Composites in Civil Infrastructure – R&D to Applications

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ABSTRACT: Research and development of composite materials and structures in the last two decades have paved way to increasing applications of composites in civil infrastructure globally. In Australia, the pioneering work was initiated at the University of Southern Queensland (USQ) within the Centre of Excellence in Engineered Fibre Composites (CEEFC) resulting in the first Australian fibre composite bridge in 2002. Since then, projects involving new and innovative design and structural concepts to make engineered composites a suitable solution in civil infrastructure have emerged. Through close involvement with major asset owners, these technologies have evolved from initial technology demonstrators to become viable commercial alternatives to traditional structural solutions. This paper highlights some of the research and development (R&D) projects on engineered composites in civil infrastructure in Australia. Moreover, field applications and case studies where composites have been effectively used are discussed. The challenges faced by the engineers in applying this emerging technology together with the need for appropriate education and training for civil infrastructure are also presented.

1 INTRODUCTION

Research and development of composite materials and structures in the last two decades have paved way to increasing applications of composites in civil infrastructure globally. There have been considerable activities in the development of fibre composites (FC) in the Australian construction industry during this time. Areas of activity have included bridge systems, replacement of hardwood girders, marine structures and strengthening of existing structures. The Centre of Excellence in Engineered Fibre Composites (CEEFC), a Research Centre at the University of Southern Queensland (USQ) has played a leading role in these developments. Pioneering research and development in fibre composites materials and structures have resulted in the construction of full-scale structures.

Through close involvement of major asset owners including state road and rail authorities and city councils, these technologies have evolved from initial technology demonstrators to become viable commercial alternatives to traditional structural solutions. This paper highlights some of the research and development projects on fibre composites in Australia. These projects include the development of the Australia's first fibre composite bridge, innovative strengthening systems using fibre composites, fibre composite railway sleepers and other innovative applications of engineered fibre composites in civil infrastructure. This has paved way for developing innovative composite products and structures by the industry partners, especially in civil infrastructure (Aravinthan & Heldt 2008).

2 R&D PROJECTS

The use of composites as a structural material in civil infrastructure is relatively new compared to other industries. Significant research and development has been pioneered by CEEFC (formally known as Fibre Composite Design and Development, FCDD), in collaboration with various industry partners, under the leadership of Prof. Gerard Van Erp since mid-1990s (Van Erp et al. 2005, Van Erp et al. 2006). Prototype structures have been constructed to demonstrate the potential of this material in civil engineering applications.

The following projects present some of the fibre composite structures that have been completed in coordination with CEEFC. These projects highlights the pioneering work carried out in Australia that proved fibre composites as a viable alternative option for civil infrastructure. Only through such research and development, it is feasible to penetrate in to an industry where traditional construction materials are heavily used.

2.1 *Australia's first fibre composite bridge*

Numerous research and development projects around the world have shown that fibre composites are viable structural materials for bridge applications. Advantages of these new materials over traditional bridge materials include low weight and high strength, greatly improved corrosion resistance and durability, ease of transportation and installation and lower energy consumption during manufacture. The CEEFC partnered with Wagners Composite Fibre Technologies (Wagners CFT), a Toowoomba based company, in collaboration with Queensland Department of Transport and Main Roads (QDTMR) and the Roads and Traffic Authority of New South Wales (RTA) to develop the first fibre composite bridge in Australia (Figure 1) in early 2002. The composite bridge is designed based on a traditional plank bridge concept, where the high tensile strength and low weight characteristics of fibre composites was combined with the high compression capacity of polymer concrete. The beam is made up a 100mm deep concrete compression flange on top of 350mm deep box girders formed using glass-reinforced pultruded profiles. Additional carbon fibre reinforcement was incorporated into the base of the deck to enhance stiffness. The technical performance of the composite beam underwent comprehensive field test at Wagner's owned quarry site near Toowoomba.

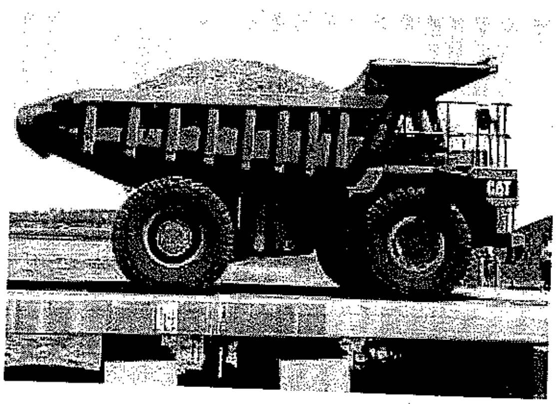


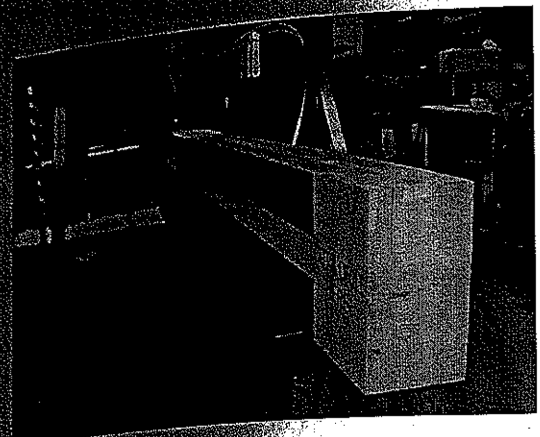
Figure 1. First fibre composite bridge in Australia

2.2 *Sandwich panels in bridges*

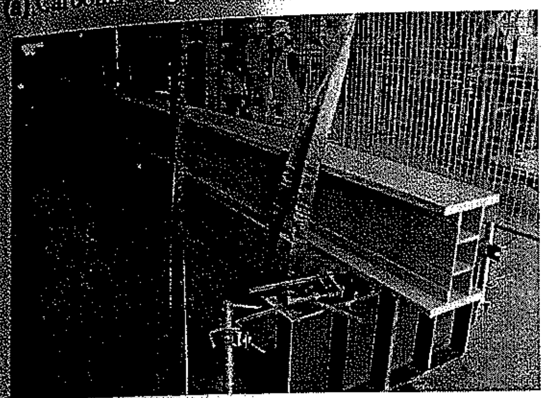
The success of the first fibre composite bridge … further developments of composites in bridges … of the technological development in Australia … the construction of a prototype bridge at USQ, … can be considered as a new generation of fibre … posite bridges using sandwich panels that could … tentially increase the span by two folds. This … technology has been realised through partn… with QDTMR and CarbonLOC Pty Ltd (… known as LOC Composites Pty Ltd), which … company based in Toowoomba. CarbonLOC … patented an innovative sandwich panel techno… which has paved way to provide innovative solu… to civil infrastructure.

2.3 *Fibre composite girders*

A major research and development project on … composite alternative girders to replace exi… hardwood timber girders is being carried ou… CEEFC in collaboration with the QDTMR and … industry partners, Wagners and CarbonLOC. … project aims to develop improved production p… esses and systems which will lead to the availab… in the Australian market of commercially viable … bre composite bridge beams through the use of … vanced manufacturing research. In order to achi… this outcome in a controlled and targeted manner, … project has been divided into distinct phases. E… phase consists of an R&D component and a … production run of 10-20 girders from each indus… partner. The industry partners aim to impro… manufacturing technology to reduce the produc… cost of these girders. At the end of each phase, … girders are tested for its performance. Over 90 gi… ers using two different types of design conc… (Figure 2) have been successfully manufactu… through this project. These girders are undergo… rigours testing including proof load testing, fatig… testing and ultimate strength testing to prove its … ability as a suitable replacement girder. Once … testing is completed, these girders are to be used … alternative girders for timber girders in existi… bridges. This is feasible with composites, due to … gineering the product to meet the requirements … timber products, which may be challenging … other materials.



(a) Carbon/UC girder with sandwich panels



(b) WCFT girder with pultruded sections

Figure 2. Fibre composite bridge girders

2.4 *Fibre composites in railways*

The use of composites in bridges provides potential usage for other applications, needing targeted research and developments. Railway sleepers are one such potential where composites could be used. In collaboration with the different railway industries in Australia, research and development of innovative fibre composite railway sleepers to replace deteriorated hardwood sleepers in existing lines have been investigated. One of the earliest technologies developed in Australia is a composite railway sleeper that can be used as replacement for timber, steel and concrete sleepers in existing or new railway tracks. The sleeper is made of polymer concrete and glass fibre reinforcement (Figure 3). A trial section of track was manufactured, trial tested and found to perform well under actual service conditions. While composites proved its potential in this area, the cost is a major factor to be considered, especially in new railway lines.

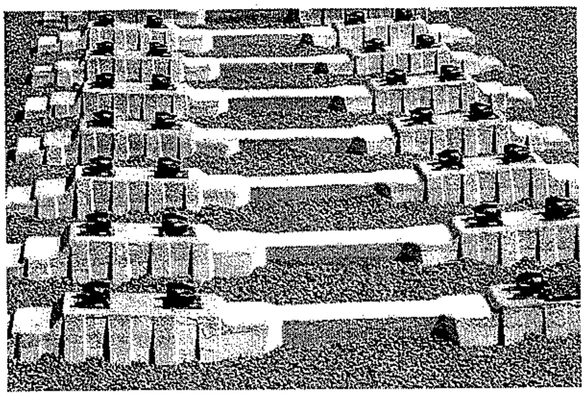


Figure 3. Fibre composite sleepers

2.5 *Fibre composites windmill structure with sandwich panels*

In fibre composites, the manufacturing costs can be significant especially in a one-off structure. An artistic concept based on the Australian traditional windmill was materialised in a landmark structure (Figure 4), as part of the 40th anniversary celebration of the USQ held in 2007, with the advanced usage of fibre composites. Due to the manufacturing technology available within the selected fabricator, all-sandwich windmill structure was used to avoid high manufacturing costs. This decision was made at early stage of the design process with close coordination with the manufacturer. CEEFC was involved in the analysis and design of the first fibre composite windmill structure, which was manufactured by Buchanan Advanced Composites Pty Ltd, a Toowoomba based company (Aravinthan & Omar 2008).

The tower of the windmill is 7900mm high with a 2300mm base that has two wings extending 300mm, at the ground level. The main structural system of the windmill is made up of sandwich construction in complex shaped structures. The sandwich panels were manufactured using resin infusion technology. The flat panels were connected together by laminates using hand lay-up techniques. Higher grade (H100) foam was used at corners to avoid the wrinkling failure and increase the capacity of the sandwich panels. The composite structure is connected to the foundations through steel brackets that are connected to the raft footing on three piers. Such structures are viable only when all parties involved work together in an alliance partnership.

Figure 4. Windmill structure with sandwich panels

2.6 *Fibre composites in structural rehabilitation*

Another application of fibre composites in rehabilitation is the use of composite laminates to wrap piles. This project was conceptualised in late 2002 when the Roads and Traffic Authority of NSW (RTA) approached CEEFC for assistance with a structural problem that is affecting a number of its bridges. These bridges were relatively new bridges that were constructed using concrete piles that suffered from a serious decay mechanism known as Alkali Aggregate Reaction (AAR). This mechanism caused expansive forces within the piles which eventually led to large cracks at the pile surface. These cracks resulted in serious corrosion of the reinforcement, in particular in submersed piles. This mechanism was significantly well understood to be largely prevented in new structures, but many existing bridge structures required major rehabilitation. Later the Queensland Department of Main Roads also became actively involved in this project as they have a number of bridges with similar problems. CEEFC developed a fibre composite pile wrap concept that can be applied to submersed piles (Figure 5). A number of prototype pile wraps and a series of underwater trials were conducted to test the effectiveness of the concept. A special pressure test was also carried out to establish that the concept could sustain the required high pressure loads in service. These tests have shown that the wrap exceeds the stringent mechanical requirements. This particular strengthening system proved to be a suitable solution, especially for underwater strengthening of piles.

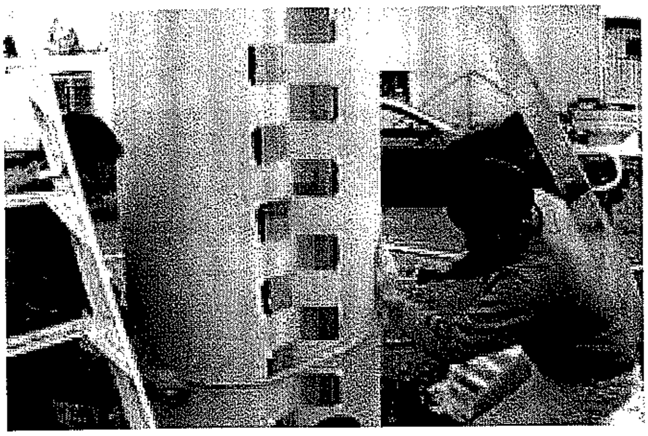


Figure 5. Fibre composites in pile rehabilitation

On the coastline of Australia, boardwalks, jetties, pontoons and marinas structures operate in a very corrosive environment. This results in serious durability problems for steel and reinforced concrete. Hardwood has traditionally been used to overcome some of these problems. The CEEFC has developed a new type of fibre composite waler (Figure 6) for use in marinas and floating walkways. The main function of walers is to tie the individual floats of marinas or walkways together. The walers are located on both sides of the floats and are generally connected to the floats by bolts or through-rods. Walers are traditionally made from steel or timber and require replacement every 10 to 15 years. Fibre composite walers are predicted to have a 50-100 year life. This particular project was developed in collaboration with Brisbane City Council. The challenges from conceptual design to final manufacturing of walers demonstrated how pioneering composites technology can be used to create world class engineering outcomes.

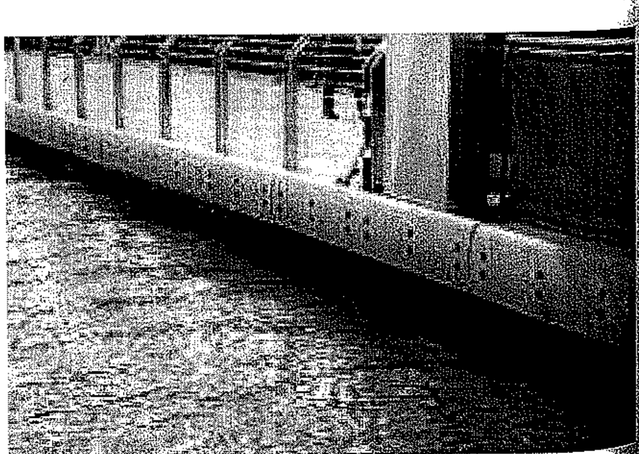


Figure 6. Fibre composite walers in marine environment

fied applications within the civil infrastructure in Australia. The following sections highlight some case studies where composites have been successfully implemented.

3.1 *Road Bridges*

The first application of fibre composites in a highway bridge in Australia occurred in 2005 when Wagners CFT reconstructed the Taromeo Creek Bridge (Figure 7) on the D'Aguilar Highway at Blackbutt, Queensland for the QDTMR (Van Erp et al. 2005). The highway bridge, which was constructed using fibre composite girders and reinforced concrete deck slab, is of two spans, 10m and 12m, and replaced an existing timber bridge. The bridge was completed in June 2005 and opened to traffic in July 2005. The deployment of the first prototype bridge lead to several road bridge projects using fibre composite in Australia. Wagners CFT which specialises in structural composite sections as load carrying members in a variety of structures has developed modular methodology of creating a variety of sections able to be tailored to specific requirements. For road bridges, Wagners CFT has designed and developed an I-beam bridge girder made up of pultruded laminated fibre composite sections such as 125x125x6.5mm SHS and 300x6 mm flat laminates bonded with rubber toughened epoxy adhesive (Kemp 2008). This technology has been applied in the reconstruction of the Manly Road Bridge in Brisbane where the composite I-girder section and concrete deck was used to replace the damaged reinforced concrete bridge. Another project that utilised the composite I-girder section is for road bridge replacement in Hawkesbury Council, Queensland. The council needed a solution to replace an aged timber bridge in a limited time frame as it was unlikely to survive another wet season in this flood prone rural district.

3.2 *Pedestrian bridges and walkways*

Pedestrian bridges and walkway structures made up of fibre composites are now common all across Australia. Due to its unique characteristics to withstand the harshest environments while providing a low swamps, alkaline desert and corrosive mining facilities. An example of a pedestrian composite bridge designed, constructed and installed by Wagners CFT for the Brisbane City Council (BCC) as part of their pedestrian infrastructure upgrade program (Figure 8). The Bowman Parade is a 3 span, 30 metre structure, and multi-use pedestrian bridge, and is made up of pultruded composite sections for the main structure and glue-laminated composite sandwich panels for the deck. Similarly, Wagners CFT was commissioned to design and supply materials for 850 metres of the Mackay Bluewater Environmental Trail (Figure 9) by the Mackay City Council. The 4km long project snakes its way through the environmentally sensitive tidal belt of the Pioneer River just north of the Mackay Central Business District. As the area is subject to regular cycles of submersion from both tidal forces and storm flooding, fibre composite solution was sought by the council.

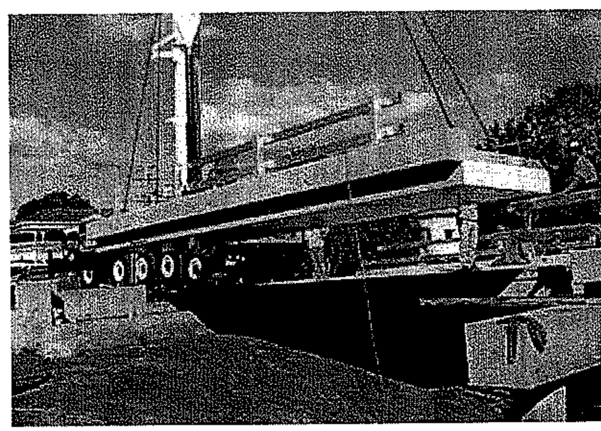


Figure 7. Taromeo Creek Bridge

Figure 8. Bowman Parade pedestrian bridge

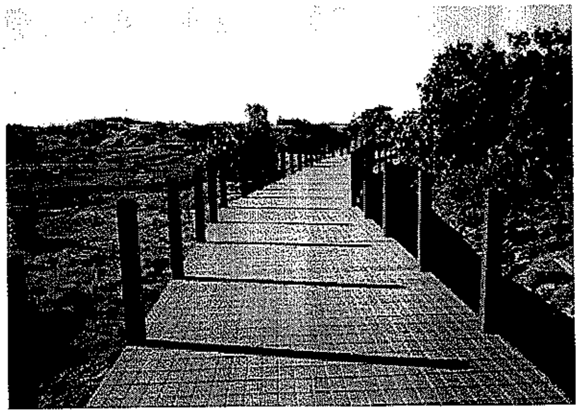


Figure 9. Mackay Bluewater Environmental Trail

3.3 *Railway sleepers and transoms*

Railway industries in Australia are now trialling the use of fibre composite sleepers to replace deteriorated hardwood railway sleepers. One of the development is the fibre composite railway transom (Figure 10) which is now being trialled on an actual railway bridge in Australia (Aravinthan & Heldt 2008). The composite railway transom is made up of a new type of fibre composite sandwich panel with additional fibre reinforcements. The first transoms were installed by the Australian Rail Track Corporation (ARTC) on a steel railway bridge located on a heavy and busy haulage line in November 2007. The ARTC has installed twenty two fibre composites transoms, which were manufactured by CarbonLOC in collaboration with Austrak Pty Ltd, one of the largest railway sleeper manufacturers. The trial installation verified that the composite transoms are performing to expectations.

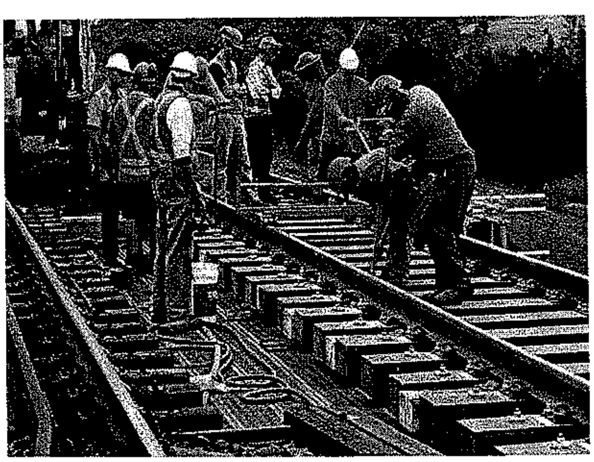


Figure 10. Fibre composite transoms on a rail bridge

3.4 *Composites for structural rehabilitation*

Engineered fibre composites offer an extremely versatile option to strengthen or rehabilitate existing structures to solve structural problems arising from environmental exposure, inadequate designs, increased traffic loads, and continuous aging. Road and bridge authorities in Australia have become actively involved in these type of projects as many of its existing bridge structures requires replacement and major rehabilitation. Australian hardwoods are an excellent general purpose building material. However, in recent years they have become more expensive, less available and of poorer quality. Fibre composite bridge components have shown to be compatible as a replacement material for rapidly dwindling hardwood bridge components. Wagners CFT and CarbonLOC has successfully developed and installed composite girder replacement solutions for timber bridges in recent years in collaboration with the QDTMR and other major timber bridge asset owners.

3.5 *Composites piles in harsh environment*

Traditional pile materials such as concrete, steel and timber are being used for deep foundation systems. However, there are problems associated with the use of these materials especially when installed in corrosive and marine environments. In the marine environment, fibre composites can be selected for their corrosion, rot, and pest resistance as well as their high strength-to-weight ratio. Given the significant number of timber-piled piers in the Australian coastline, there is an increasing interest for a cost effective fibre composite system. Recently, BA Technologies Pty. Ltd. has developed and supplied more than 50 piles to BCC for the rehabilitation of the Shorncliffe Pier in Brisbane (Figure 11). The project used 300 - 450 mm diameter hollow composite tubes for partial repair and total replacement of damaged timber piles (Sirimanna 2011).

Another application using fibre composite pultruded sections were adopted by Wagners CFT to shore up the Jack Evans Boardwalk in Tweed Heads, New South Wales (Figure 12). This 2,250 square metre project was Wagners CFT's the first use of composite piles in the field where a total of 410 piles were driven to set the boardwalk structure in reclaimed soil and near the shore (Guades et al. 20

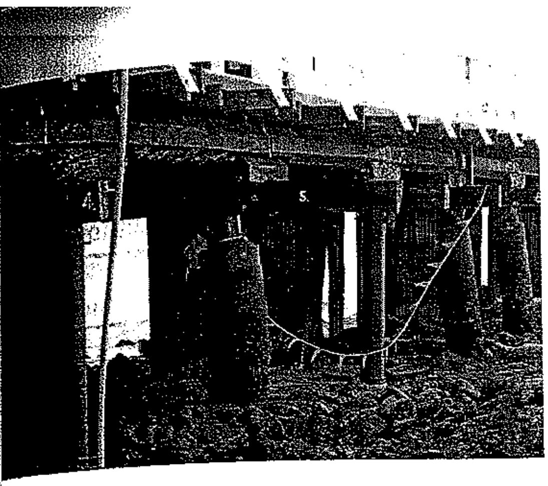


Figure 11. Timber pile replacement at Shorncliffe pier

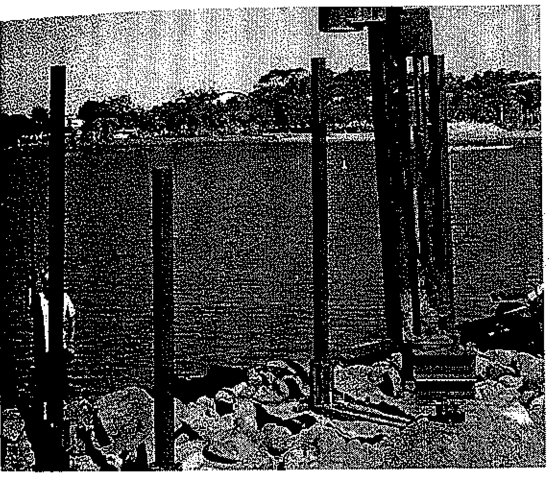


Figure 12. Composite piles for Jack Evans Boardwalk

4 CHALLENGES

The research and development together with field applications discussed above show that Australia is among the leaders in using fibre composites in civil infrastructures. However, there are challenges in making these projects into a reality. While these difficulties are substantial, all parties have worked together to ensure that these barriers are minimised and the best outcome for the project is achieved. Key barriers to the growth of fibre composites in civil infrastructure include:

- System proof – typical infrastructure prototypes need to be developed and installed for a considerable period (10 years) before market acceptance is sufficient to build a market volume;
- Market volume – is critical to commercial success because fixed development and production costs need to be amortised over large production volumes in order to be acceptable to the market;
- Intellectual property – commercial organisations need to protect their intellectual property as the most tangible initial asset to their development investment, however reduced knowledge sharing tends to reduce the speed of development.

While these barriers are substantial, they are not insurmountable. Governments and owner organisations can substantially reduce these barriers by their investment choices, and commercial organisations can position themselves by carefully selecting the products they develop to ensure that these barriers are minimised.

Capital cost is the key driver for infrastructure projects. Consequently, the types of materials used, and the manner in which they are used differ from other industry sectors such as marine and aerospace. Fibre composites will generally be feasible in infrastructure when the need for corrosion resistance, reduced weight, or fast installation is a driver for the system. Typical systems that have previously been based on Australian hardwoods (bridge girders, railway sleepers etc) are likely to be cost effective because fibre composite systems can be produced for a similar cost to hardwood, and it is anticipated that hardwood products will continue to increase in cost as they become scarcer. Combining fibre composite materials with traditional engineering materials (steel, concrete etc) can be an effective means of managing capital cost provided this does not compromise the reason for using composites (eg corrosion resistance). Fibre composites engineered systems are typically high strength, low stiffness in nature. Combining fibre composites with traditional materials can be an effective way of improving stiffness without excessive increase in capital cost.

The business development strategies adopted by individual companies will play a major role in making composites as a viable alternative in civil infrastructure. In this context, industry partners such as CarbonLOC and Wagners CFT have both adopted a policy of establishing a market for a simple basic product (waterproof building panel or pultrusion) which enables efficient production in larger quantities. These products areas used as the key elements to develop structural systems that can compete with traditional materials. This approach will eventually lower construction costs and makes fibre composites competitive with other conventional materials.

5 EDUCATION AND TRAINING IN FIBRE COMPOSITES FOR CIVIL ENGINEERS

Several successful R&D projects completed leading to several applications are a testimony that composites are viable alternative in civil infrastructure. However, there is still a lack of practicing engineers who are trained to design and use fibre composite materials. Most engineers are trained in the general specialisations of engineering such as civil, mechanical or aeronautical engineering need to upgrade their knowledge on fibre composites to be suited for this industry. To fill this gap, courses in fibre composites needs to be developed. University of Southern Queensland (USQ) has taken the initial steps by developing the first course on engineered fibre composites with the focus on civil and structural engineers. With the reputation of being the Australia's distance and e-learning educator, USQ is offering this course entirely online. This provides a flexible learning environment for practicing engineers who can continue to develop their professional skills in this new technology. The first offer of this course was successfully completed in 2008. Further improvements including appropriate resource development has been completed in order to educate and train engineers in the area of fibre composites for civil infrastructure. Such education and training engineers will be a key factor to embrace fibre composites as an alternative material.

6 CONCLUDING REMARKS

This paper has presented research and developments that lead to field applications of fibre composites into civil infrastructure in Australia. Several new and innovative structural systems have shown that fibre composites are reaching a point of commercial reality in the Australian construction industry. Engineered fibre composites have huge potential in civil infrastructure. However, there is a great challenge for the civil engineer and structural designer when there are no specific design standards and familiarity with the behaviour of such new materials. This is further affected by the limitations of the manufacturing technology possessed by the contractor. By forming an alliance with the designer, client and the manufacturer, working towards the best outcome for the project within the constraints had led to the successful completion of the fibre composite structures in Australia, as discussed in this paper. It is believed that such model could be very effective in gaining acceptance of this innovative material in civil infrastructure.

Other challenges faced by the civil and structural engineers in such cases are the understanding of the behaviour of the fibre composite materials, its failure mode and adopting available design guidelines to the local needs. This also emphasise the need to train civil and structural engineers in fibre composites and the development of relevant design standards/guidelines in Australia. When these are achieved, the fibre composites will become more competitive with the traditional construction materials and it would be possible to harness its potential in civil infrastructure.

7 ACKNOWLEDGEMENTS

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8 REFERENCES

Aravinthan T. 2012. Research and development of fibre composites in civil infrastructure - The Australian experience, *Proc. 3rd Asia-Pacific Conference on FRP in Structures (APFIS)*, Sapporo, Japan.

Aravinthan T. and Heldt T.J. 2008. R & D on engineered fibre Composites- Past, Present and Future, *Fibre composites in Civil Infrastructure – Past, Present and Future*, December, 3-10.

Aravinthan T. and Omar T. 2008. Fibre Composite Windmill Structure, *4th International Conference on FRP in Civil Engineering (CICE2008)*, Zurich, Switzerland.

Guades E.J., Aravinthan T., and Islam M.M. 2011. Driveability of composite piles, *Proceedings of the ... Intl. Postgraduate Conference on eddBE2011*, Bri[s]bane, Australia, 237-242.

Kemp M. 2008. Use of pultruded sections in civil infrastructure, *Fibre composites in Civil Infrastructure – Past, Present and Future*, December, 29-35.

Sirimanna C.S. 2011. Behaviour of fibre composite piles for timber pile rehabilitation, Master's Thesis, University of Southern Queensland, Australia.

Van Erp G., Cattell C. and Ayers S.R. 2006. A fair dinkum approach to fibre composites in civil eng...

neering, *Construction and Building Materials*, Vol. 20, No. 1-2: 2-10.

Van Erp G., Cattell C. and Heldt T. J. 2005. Fibre composite structures in Australia's civil engineering market: an anatomy of innovation, *Progress in Structural and Materials*, Vol. 7, No. 3: 150-160.

Van Erp, G. and Rogers, D. 2008. A highly sustainable fibre composite building panel, *Proc. Fibre Composites in Civil Infrastructure – Past, Present and Future*, 17-23.