Research and Development of Fibre Composites in Civil Infrastructure
- The Australian Experience

Thiru Aravinthan
Assoc. Prof., Centre of Excellence in Engineered Fibre Composites, University of Southern Queensland, Toowoomba, Australia

ABSTRACT

During the past 15 years, there have been considerable activities in the research and development of fibre composites (FC) in the Australian construction industry. 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. This work has involved not only the initial concept development but also the construction and deployment of full-scale prototypes. 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 past and present research and development (R&D) projects on engineered fibre composites that the authors have been involved in. These projects include the development of the Australia’s first fibre composite bridge, innovative strengthening systems using fibre composites, fibre composite railway sleepers, a fibre composite windmill structure and other innovative applications of engineered fibre composites in civil infrastructure. Future R&D prospects on this advanced composite material are also discussed.

KEYWORD

fibre composites, research and development, bridges, structural rehabilitation
1. INTRODUCTION

There have been considerable activities in the research and development of fibre composites (FC) in the Australian construction industry in the last two decades. 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 past and present research and development projects on fibre composites in Australia. These projects include the development of 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 by the industry partners, especially for the civil engineering applications [1]. Based on these outcomes, future prospects of these advanced composite materials are also discussed.

2. PAST PROJECTS

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 [2,3]. 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.

2.1 Fibre Composite Bridges

Numerous large-scale demonstration 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 has been engaged in the R&D of several fibre composite bridges now being used in Australia.

In collaboration Wagners Composite Fibre Technologies (WCFT) a Toowoomba based company, CEEFC developed the first fibre composite bridge in Australia. This was only achievable by the support provided by the two state road authorities, namely, the Queensland Department of Transport and Main Roads and the Roads and Traffic Authority of New South Wales. After extensive testing, this bridge was installed near Toowoomba, Queensland in early 2002 (Fig. 1). This research and development led to WCFT to specialise on an innovative fibre composites pultruded sections for their products.

Another technological development in Australia was the construction of a prototype bridge at USQ (Fig. 2), which can be considered as a new generation of fibre composite bridges using sandwich panels that could potentially increase the span by two folds. This new technology has been realised through partnership with QDMR and LOC Composites Pty Ltd, which is a start-up company based in Toowoomba. LOC Composites has patented an innovative sandwich panel technology, which has paved way to provide innovative solutions to civil infrastructure.

Fig. 1 First FC bridge in Australia
2.2 Marine and Floating Structures
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 (Fig. 3) 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.

2.3 Rehabilitation and Strengthening of Existing Structures
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 of existing structures. An innovative system using fibre composite have been investigated by CEEFC for strengthening existing structures with deficient structural performance.

One of the major problems in strengthening headstocks in bridges using conventional external post tensioning system is that, the prestressing steel is exposed to the environment. These rods need to be protected by an encasing in a grouted tube or other protective measures such as HDPE sheaths. Another issue with such system is that an anchorage system will need to be designed to suit the existing headstock. While FRP tendons or rods could be used to prevent corrosion related problems, the major challenge in such cases is designing a suitable anchorage system. These problems are eliminated by having a prestressed fibre wraps, which forms essentially an infinite loop around the headstocks. The concept of such system is shown in Fig. 4. By designing a suitable anchorage block, stress concentrations issues at the anchorage zone could be eliminated. Using a suitable prestressing jack, the anchorage blocks could be ‘pushed-out’ together with the fibre wrap, which introduces a prestressing force in the headstock. By ‘packing’ the gap with suitable spacers, the applied force could be maintained in the headstock [4]. The prestressed fibre wrap system provides an ideal solution for strengthening of headstocks in bridges. This technique also provides flexibility to the design engineer where suitable fibres could be used as laminates. This technology is applicable not only to headstocks but also to other similar structural elements.
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.

The CEEFC developed a fibre composite pile wrap concept that can be applied to submersed piles (Fig. 4). 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. Large scale production techniques were proposed in collaboration with a private company at the Gold Coast to install 100 fibre composite casings at the Missingham Bridge in Northern NSW. This particular strengthening system proved to be a suitable solution, especially for underwater strengthening of piles.

Traditional pile materials such as concrete, steel and timber are being used for deep foundation system. 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, BAC Technologies Pty. Ltd. has developed and supplied more than 50 piles to BCC for the rehabilitation of the Shorncliffe Pier in Brisbane (Fig. 6). This project used 300 - 450 mm diameter hollow composite tubes for partial repair and total replacement of damaged timber piles [5].

Fig. 5 Pile rehabilitation using fibre composites

Fig. 6 Timber pile replacement using composites

Another application using fibre composites pultruded sections were adopted by WCFT to shore up the Jack Evans Boardwalk in Tweed Heads, New South Wales (Fig. 7) [6]. This 2,250 square metre project was the first use 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.

Fig. 7 Composite piles for a boardwalk
2.4 Modular Deployable Composite Shelter
Strarch International have successfully developed and constructed a range of stressed steel arch buildings around the world, and recognised the potential to extend the structural concept to fibre composite materials, but these materials were believed to offer additional benefits, including modularisation.

The CEEFC and the Strarch International collaborated on an R&D project aimed at the development of a fibre composite re-deployable arched shelter system with rigid PVC or fabric cladding (Fig. 8). The main frames of this system are formed from modular fibre composite panels that are connected and stressed in position by prestressing cables. Using prestressing as a deploying mechanism, different geometries can be obtained using this system by changing the number of panels per frame and the packer sizes between panels. Strarch uses this new development as a deployable shelter structure for military forces, civilian humanitarian aid, and post-natural disaster scenarios [7].

![Modular deployable composite shelter](image)

Fig. 8. Modular deployable composite shelter

2.5 Fibre Composite Windmill Structure
An artistic concept based on the Australian traditional windmill was materialised in a feature structure (Fig. 9), as part of the 40th anniversary celebration of the USQ held in 2007, with the advanced usage of fibre composites. The CEEFC was involved in the analysis and design of the first fibre composite windmill structure, which was manufactured by BAC Technologies Composites Pty Ltd. [8].

![Fibre composite windmill structure](image)

Fig. 9. The fibre composite windmill structure

3. PRESENT R&D PROJECTS

Current projects carried out in Australia include research and development on alternative fibre composite girders, fibre composite railway sleepers for spot replacement and investigation of the innovative fibre composite sandwich panels. These projects highlight the current trend on the application of fibre composites in civil infrastructure in Australia.

3.1 Fibre Composite Bridge Girders
A major research and development project on fibre composite alternative girders to replace existing hardwood timber girders is being carried out by CEEFC in collaboration with the Queensland Department of Transport and Main Roads and two industry partners, Wagners Composite Fibre Technology Pty Ltd and LOC Composites Pty Ltd. This project aims to develop improved production processes and systems which will lead to the 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.
availability in the Australian market of commercially viable fibre composite bridge beams through the use of advanced manufacturing research. In order to achieve this outcome in a controlled and targeted manner, the project has been divided into four distinct phases. Each phase consists of an R&D component and a trial production run of 40 girders, 20 each from the two industry partners. Each industry partner will research and develop improved manufacturing technology in order to reduce the production cost of these girders. At the end of each phase, the girders are tested for its performance and cost is evaluated. Over 90 girders (using two different type of design concept shown in Fig. 10) have been successfully manufactured through this project. These girders are undergoing rigours testing including proof load testing, fatigue testing and ultimate strength testing to prove its viability as a suitable replacement girder. Once the testing is completed, these girders will be used as alternative girders for timber girders in existing bridges.

3.2 Fibre Composite Railway Sleepers

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 has 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 (Fig. 11). In its continuous effort on providing innovative solutions to the problems of the railway industry, a research project is being conducted in collaboration with Austrak Pty Ltd (Australia’s largest railway sleeper manufacturer) to develop an optimised fibre composite railway sleeper. The Australian Rail Track Corporation has installed twenty two fibre composites transoms for a railway bridge in Newcastle (Fig. 12). These transoms were manufactured by LOC Composites in collaboration with Austrak.

Fig. 10. Fibre composite bridge girders

(a) LOC Composites girder

(b) WCFT girder

Fig. 11. Fibre composite sleepers

Fig. 12. Fibre composite transoms
4. FUTURE PROSPECTS

4.1 Lessons from Previous Projects
Capital cost is a key driver for infrastructure projects. Consequently the types of fibre composite materials used, and the manner in which they are used differ from other industry sectors such as marine and aerospace. In practice the following principles generally apply:

- 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 more scarce;
- 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 (3 above) can be an effective way of improving stiffness without excessive increase in capital cost.

Key barriers to the growth of fibre composite 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.

4.2 Industry Related R&D Projects
There is a huge level of research interest in engineered fibre composites for civil infrastructure. Consequently, research and development projects which involve new and innovative design and structural concepts are the focus within our research centre to make the engineered fibre composites a suitable solution and cost effective alternative to the existing construction materials. These are industry related R&D projects that has the potential to be commercialised both nationally and internationally.

4.3 Education and Training in Fibre Composites for Civil Engineers
In Australia, particularly through extensive research and development, CEEFC has developed expertise in the application of fibre composites in civil infrastructure. Several successful R&D projects completed leading to several applications are a testimony for this. 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 the first semester of 2008. Further improvement and resource development is underway 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.
5. CONCLUDING REMARKS

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 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.

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REFERENCES


