Development of an Australian Code of Practice for the Structural Design of Fibre Composites

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Fibre Composites Design and Development
PCIC and Civil Engineering Composites.

- Australian composites industry traditionally driven by non-civil engineering companies:
  - Boat builders
  - Swimming pool manufacturers
  - Aerospace (limited)

- Civil engineers like to control their own industry

- Composites Institute of Australia recognized a need for civil engineering industry group in composites.

- Polymer Composites in Construction (PCiC) division formed in July 2001.

- PCiC is now driving the Australian push for composites in civil engineering applications
PCIC and Civil Engineering Composites.

One of the issues high on the agenda of the PCIC is the development of an Australian Code of Practice for the structural design of fibre composites.
An Australian Code of Practice

A detailed understanding of the civil engineering industry and design process is one of the key issues in creating an appropriate civil engineering design code.

The civil engineering industry is fundamentally different from most traditional composites industries and these differences and their implications must be properly understood.
Manufacturing Industry

- Series production of a limited number of products
- Close interaction between design and manufacture
- Fibres types, resins and manufacturing techniques to be used are known during the design phase.
- Laminate test data available or easy to obtain
Civil Engineering

- One-off projects
- Commissioned by government, statutory authorities or private enterprise
- Different parties undertake and are liable for design and manufacture
- Often the manufacturer is not known during the design process
- Careful and conservative approach to design, which relies heavily on standards and codes
Due to the separation of design and manufacture, the civil design process involves the preparation of a set of explicit specifications and drawings that tell the manufacturer how to build the structure.

Specifications generally address

- the extent of the work to be carried out
- the materials to be used
- the workmanship required and,
- construction methods to use or not to use.
Civil Engineering

Preparation of specifications needs careful consideration

• Specifications that are too prescriptive might shift the liability for the quality of the product from the manufacturer to the designer.

• Publicly funded projects have to comply with strict freedom of competition rules.

• Specification of specific brands and products is normally not allowed, type and quality or performance should be specified instead.
Civil Engineering

Steel is specified by grade, making it easy for the designer, fabricator and inspector to know the level of properties that must be achieved.

The myriad combinations of fibres and resins and the seemingly infinite capacity to tailor properties and performance make it difficult for the civil engineer to specify composites with a relatively high degree of comfort.
In order to resolve this problem, it is extremely important for the composites industry to provide the civil engineering community with a methodology through which uncertainties related to materials performance can be eliminated.

To be successful the approach should have a time and cost structure appropriate to typical civil engineering works.
Civil Engineering

For civil engineers to successfully utilise composite materials in a structure, they must

• possess appropriate information to undertake engineering design
• be able to specify required materials in project specifications
• have appropriate methods to assess materials and material combinations proposed by manufacturers in submitted tenders
• be able to ensure the quality and performance of the materials in the completed structure
Civil Engineering

The foundation to all these points is the ability to accurately and reliably characterise the performance of composite materials, both in constituent form and as a combination.
Civil Engineering

Aerospace applications have been based on extensive materials testing and strict adherence to prescribed specifications for autoclave based fabrication in highly controlled factory environments.

Civil engineering applications are more likely to use:

- processes other than autoclave moulding such as wet lay-up, resin infusion and pultrusion
- fibre and resin as separate constituents rather than in the form of pre-impregnated material and
- a much wider range of resin systems such as polyesters, vinylesters, phenolics and low temperature cure epoxies
Fibre Composites Design Standard

Design of fibre composites produced with resin and fibres as separate constituents requires an understanding of:

- the behaviour of the individual constituents,
- their compatibility with each other and
- the performance offered by the resulting composite
Civil Engineering

The composites industry is rather fragmented with respect to constituent materials. Reinforcement fibres and resins are generally produced and supplied by different companies who have little interaction with each other.

Consequently, decisions with regards to the compatibility of constituents and viability of final composite combinations basically rest with the design engineer and there is currently only limited guidance available.

One cannot expect civil engineers to be an expert in the detail of every material they work with.
To address these problems, the proposal for the Australian Code of Practice currently incorporates

1. A civil engineering based characterisation and specification system for constituent materials.

2. Civil engineering design data based on the proposed characterisation system.

3. Methods to assess materials and material combinations proposed by manufacturers in submitted tenders.

4. A quality control system to ensure the quality and performance of materials in the completed structure.
Regulating Materials Use

• Integrated system of characterisation and grading for constituent materials
  – The cornerstone of materials control in the new Code of Practice.

• ALL constituent materials used in civil and structural engineering projects will require certification by PCIC.

• Constituent certification programs being developed for:
  – Polymer resins for fibre reinforced laminates
  – Reinforcement fibres
  – Core materials
  – Adhesives
For example

the “Grade A Reinforcement” grading is for high grade structural fibres and will cover reinforcement suitable for primary load carrying functions.

“Grade A Resin” will similarly cover structural resins for primary load carrying elements.

Grade B and Grade C resins will only be allowed for non-structural applications.
Aim of Grading Program Development

- Engineer specifies required material grades
- Fabricator selects materials of appropriate grades from range of certified products
- Fabricator performs limited testing on material combinations to ensure compatibility.
Stage 1: Development of Polymer Resin Program

- 1 year project to develop a grading and certification program

- Undertaken in collaboration with major resin manufacturers including:
  - Ashland Chemical Company
  - The Dow Chemical Company Australia
  - Nuplex Industries
  - ATL Composites Pty Ltd
  - Huntsman Chemical Company
  - Vantico

- Seeking to provide a united industry response to this issue

- Project will address:
  - Testing protocols for assessment
  - Benchmarks for classification of materials into performance grades
  - Implementation of the grading system
Civil engineering design data based on the proposed characterisation system
Fundamental Basis for Composites Code.

- New Approach for Fibre Composites
  - The unidirectional lamina is the fundamental building block for fibre composites
  - The cornerstone to successful composites engineering is the ability to accurately and reliably characterise lamina behaviour
  - Composites require the use of sophisticated analysis techniques such as finite element analysis

- “This Code of Practice is based upon characterisation of the behaviour of unidirectional fibre reinforced lamina and the analysis of laminated composite structures through the use of advanced structural analysis techniques such as the finite element and boundary element methods.”

  Paragraph 1.1.1,
  Draft Australian Code of Practice
  Structural Design of Fibre Composites
Problems with existing characterisation of laminae

- Major variation in reported properties

<table>
<thead>
<tr>
<th>Material</th>
<th>Ultimate Tensile Stress (MPa)</th>
<th>Modulus of Elasticity (GPa)</th>
<th>Reference</th>
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<tr>
<td>E-Glass / Epoxy</td>
<td>1310</td>
<td>42</td>
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</table>
An alternative to stress

• Improved system can be gained by replacing thickness with “amount of reinforcement”

• New strength (load capacity) parameter:
  – Normalised Unit Strength = $N/mm_{\text{width}}$ per kg/m$^2$ of reinforcement

• New stiffness parameter:
  – Normalised Unit Modulus = $N/mm_{\text{width}}$ per kg/m$^2$ of reinforcement
Civil Engineering Design Data

![Graph showing Ultimate Tensile Stress vs. Ultimate Failure Strain and Normalised Unit Strength vs. Ultimate Failure Strain.](image-url)
• Normalised Unit Modulus and Normalised Unit Strength approach offers significantly improved consistency over traditional stress characterisation

• Initial experimentation shows properties not significantly affected by:
  – resin type
  – fabric weight
  – fabric form
Utilisation of Material Data in Design Code

<table>
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<tr>
<th>Direction</th>
<th>Action</th>
<th>Normalised Unit Modulus</th>
<th>Characteristic Failure Strain (%)</th>
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<td></td>
<td>N/mm per kg/m² reo.</td>
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Grade UGA Fibre Reinforcements
Characteristic Properties in Code

• 3 tables for reinforcement properties
  – Unidirectional E-glass
  – Unidirectional HS carbon
  – Random fiber glass

• Woven fabrics
  – Unidirectional properties modified by:
    • Percentage of fiber in direction of interest
    • Fabric modification factor
Design Properties in Code

• Lamina design capacity:
  \[(\phi R) = \phi_1 \phi_2 \phi_3 \phi_4 \phi_5 (f_{iio})\]

• Capacity modification factors (\(\phi\)) factors account for influences of:
  – Method of property determination \((\phi_1)\)
  – Production method \((\phi_2)\)
  – Production environment \((\phi_3)\)
  – Cure conditions \((\phi_4)\)
  – Load duration \((\phi_5)\)

• Research is continuing into appropriate capacity modification factors
Conclusion

• This paper has discussed a number of proposals currently under consideration for the Australian Code of Practice for fibre composites.
• The proposals are at present being discussed with industry stakeholders.
• Decisions regarding their implementation are expected to be taken early 2002.