utilise welding and allied (cutting, brazing, etc.) processes as a key part of their operations. The range of materials vary from structural steel, stainless steel, aluminium and copper. It has also been estimated that individual workplace monitoring, on average, can cost up to $10,000 per site which, due to the lack of monitoring organisations and resources, could take as long as five years. Consequently, the significant work to be undertaken by the CRC-WS in fume control guidelines will assist industry in avoiding or substantially reducing up to $1 billion in costs needed to demonstrate compliance with the HSR. This figure is believed to be conservative as the social costs of sick days, and ongoing health problems have not been allowed for.

The Welding Health and Safety research plan also involves fundamental work aimed at controlling fume formation at source. Success in this area would substantially reduce the need for engineering controls of welding fume, and could easily provide cost reductions of $50 million without allowing for the social benefits of the resulting improvements in health of welding industry workers.

Other projects are also expected to provide significant economic and social benefits including reduced acoustic and radio frequency noise emissions.

In the light of the above figures $100 million is a highly conservative assessment of the economic benefits to Australia of the Health and Safety research program.

Ozweld technology support centres network and links to small and medium sized enterprises (SMES) [3]

Including the resources of WTIA, which has the key role in Australia for technology transfer, the OZWELD TSC Network includes:

- six State Technology Managers based at technology centres around the country
- ten national Technical Panels comprising 280 experts specialising in various industry sectors
- research and industry experts with expertise in automation, energy, offshore, petro-chemical, pipelines, reclamation, robotics, ship-building, steel fabrication, transport, and welding equipment and consumables industries.
- an Internet based Integrated Project Management Information System (IPMIS) for tracking research and technology projects
- an Internet site providing a capabilities register of research and technology providers
- a database capturing the needs and interests of all industry users
- a national Technology Hotline Service
- an integrated program of "Technology Demonstration and Awareness Forums" including workshops, conferences and exhibitions
- regular publication of The Australasian Welding Journal, newsletters and technical notes
- involvement in the Australian education and certification system in welding and joining
- operating relationships with industry and professional associations
- international linkages with some 15 or more organisations in 8 different countries including TWI (the UK Welding Institute), and the International Institute of Welding (IIW).

Through this network, WTIA, is able to identify opportunities for industrially beneficial research which will attract industry to provide funding.

Technology transfer strategies : An initiative of WTIA which supports this goal is the establishment of "SMART" (Save Money and Re-engineer with new Technology) groups in the pipelines, petro-chemical, steel fabrication, ship-building, energy and offshore industry sectors. These will be based on the successful "CRINE" program operated in the UK.

Technology awareness and demonstration forums will be organised to showcase new welding and joining technology and broadcast the outputs of research and development projects. World authorities will be brought to Australia to participate and thus ensure local industry is kept at the leading edge of technology.

In servicing the needs of their members on a local basis, WTIA and APIA will identify opportunities for application of new technology in Australian industry. The majority of the membership base are small/ medium enterprises (SMEs) providing access to the broad spectrum of Australian industry.

Researchers play a vital role in the technology transfer process and are encouraged to participate in the WTIA Panels and in the preparation and revision of Australian Standards.

Novelty of the research

Some examples of the novelty of the advances which will be made are highlighted as follows :

Pipelines

Australia's gas pipelines are of smaller diameter, highter strength, and operate at higher pressure than overseas. They are also constructed through different terrain and climate than in developed overseas countries. Due to this, the research performed overseas is not completely applicable to Australian conditions, and the Australian industry needs to understand the effect of weld defects which are a higher proportion of wall thickness than in thick pipelines constructed elsewhere. The Australian industry cannot directly apply mechanised welding systems developed elsewhere for large diameter pipelines, but is able to employ the very productive high hydrogen potential cellulosic electrodes to higher strength levels than could be achieved on the thick-walled pipelines used in Europe and North America. For this reason our research in this area is entirely novel.

Thin-walled pipelines are more susceptible to damage from interference by earthmoving equipment and so other novel research needs to be undertaken to provide design guidelines to provide both primary and secondary safeguards against penetration.

Arc welding systems

The CRC for MW&J has world leading researchers and facilities in gas metel arc welding arc behaviour and metal transfer characteristics. The capabilities are based upon a critical mass of highly qualified researchers at CSIRO and the University of Wollongong. They are supported by unique arc diagnostic capabilities at Wollongong, and internationally acclained arc physics capabilities within CSIRO. These capabilities provide the basis for the breakthroughs which are necessary for welding zinc coated steels so as to enable BHP Steel Products to reap the full rewards of their internationally patented in-line galvanising process. They also provide the basis for CIGWELD to develop world leading welding power sources with improved metal transfer and fume generation performance.

CSIRO

The joining and Thermal Processing Program of CSIRO Manufacturing Science and Technology (CMST) Division is heavily involved in joining research and development (R&D) for various metallic materials. Approximately 32 people are directly working on joining-related research with an operating budget of over $A4M. A wide range of projects are in progress involving joining, surfacing and cutting of ferrous and non-ferrous alloys using modern equipment and facilities. Investments are continually made in order to keep the standard of the facility in line with latest technology developments. A large number of these projects, both strategic and applied, are forcussed on productivity improvement of the manufacturing industries through use of automation/robotisation, application of new/improved joining processes and minimisation of repair and rework.

All the joining activities are grouped into seven major projects areas.

Joining process technology : A number of projects are in progress to join similar and dissimilar metallic alloys. The current and most recent projects include :

- narrow gap welding of C-Mn steels, HSLA steels and aluminium alloys;
- robotic arc welding of small and large structural elements;
- ultrasonic and thermo-compression bonding of dissimilar metals;
- friction stir welding of aluminium alloys;
- gas metal arc and flux cored arc welding of ferrous and non-ferrous alloys;
- gas tungsten arc welding of ferrous and non-ferrous alloys;
- plasma arc welding using metallic and oxide cathodes.

Computational weld mechanics : Weld Pool and Weld Thermal Cycles high power computers are now readily available to make numerical calculation of the temperature profiles in the molten weld pool and in the base materials during fusion welding processes, an attractive possibility. Computer models of the welding process enable welding engineers to optimise welding conditions thus reducing the time and money spent during procedure development.

Post weld stresses and distortion : Non-linear elastic-plastic finite element analysis of the non-uniform temperature fields during fusion welding enables calculation of the resulting stresses and of distortion. However, the complexity of non-linear material properties and the inhomogeneity of welded structures make application to welding processes difficult. Simplified models are thus being developed to predict distortion in which the welding process is simulated semi-empirically. Such models aim for shorter computer processing time so that they can be efficiently applied to large industrial fabrications.

Arc welding consumables and OHS: A key to achieving optimum welding operation and weld properties from many processes is the choice of consumables. Design of consumables is a complex field with many features having profound influence on welding and weldment properties. Research and development into consumables is an ongoing area of activity and expertise exists in the development of a wide range of flux-cored wires, submerged arc fluxes and manual metal arc electrodes. The range of applications for which consumables are developed includes those for joining of structural steels, high strength steels and stainless steels as well as hard facing.

Health and safety in welding : Both particulate and gaseous fume emissions from welding and related processes are a potential health hazard and it is vital that the most efficient means are found for dealing with such fume. Several aspects of this problem are being investigated and this has involved developing expertise in the measurement of both total and breathing zone fume. In particular, studies are underway aimed at better understanding the mechanisms of particulate fume formation in gas-metal-arc welding and at optimising welding power supply characteristics with respect to fume formation.

Equipment development : Welding power sources are developed in liaision with clients and researchers for specialty applications with features such as data acquisition, computer interfaces and waveform synthesis. The design process uses computer simulation of electrical characteristics of the equipment including the welding arc load to prove the design concepts before prototypes are built.

Recent work also includes

- a welding monitor, which is widely used by industry;
- a resistance welding and flash-butt welding monitor with expulsion sensing;
- a micro-processor arc voltage controller for high current Gas Tungsten Arc Welding.

Electromagnetic compatibility (EMC) assessment : The laboratory is equipped to evaluate welding equipment and systems for EMC compliance. Recent consultancy projects include emissions tests, advice on redesign, and joint development of welding power sources for major Australian manufacturers leading to their obtaining CE-marks and C-ticks for their products.

Aluminium fabrication : High quality and productive fabrication methods are essential in the manufacture of aircraft, high speed ferries, and road and rail transportation. Research projects cover all stages of design and manufacture to assist industry to improve quality and productivity.

Current projects include :

- ❑ fatigue performance of weldments in old and newly developed marine-grade aluminium alloys;
- ❑ development of flexible and portable automated welding processes;
- ❑ precision welding to maintain quality without over-welding;
- ❑ integration of castings and forgings into fabricated structures;
- ❑ in-situ repairs to improve service efficiency.

Higher design efficiency is being sought by the use of advanced materials such as titanium and magnesium and is being supported by research into new alloys, development of welding consumables and of novel welding procedures using fusion and solid-state processes.

Hardfacing : Industrial operations such as mining, mineral processing and sugar cane crushing incur high recurrent costs due to wear of equipment components that are in contact with the process material. CMST has expertise and experience in :

- ❑ identification of wear mechanisms by investigation of the worn surfaces using SEM techniques;
- ❑ selection of materials appropriate to the wear environment;
- ❑ application of wear resistant overlays using
  - arc welding processes;
  - plasma transferred arc deposition
  - laser fusion and arc spraying techniques.
- ❑ contributing to design and manufacture of welding consumables and
- ❑ wear testing to evaluate the performance of the applied materials.

Laser processing : The CMST Industrial Laser Centre conducts research to develop improved laser processes for cutting, drilling, welding and surface treatment applications in Australian industry. Strategic research on beam delivery and optimal systems for Nd:YAG lasers enables the beam energy profile to be optimised for each laser processing application. This has led to the design of a fibre-optic, tandem beam, laser processing head which can be optimised for specific materials, thicknesses and weld joint configurations. Processing heads utilising tapered optical fibres have also been developed. Facilities include Nd:YAG lasers with average powers currently up to 500 Watt and shortly up to 2.5 kW from 50 to 500 Watt and beam analysis equipment. A 3-axis CNC, laser-positioning control system provides accuracy of 0.001 mm and repeatability of 0.010 mm, and allows precision drilling, welding and cutting of materials.

In all of these project areas CSIRO works closely with Australian and overseas companies to develop technologies jointly for the benefit of industries. For that reason a large number of projects are industry driven and the outcomes of such projects benefit both the CSIRO and industry.

Cooperation with industry : An example - In September 1995 ANI Engineering approached CMST for help with a proposed contract to build 14,600 anode stem assemblies within a six-month period for the Tiwai Minenco and Bechtel Engineering (TMS) - New Zealand Aluminium Smelters (NZAS) expansion project. The project involved all of the machining and fabrication for the components, which required approximately 41 tonnes of aluminium welding consumables, 48 tonnes of steel welding consumables and approximately 6,500 tonnes of aluminium and steel assemblies.

The basic function of anode assemblies is to provide support for large carbon anode blocks and to convey electric current, averaging between 10,000 and 12,000 amperes, in the reduction cells of an aluminium smelter. The anodes are recyclable and are required to withstand large cyclic stresses and high temperature gradients during reprocessing. Each complete anode assembly is made of four different parts; an aluminium stem, an aluminium offset, a bimetallic transition piece and a cast steel yoke. These parts are joined together by partial penetration welds around the rectangular sections using the gas metal arc welding (GMAW) process. Confidentiality agreements do not permit the authors to give details of the chemical composition and dimensions of the anode components.

Following a series of meetings with ANI management, a CMST-ANI project was defined with the following objectives :

- establishment of an experimental robotic welding cell at the CMST Welding Laboratory in Adelaide;
- development of welding procedures for robotic joining of anode components to form a complete anode assembly;
- destructive and non-destructive testing of weld joints of a complete anode;
- transfer of technology through assistance in programming specific production robotic cells and training.

By the end of October 1995 a robotic system with partially harmonised positioners was installed in the Welding and Joining Laboratory of CMST in Adelaide. Developmental jigging was designed and manufactured within the following week.

A project team from the welding group at CMST and staff from ANI Engineering Technology group, proposed several different techniques for these welds. One technique was similar to that reported by engineers from Panasonic (Japan) whereby copper dams were used to block the side penetrations whilst the top and bottom preparations were filled.

Having a semi-proven technique as a back-up, the project team decided to attempt a more attractive technique for production requirements. This involved continually filling a rotating assembly and maintaining the profile around the corners. Japanese, South African and Canadian researchers have attempted similar techniques but without success. With careful control of weaving techniques and selection of welding parameters, the project team produced successful welds for all three joint configurations. Towards the end of February 1996, the project team travelled to New Zealand to transfer these procedures to the welding robots installed in the production facility under construction, and gain final approval for production welding.

In March 1996 ANI started the production of anodes in New Zealand. Six months later, 14,600 complete anode assemblies had been produced and delivered to the aluminium smelter, two weeks ahead of schedule.

CONCLUSIONS

This paper has given a short overview of research, development and technology transfer in Australia.

Education, training, qualification and certification also involve major initiatives which are driven on a national basis by the WTIA with valuable contributions from the CRC for MW&J, Universities and the TAFEs (Technical and Further Education Colleges).

The WTIA is shortly to become the International Institute of Welding (IIW) Authorised National Body (ANB). This will lead to a major drive through a WTIA/IIW network of Approved Training Bodies (ATB).

Opportunities for cooperation exist between India and Australia. These should be actively encouraged by the Indian Institute of Welding and WTIA.

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