Research support for the regional steel industry

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Building on a long history of collaboration, the University of Wollongong jointly with BHPSteel, has developed a strategy for strengthening the competitive position of the local steel industry. This strategy is based on the premise that a sustainable alliance between industry and university would help ensure that opportunities are created for the development of innovative and creative solutions to problems facing the steel business and its customers. Focussed research groups were founded in the Institute for Steel Processing and Products, University of Wollongong. These dedicated teams have built a specialised equipment infrastructure that is shared by university and industry researchers. This infrastructure is unique in Australia and is specifically tailored to the needs of the steel industry. As this infrastructure base has grown, BHPSteel’s in house research and metallurgical organizations and the University have progressively started to eliminate costly duplication of equipment by sharing facilities. The Institute's major contribution to BHPSteel has been the enhancement of the business through multi-disciplinary collaborative research between BHPSteel and the University to gain a better understanding of the key technical issues facing the company. In addition, the Institute provides advanced education and training to BHPSteel engineers. Through these collaborative efforts, the Institute has contributed to the strengthening of the competitive position of the local steel industry in the world market. This model of interaction need not be confined to interaction within Australia, but can be extended to enhance the competitive position of the regional steel industry.

Keywords: alliance, steel industry, confocal microscopy, innovation.
INTRODUCTION

One of the important questions in our quest to develop successful strategies for strengthening the competitive position of the regional steel industry in the world market is to what extent our institutions of learning can, should and are obliged to play a role. If universities, specifically, are to make a contribution to the strengthening of the competitive position of our regional steel industry, what should the mechanism be and importantly, can it be done without universities losing their independence and academic freedom. It is of great importance to address these questions but it is necessary firstly to briefly evaluate the current situation.

In recent years the steel industry has been restructured, globally and on a very large scale. In most companies the workforce today is a fraction of what it was a decade ago and research support is decreasing at an ever-increasing rate. To compound these difficulties, there has been a global trend in the decline of engineers interested in entering the steel industry. Whereas many universities offered specialised programs in iron and steel technologies in the past, very few of those were retained in undergraduate engineering curricula. This is a global trend. In his recent address to the Electric Arc Furnace Congress, Dr Gordon Gaiger referred to the training of staff for the steel industry in the United States [Geiger].

"In the not too distant future, few to no faculty at all will be available to teach an in-depth course in steelmaking chemistry. Almost none teach rolling theory and practice. The (steel) industry is in serious danger of having no employees trained in the basic fundamentals of the business"

Similar arguments apply in Australia and most probably in the region at large. Most engineering graduates today enter the small and medium sized enterprises rather than large corporations. Universities have responded by revising curricula and offering a broad-based education with more emphasis on business skills. If expert knowledge in iron and steel technologies is to be captured, it has become necessary for the industry to work with universities to develop specialised programs; post graduate courses, professional enhancement modules or preferably both. This approach has become necessary to shape the attitudes and expectations of the next generation of workers, and their awareness of opportunities in the steel industry. It has become necessary for industry to make this investment in advanced education in order to create and, if possible, to capture tomorrow's expert work force. Advanced education and postgraduate training will help to change the perception that steel is low-tech. This perception is already prejudicing the career choices of young potential entrants to the steel industry.

Responding to the challenge to forge closer ties between industry and university and building on a long history of collaboration and interaction, BHP (now BHPSteel) established in 1995, in alliance with the University of Wollongong, the BHP Institute for Steel Processing and Products as a multi-disciplinary research and educational institute within the University. One of the driving forces behind this development was the decision by BHPSteel in the mid-nineties to embark upon a strategy of developing steel processing plants throughout South-East Asia. The future need for more highly skilled technologists to support these plants as well as its existing steel operations were identified and mechanisms were sought to fulfil these needs. The decision to select the University of Wollongong as a partner was influenced, at least in part, by the fact that the University is located in close proximity to the Port Kembla Steelworks and also by earlier interaction between the two institutions when, shortly after the
war, the pressing need for technical education in the Illawarra region, where BHPSteel's Port Kembla Works is located, prompted BHP to play a major role in establishing the University of Wollongong which eventually gained full autonomy in 1975.

The Institute was founded on the shared vision that some form of a joint venture would provide opportunities for academic staff to play a greater role in assisting the steel industry generally, and BHPSteel specifically, in enhancing its business. It would also enhance the opportunities for BHPSteel staff to make a contribution to fundamental research and education. In addition, the new generation would be provided with the opportunities to develop innovative and creative solutions to problems facing the steel business and its customers. In the process of building multi-organisational teams it was recognized that while industry and university represent different cultures, with different objectives, the synergy that can be derived from effective communication between them affords a unique opportunity for innovative developments. In addition to providing fundamental research support to BHPSteel, the Institute was to also provide formal postgraduate education and to assist BHPSteel in the transfer of new knowledge to the workplace through regularly scheduled short courses.

**THE CURRENT ALLIANCE**

Although Institute projects supported by BHP, are closely linked to BHP business, the Institute is and remains an academic research unit. It is recognised that there is a strong nexus between research and education. Quality researchers develop good infrastructure, provide advanced training and attract talented students. Talented students become talented engineers and enhance the business. The strategy is to develop technologists empowered with knowledge commensurate with the needs of the steel industry, by undertaking research in areas relevant to BHPSteel's business interests. The Institute concentrates on focussed academic and applied research in support of BHPSteel's strategic goals, complementary to research conducted by BHPSteel. In order to ensure that the correct balance of knowledge and skills are available, the Institute also provides advanced education to graduate engineers and creates opportunities for professional development. Contact is maintained with a number of similar centres abroad to benchmark the activities of the Institute and to ensure continued participation in international exchange.

A Board, comprising senior BHPSteel and University of Wollongong staff, governs the Institute. It determines policy and oversees the research and educational activities of the Institute. It specifically ensures that Institute projects are aligned with the strategic objectives of BHPSteel and that the educational program is of high academic standard whilst at the same time, relevant to industry needs. A Technical Advisory Committee consisting of four sub-committees, each chaired by a BHPSteel technologist, advises the Board on technical issues. The Technical Advisory Committee creates forums in which University and BHPSteel staff interact and jointly develop research projects and training modules.

The research activities of the Institute are currently centred in three major programs, Figure 1. The Primary Processing Program focuses on iron and steelmaking processes as well as the associated process technologies. The Casting and Rolling Program attends to continuous casting technology, thermo-mechanical processing, and steel product development. Research in the Coatings Technology Program investigates the basic scientific and technological issues underpinning future product advancement in metal and polymer coatings.
A Chair in Steelmaking and a second Chair in Coatings Technology guide the Institute's research activities. Members of academic staff in the engineering or other faculties channel their steel related research activities through the Institute so as to derive full benefit from the network and opportunities created by the alliance. Recognising that people transfer technology and that the transfer is through communication, the Institute encourages its students to enrol in parallel for a postgraduate diploma designed to complement their research training by equipping them with essential communication, inter-personal, business and managerial skills.

Currently most projects are funded through the Australian Research Council's Linkage Grant scheme. One of the objectives of this funding scheme is to support high risk, fundamental research in academic institutions with the partial support of industry so that the research is focussed on the development of Australia's technology base. By participation in this funding scheme, a relationship is built between government, industry and the university. The government plays a pivotal role in this triangular alliance, Figure 2. By providing research funds and scholarships to students working on industrially relevant projects, industrial development in the country is guided and innovation is encouraged. The Institute now collaborates with BHPSteel on projects that cover a wide spectrum of activities and involves members of academic staff, postdoctoral research fellows, graduate students and BHPSteel staff. The operating funds of the Institute are almost equally shared between the government in the form of competitive grants, BHP as the industrial partner and the University.

Figure 1 The structure of the Institute for Steel Processing & Products, University of Wollongong

Figure 2 The triangular alliance
RESEARCH OUTCOMES

Having stated the aims, objectives and structure of the Institute for Steel Processing and Products, University of Wollongong, the question remains as to whether it has been a successful model of interaction between university and industry. Also, whether it has contributed towards strengthening the competitive position in the world market of BHPSteel. Should the answer to these questions be in the affirmative, the next question, relevant to the theme of this conference, is whether such a model can be adapted to and adopted by others in our region or alternatively, whether it is possible for the Institute to extend its support function to the South East Asian region at large. An attempt will be made to address these questions by referring very briefly to the performance and research outcomes of the Institute for Steel Processing and Products, University of Wollongong.

The Institute Chairs provide leadership in our continuing quest for clearer understanding and strong and focussed research groups founded in the Institute attracted talented staff to the Institute and the associated teaching disciplines. These dedicated teams have built a specialised equipment infrastructure that is shared by university and industrial researchers. This infrastructure is unique in Australia and is specifically tailored to the needs of the steel industry. As this infrastructure base has grown, BHPSteel’s in house research and metallurgical organizations and the University have progressively started to eliminate costly duplication of equipment by sharing facilities.

The Institute’s major contribution to BHPSteel has been the enhancement of the business through multi-disciplinary collaborative research between BHPSteel and the University to gain a better understanding of the key technical issues facing the company. Although the Institute is an academic research unit within the University of Wollongong, contributions to BHPSteel's business have been made towards improvements in product quality, technical marketing, production technology and customer service. It is pertinent to refer very briefly to a few examples of collaborative research that has led to an improved understanding of critical processing problems and product quality or to improved technical marketing and customer service.

Thin-strip casting

The commissioning of a thin-slab continuous caster and the development in parallel, of a twin-roll strip-caster for the production of carbon steel by BHPSteel, have elevated the need to elicit knowledge that will aid in the design of an optimal operation of these new high-speed casting techniques. Through strong interaction with the strip-casting team, the Institute’s team contributed to the optimised design of the carbon steel strip caster. The mechanical properties of steel in the partially-solidified condition, enabled the calculation of the roll forces required to ensure that solidification occurs in the ‘nip’ without excessive deformation of the partially solidified shell. The effect of key processing parameters on the development of texture was assessed through simulated strip-casting and the use of electron back-scattered diffraction analysis. The ability to change the properties of strip-cast steel sheet by in-line hot-rolling or subsequent thermo-mechanical processing was assessed through simulation studies on the Gleeble 3500 thermo-mechanical simulator. Of special significance was the determination of high-temperature mechanical properties of in-situ cast material.

In addition to these contributions directly concerned with process development, we sought fundamental understanding of the events occurring in the meniscus region of high-speed continuous casters that determine the quality of the cast product. Unlike conventional continuous casting, there is no moderating mould flux or lubricant in strip-casting so that roll
texturing and surface modification become important as a means to moderate the heat flow and to allow uniform heat transfer. These developments and the need to more fully understand the underpinning scientific principles have prompted us to investigate the possibility of in-situ observation of events occurring at high temperature. These considerations in turn, aroused interest in high temperature confocal microscopy as a technique to investigate high temperature phase transitions in steel. It is not only necessary to understand nucleation from the liquid upon solidification but it is equally important to fully understand the mechanism of nucleation and the rate of transformation of subsequent solid-state phase transformations. This is particularly true for a proper understanding of the microstructural development of high-speed continuous casting techniques because in strip-casting and to a lesser extent in thin-slab casting, the opportunities for microstructural control by means of thermo-mechanical processing are limited. The exact way in which the delta-ferrite to austenite phase transformation occurs following solidification becomes increasingly important. An impediment to success in previous studies has been the inability to study this transformation directly because subsequent phase transformations mask the transformation mode. Driven by the desire to contribute to increasing the competitiveness of our industry by the provision of new knowledge, we have attempted to provide new insights by studying this important transformation using the laser-scanning confocal microscopy.

**High temperature laser-scanning microscopy**

In confocal microscopy, laser light is focused by an objective lens onto the object and the reflected beam is focused onto a photo detector via a beam splitter. An image is built up by scanning the focussed spot relative to the object, which is then stored in an imaging system for subsequent display. Through the use of a confocal pinhole, only light incident from the focal plane is permitted to pass through to the photo detector. Light not returning from the specific optical plane is blocked by the pinhole. Hence, an extremely thin optical section is created, providing a sharp image at high resolution. Because thermal radiation is also blocked by the confocal pinhole, only the polarised reflection of the high intensity laser beam reaches the imaging sensor and a sharp image is produced at high temperature.

Because of the high heat extraction rates in strip casting [Grosjean et al, Muojekwu et al], increasing levels of undercooling can be achieved. These high cooling rates impact significantly on nucleation, which, in turn, has a dominant influence on the development of microstructural morphology. Stezov, Dippenaar and Evans [Strezov et al] and Evans and Strezov [Evans et al], using the experimental data of [Evans], have postulated that it is possible to suppress the nucleation of equilibrium phases at the high undercoolings achieved during strip-casting. The very large undercoolings predicted are expected to occur at the very first nuclei that form, hence when the shell is extremely thin. These findings led us to further investigate phase transformations occurring in low-carbon steel subsequent to solidification. We have found experimental evidence that meta-stable phases may form upon cooling a 0.06 % carbon silicon killed steel (Table 1) from delta-ferrite to austenite, Figure 3. Although the exact mechanism of formation is not fully understood as yet, this observation does provide evidence of the fact that meta-stable phases can form on the delta-ferrite to austenite transformation.
[Hauser et al.], have shown that transformation stresses accompanying phase transformations can produce low angle boundaries even in the absence of mechanical working. This phenomenon has been observed in alpha-ferrite and in a number of other alloy systems, [Baker et al., Talbot et al.]. At elevated temperature dislocation structures can be reorganised into sub-grain boundaries through a process of polygonisation. Hence, if austenite is heated into the delta-ferrite region, it might be expected that the transformation stresses accompanying this transformation will result in dislocation structures, which at the high pertaining temperatures, may form sub-grain boundaries through polygonisation. In order to test this hypothesis two commercial alloy steels were selected for analysis [Phelan]. Both steels contained 0.06% carbon, one aluminium-killed and the other silicon-killed. The analyses of these steels are given in Table 1.

Table 1 Composition of alloys used in delta-ferrite to austenite study

<table>
<thead>
<tr>
<th>Steel</th>
<th>C</th>
<th>P</th>
<th>Mn</th>
<th>Si</th>
<th>Al</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al killed</td>
<td>0.06</td>
<td>0.11</td>
<td>0.23</td>
<td>&lt;0.005</td>
<td>0.04</td>
<td>0.014</td>
</tr>
<tr>
<td>Si killed</td>
<td>0.06</td>
<td>0.10</td>
<td>0.4</td>
<td>0.29</td>
<td>&lt;0.005</td>
<td>0.014</td>
</tr>
</tbody>
</table>

The samples were heated in the laser-scanning confocal microscope from room temperature to 1400°C and held for 10 minutes. It was then heated to 1450°C at a rate of 100°C/min and held for 10 minutes. Once a sub-grain structure has developed, it appears to be quite stable as shown in Figure 4. A fine network of sub-grain boundaries has formed within delta-ferrite grains. This substructure has been observed in both the aluminium and silicon-killed steels although they are far more pronounced in the silicon-killed steel. The energies of the sub-grain boundaries vary between 7% and 36% of the energy of the delta-ferrite grain boundaries. The existence of such sub-boundaries which have not been seen before, clearly influence the subsequent transformation of austenite to ferrite and hence, the final microstructural development.
Microstructural development following the decomposition of austenite determines the mechanical properties of the final product. The mechanism and rate of austenite decomposition has been studied very extensively but there remains a controversy with respect to the nucleation and rate of propagation of Widmanstätten plates in low carbon steel. One school of thought will have it that Widmanstätten plates form by an unstable interface mechanism, [Townsend and Kirkaldy]. Conversely, others have proposed that a mechanism of sympathetic nucleation is operative [Aaronson and Wells]. We have used the laser-scanning microscope followed by electron back-scattered diffraction analysis to investigate the formation and growth rate of Widmanstätten alpha-ferrite plates in a low-carbon, silicon killed steel, Table 1. Samples were solution treated at 1400°C for ten minutes such that they were fully austenised with a large and stable austenite grain structure [10]. They were subsequently cooled at a rate of 100°C/min to a temperature of 700°C, then held isothermally until the phase transformation was completed. The sequence of events observed in the laser-scanning confocal microscope is depicted in Figure 5. The ferrite allotriomorph has a somewhat stepped appearance, (a), and it is apparent that the Widmanstätten alpha-ferrite plate has formed on the ledges of the allotriomorph, (b). A second Widmanstätten alpha-ferrite plate forms one second later on another ledge, (c), and a third plate on a third ledge, (d). Electron back-scattered diffraction analysis has shown that there is a misorientation of about 10° between the allotriomorph and the Widmanstätten alpha-ferrite plate. This observation provides convincing evidence that Widmanstätten alpha-ferrite plate formation occurs by the nucleation of an alpha-ferrite plate at the interface between a pre-existing alpha-ferrite precipitate (in this instance an allotriomorph) and the parent austenite phase. This mechanism, initially proposed by Aaronson and Wells termed sympathetic nucleation is in stark contrast to the alternative suggestion that Widmanstätten alpha-ferrite plate initiation occurs by the development and progression of an unstable interface, [Townsend and Kirkaldy]. We have found no evidence of Widmanstätten alpha-ferrite plate formation by a Mullins-Sekerka type of unstable interface in this or other similar experiments.
Preheating of hot briquetted iron

Electric-Arc Furnace (EAF) production of high quality steel, including flat products and special bar quality steels requires low residual iron feedstocks, and Hot Briquetted Iron (HBI) is a cost-effective source of virgin iron. HBI is also well suited to be used as a coolant in modern Basic Oxygen Furnaces. BHP has constructed what will become the world's largest merchant HBI plant; the first briquettes, marketed under the trade name 'Boodarie Iron', were produced on 18 Feb 1999, and the first cargo of 22,500 tonnes of HBI was shipped from Port Hedland on 10 May 1999 [Brent et al]. The introduction of HBI as a source of iron units to the Electric Arc Furnace (EAF) will lead to higher energy consumption, mainly due to the presence of unreduced oxides and gangue. By applying the Institute's expertise in high temperature thermodynamics and process dynamics it was revealed that significant energy savings can be realised by pre-heating the HBI. 180 kWh/t can be saved by pre-heating the charge with the off-gas from the furnace prior to its introduction into the EAF. It was shown that pre-heating in a simulated EAF off-gas could increase the metallisation of the HBI significantly while only the external surface is oxidised. This important finding that HBI does not oxidise excessively and that carbon present in HBI, reduces residual iron oxide during pre-heating have been captured in BHP's campaign to market HBI. Pre-heating in a simulated EAF off-gas could increase the metallisation of the HBI significantly while the external surface only is oxidised. The mass loss as a function of time in a gas mixture simulating the off-gas of an EAF is shown Figure 6. It follows that the optimum pre-heating temperature should be between 700°C and 800°C [Galvez].
Rolling Technology

Research in rolling technology aims to optimise hot and cold rolling mill operations and an attempt is made to establish the linkage between process and product. Specifically, the relationship between rolling mill dynamics, the quality of strip/plate produced and the implementation of control strategies is under scrutiny and mathematical models, verified by laboratory and in-plant experiments, have been developed to study this relationship. A fully instrumented Hille experimental rolling mill with thickness gauges, hydraulic gauge control and sensor rolls has been developed into a world-class research and teaching facility and is augmented by a well equipped laser diagnostics laboratory. These facilities are extensively used in the research described below.

The dynamics and friction at the strip-roll interface as well as lubrication during cold rolling has been studied. The distribution of the friction coefficient in the roll bite has been determined experimentally as a function of mill parameters and a finite-element rolling model which allows for the variation of friction in the roll/strip interface to be specified, has been developed. Different techniques are used to measure friction in the Hille experimental rolling mill, two of which are illustrated in Figure 7. A Laser-Doppler technique in which two LDV probes are used is shown in Figure 7a. One probe tracks the speed of the strip while the other measures the speed of the roll surface. From this data, the slip between roll and strip can be calculated, which in turn, leads to a calculation of the friction coefficient. In the other method, illustrated in Figure 7b, two pins with sensors are embedded in a roll at two different angles, one in the radial direction and the other 25° to the radial direction, to measure the local force in the roll bite, [Liu, Li et al, Liu, Wang et al]. Whereas the Laser-Doppler method only yields an average value of the friction coefficient, it is possible to determine the variation of friction in the roll bite by the use of the sensor roll. Using these experimental measurements as input data into a mixed lubrication model [Qiu et al], it has been possible to predict the value of the rolling force in a cold rolling mill to within 10%.

Figure 6 - Mass change of HBI samples reacted isothermally in a 32.9%CO₂/61.8%N₂/5.3%O₂ gas mixture, simulating the off gas composition of an EAF.
Improvement of product quality and technical marketing

Capitalising on their international reputation for expertise and achievements in the chemistry and physics of polymers, the Polymer Coating Team applied their knowledge to the quantitative assessment of the delamination of paint films and the discolouring of paint. In order to improve product quality, a novel and practical test based on a fracture-mechanics approach was introduced and validated to measure and quantify adhesion of paint films to other paint films or metal substrates.

The effectiveness of Zeus as a means to prevent discolouring of paint has been verified by using new experimental techniques that have specifically been developed to measure the adhesion of fine particles on paint thereby providing technical credibility to BHPSteel's marketing campaign. Adhesion of small dirt particles to paint surfaces occurs rapidly in tropical environments, causing unsightly colour changes. A research project was instigated into understanding the adhesion mechanisms involved, with the aim of developing dirt-resistant paint systems. As the particles are extremely small and the conditions of interest unfavourable to most experimental techniques, it was necessary to construct dedicated equipment. Initial use of a scanning electron microscope revealed that the contact area between simulated dirt particles and paints increased significantly with heat and humidity [Toikka et al 1999, Toikka et al 2000]. Whilst intuition suggested that such an increase would make the particles more difficult to remove, neither the adhesion nor the removal force could be determined. A mechanical device was therefore designed to remove the particles, using an atomic force microscope cantilever inside a scanning electron microscope. Figure 8 shows the schematic operation of the device and the observed detachment of a spherical 22 μm glass particle from a soft surface. Both the adhesion (950 mJ/m²) and the detachment mechanism (crack propagation) are disclosed in the process. A more ideal adhesion rig was also constructed since it is difficult to elevate and control heat and humidity inside the vacuum chamber of the scanning microscope, Figure 9. In this rig it is possible to place a single particle indefinitely into contact with a heated paint surface, inside an environmental chamber, and then measuring the pull-off force. The externally placed laser and position-sensing device detect forces less than one nano (10⁻⁹) Newton in magnitude. The technique has shown that the pull-off force between a zirconia particle and a paint polyester film increases by almost two orders of magnitude as the polymer is heated from 20 °C to 50 °C.
This particular result explains, in part, the problem encountered in the tropics since the latter temperature is not uncommon to buildings, during tropical daytime (BHPSteel has developed a surface treatment called Zeus which has solved this problem in Asia)

![Diagram](image)

Figure 8 - Schematic illustration of a device used to remove model dirt particles from paint surfaces and an electron micrograph showing actual detachment.

![Diagram](image)

Figure 9 - A rig designed to directly measure the adhesion between micron-sized particles and paint surfaces under elevated temperatures and humidity.

**EDUCATION PROGRAM**

The postgraduate program designed and offered at the inception of the Institute was aimed at training managers for mini-mills that were to be established in the Pacific Rim. BHPSteel's strategy has changed and the program was suspended. However, there is general acceptance within BHPSteel that there is a need to offer formal postgraduate training to young engineers. It has become clear that every attempt should be made to attract talented young individuals to the steel industry and to change the perception that it is a low-tech industry. These goals can be achieved at least in part, by the industry encouraging young engineers to enhance their technical qualifications, by emphasis on the need of education beyond undergraduate training and by providing awards to advanced educational achievements. It is implied that postgraduate education focussed on the steel industry is not the sole responsibility of the University and that active participation by the industry itself is required in order to ensure that relevant and expert knowledge is transferred. Hence we are currently involved in a
process of jointly developing a postgraduate program designed to address the future educational needs of the steel industry.

This development affords a unique opportunity for collaboration and closer interaction between steel companies and universities in South East Asian region. Ideally, this program should be developed in such a way that it can be delivered in a distance education mode so that local universities can offer the same course on location at steel works sites and in the local language.

A never-ending challenge to the competitiveness of the steel industry is the application of knowledge on the shop floor where, finally, productivity and quality are realised. Hence, apart from formal postgraduate education, new knowledge should also be transferred to the workplace through regularly scheduled short courses. The Institute has offered a variety of short courses in the past. In most cases short courses were offered when experts from abroad visited the Institute. Examples are Solidification Processing, Mould Flux Technology, Advanced Concepts in Steel Production, Clean Steel Production and Metallurgical Reaction Kinetics. BHPSteel and the Institute work together in the identification of existing short courses and in the development of new material to meet the needs of the steel industry. Continuing education and professional course development is not limited to BHPSteel only but are of equal significance to its customers. Unique opportunities also exist for other steel companies and their customers to participate in this development.

DISCUSSION

In his 1996/7 annual report, President Charles Vest of Massachusetts Institute of Technology outlined the role universities could play in supporting innovation [Vest]:

"the single most important contribution of research universities to our innovation system is the education of men and women with an understanding of emerging new science and technologies, and the creativity, mindset, and skills to apply them wisely"

If we in the regional steel industry are to achieve what President Vest envisaged, undergraduate education, postgraduate training, research, continuing education and workplace experience are to be integrated to a greater extent, not only nationally but also throughout our region.

The Institute for Steel Processing and Products in the University of Wollongong has facilitating enhanced contact between industry and university by conducting focussed research in collaboration with the local steel industry and by jointly developing postgraduate education and training programs. These efforts have empowered young engineers with new knowledge relevant to the steel industry, which in turn, helped strengthen the competitive position of the industry in the world market. A model of interaction between university and industry has been developed. It has been proven beyond reasonable doubt that research conducted within university context can contribute to enhancement of steel business objectives.

This model of university/industry interaction can easily be adapted to include international collaboration. Such a development can have significant implications for our regional steel industry by providing a cost-effective means of research and educational support to the industry, thereby contributing to the strengthening of the competitive position of the industry in the world market.
CONCLUSIONS

• A multi-disciplinary research and educational institute, created as an alliance between BHPSteel and the University of Wollongong has been established and a model now exists for research collaboration between industry and a university.

• The industry partner collaborates with the university in conducting focussed research of academic nature and training aligned with business objectives.

• Industry benefits from the collaborative research support as well as the education and training provided to its staff. This model of interaction has proven to be a successful strategy for strengthening the competitive position of the local steel industry. Focussed research, supported by appropriate training and education provide young engineers with the necessary skills to seek innovative and creative approaches to technical and business solutions.

• This proven model of collaboration can be adapted to the benefit of the regional steel industry, specifically to strengthen its competitive position in the world market.

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