ANNUAL REPORT

2006/07

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## CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td>Sponsors</td>
<td>2</td>
</tr>
<tr>
<td>Research Project summaries and associated publications</td>
<td>3</td>
</tr>
<tr>
<td>Polymer matrix composites</td>
<td>4</td>
</tr>
<tr>
<td>Biocomposites</td>
<td>4</td>
</tr>
<tr>
<td>Failure analysis and fracture mechanics</td>
<td>8</td>
</tr>
<tr>
<td>Interfaces</td>
<td>15</td>
</tr>
<tr>
<td>Joining and repair</td>
<td>16</td>
</tr>
<tr>
<td>Manufacture</td>
<td>18</td>
</tr>
<tr>
<td>Mechanical properties and characterisation</td>
<td>19</td>
</tr>
<tr>
<td>Nanocomposites</td>
<td>23</td>
</tr>
<tr>
<td>Non-destructive testing</td>
<td>27</td>
</tr>
<tr>
<td>Structural applications</td>
<td>30</td>
</tr>
<tr>
<td>Metal matrix composites</td>
<td>34</td>
</tr>
<tr>
<td>Ceramic matrix composites</td>
<td>35</td>
</tr>
<tr>
<td>Glass ceramic composites</td>
<td>35</td>
</tr>
<tr>
<td>General</td>
<td>40</td>
</tr>
<tr>
<td>Modelling, design and finite element analysis</td>
<td>43</td>
</tr>
<tr>
<td>Other publications</td>
<td>47</td>
</tr>
<tr>
<td>Books and contributions to books</td>
<td>47</td>
</tr>
<tr>
<td>Technical reports and technical memoranda</td>
<td>49</td>
</tr>
<tr>
<td>Composites Centre MSc project reports</td>
<td>57</td>
</tr>
<tr>
<td>PhD theses</td>
<td>61</td>
</tr>
<tr>
<td>Facilities</td>
<td>63</td>
</tr>
<tr>
<td>Academic staff directory (contact details and areas of expertise)</td>
<td>64</td>
</tr>
<tr>
<td>Keywords index</td>
<td>68</td>
</tr>
</tbody>
</table>

Front cover pictures (From left):
Helmet FE model; Scanning electron microscopy (SEM) image showing the fracture surfaces of borosilicate glass matrix composites containing a high volume fraction of carbon nanotubes (10 vol%) fabricated by hot-pressing in a dedicated facility in the Department of Materials; Post buckling deformation of a stiffened panel.
INTRODUCTION

Welcome to the Composite Centre’s 2006-2007 Annual Report which contains details of projects in progress in the period 1 January 2004 to 30 June 2007 and related publications. Also included is a Keyword Index, which can be used to identify Imperial staff members active in a particular aspect of composites research and an Academic Staff Directory, which contains staff contact details and areas of expertise.

Imperial’s composites research portfolio continues to be very strong and this reflects the high quality of research staff and facilities in our collaborating departments. The composites community in Imperial remains the largest of any UK university with more than 40 academic staff members engaged in research programmes which involve over 70 postgraduate research students and assistants. As you will see in this report the breadth of research activity that has characterised previous annual reports is continuing and I hope you will find the report both helpful and interesting.

The total value of composites research programmes included in the report is over £6m and this funding breaks down approximately as 37% from EPSRC, 17% from MOD and DTI, and the remaining 46% is provided by industry, EEC, and overseas organisations. A separate list of our research project sponsors is provided in this report and I would like to thank them all most sincerely for their support.

Finally if you wish to receive further information on any of the projects listed in this report you are most welcome to contact either me or the staff directly involved.

Paul Robinson
Head, The Composites Centre
SPONSORS

The support of the following organisations is acknowledged:

Advanced Composites Group
Airbus UK
ARL (US army)
Alenia
AMC
AMT
Atofina
BAE Systems
British American Racing
Bekaert NV, Belgium
BG Technology
British Nuclear Fuels
Brazilian Government
Bridgestone
Calcarb plc
CEC
CIRA
Creuzet
CSM
Cytec Engineered Materials
DERA
Delphi Automotive Systems, USA
Devold
DLR
Dowty Aerospace Propellers
DSTL
DTI
EADS
EPSRC
ESI
European Structural Integrity Society
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FACC
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Fiat
Ford
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Halliburton Energy Services
Hamble Aerostructures
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SIGOMP
Singapore Government
Smiths Aerospace
Tenax
Mitsui Babcock Ltd
University of Malta
Uponor Limited
URENCO
US Army ERO
US Automotive Composites Consortium
Westland Helicopters
The following sections contain details of all current and recently completed research projects in the field of composite materials in Imperial College. The projects are collected under broad headings and reflect the College-wide involvement of the staff from the eight participating academic departments. A list of publications from the past three years is included in each section.

Underlining in project summaries indicates Imperial College academic staff. Please see the staff directory (pp 64 – 67) for contact details and areas of expertise.
Novel biodegradable composite foams based on PDLLA/Bioglass and PDLLA/nanoceramic particles for tissue engineering

A R Boccaccini

In order to enhance the bioactivity and the osteoconductivity of scaffolds for bone tissue engineering, bioactive glass microparticles and TiO$_2$ nanoparticles are used as fillers and coatings of porous biodegradable polymeric substrates. In this project poly(DL-lactide) (PDLLA) composite foams containing different volume fractions of TiO$_2$ nanoparticles and coated by bioactive glass layers are produced and characterized in terms of their mechanical and biological response. The degree of bioactivity will be tested “in-vitro” by immersion of samples in simulated body fluid (SBF). Scanning electron microscopy (SEM) will be used for the analysis of the pore size and morphology in foams both in the as-received conditions and after immersion in SBF.

Bioactive composite scaffolds for bone tissue engineering with functionalised properties

A R Boccaccini

Bioglass-based foams are being produced and characterised for tissue engineering scaffolds. The foams are coated with a thin poly(D,L-lactic acid) (PDLLA) layer. The Bioglass-based foams, fabricated by the (patented) replication process are sintered under controlled conditions determined in experimental investigations. As-sintered foams are coated by dipping in a PDLLA dimethanol carbonate (DMC) solution. The bioactivity of foams is maintained in the PDLLA-coated foams, but the kinetics of the transformation of the crystalline phase (Na$_2$Ca$_2$Si$_3$O$_9$) in the foam struts to an amorphous phase was slower in the PDLLA-coated foams, compared with as-sintered foams. Another focus of the project is on assessing the improvement of mechanical strength and fracture resistance of the brittle foams, achieved by the polymer coating. The compressive and three-point bending strengths of the Bioglass-based foams are being measured. The study is completed with in-vitro and in-vivo studies to assess the suitability of the scaffolds for bone regeneration.

Functionalisation strategies for composite tissue engineering scaffolds

A R Boccaccini

The aim of this project is the functionalization of Bioglass-based scaffold surfaces in order to bind biomolecules (proteins or growth factors) with the purpose to promote cell adhesion and proliferation. The scaffold is a composite based on PDLLA coated Bioglass foams. The scaffold surface can be functionalized by adapting an immobilization technique as used in previous
Polymer Matrix Composites: Biocomposites

studies by the investigator. The sol–gel precursor for the surface modification is 3-Aminopropyl-triethoxysilane (APTS). After the surface treatment, the surface amine groups can dock to the carboxyl groups of a biomolecule. The advantage is that proteins are firmly bound to the scaffold surface while maintaining almost 100% activity.

PUBLICATIONS


**POLYMER MATRIX COMPOSITES**

**FAILURE ANALYSIS AND FRACTURE MECHANICS**

*Kink band microscopy of a failed unidirectional carbon fibre composite.*

**Fracture of highly filled polymers**

JG Williams  
M Charalambides

This study investigates how a composite's stiffness and fracture toughness change with volume fraction of particulate fillers (aLuminium trihydrate) in a PMMA matrix.

**Virtual testing of motorbike helmets**

U. Galvanetto and L. Iannucci

This project will be the continuation of the one on 'Numerical crash analysis of motorbike helmets'.

**Development of numerical models for failure propagation**

Silvestre T Pinho, Paul Robinson

This project will develop more accurate models for representing failure propagation numerically.

**Fracture toughness measurement for in-plane failure modes of laminated composites**

Silvestre T Pinho, Paul Robinson, Lorenzo Iannucci

This project aims at developing procedures for measuring the energy-absorbing capabilities of laminate composites during failure. Test methods for measuring the fracture toughness for the fibre-dominated and matrix-dominated failure modes will be developed.

**Development of Failure Models and Criteria for Laminated Composites**

Silvestre T Pinho, Paul Robinson

This project will contribute to the capability of predicting failure of laminated composites consisting of unidirectional plies, by focusing on (i) experimental characterisation of each failure mode, (ii) analytical interpretation of the failure mechanisms and (iii) development of numerical simulation tools for failure propagation.

**Delamination testing of stitched and asymmetric glass-fibre laminates**

B R K Blackman, J G Williams

This project is designed to develop methods for the evaluation of the delamination toughness of various forms of glass fibre-polymer matrix composite laminates. Of particular interest in this project are the effects of using asymmetric laminates and the effects of mode II loading.

**The Application of Fracture Mechanics to Engineering Adhesive Joints: An Investigation into Mode II and High Rate Loading.**

B R K Blackman
This project will investigate (i) methods to determine mode II fracture in adhesive joints and (ii) methodology to determine mode I and mode II fracture in adhesive joints at high loading rates. A combination of experimental, FE and theoretical studies will be undertaken. It is intended that these studies will enable the development of new test protocols which will be validated via ESIS TC4 round robins.

**Development of translaminar migration and fatigue facilities in a FE-based delamination growth model**

D Hitchings and P Robinson

The delamination of high stiffness and strength fibre reinforced polymer matrix composites remains one of the most debilitating damage modes in laminated structures. Much research effort has been expended over the last fifteen years to devise strategies for overcoming this problem. Several approaches are based in materials research with efforts focussed on the development of composites with improved interlaminar toughness and the provision of through-thickness reinforcement by the use of 3-D woven fabrics, stitching and z-pinning. Another line of attack is to provide the design engineer with tools to model and predict the development and propagation of delamination in laminated composite components. Finite element analysis modelling strategies have been developed incorporating fracture mechanics either directly or indirectly to predict delamination growth and these have shown considerable success in modelling simple single delamination cases subjected to monotonic loading. However practical structures often exhibit delamination failures which are much more complex than those in single delamination coupons. These complexities include multiple delaminations (often associated with impact) and the tendency of delaminations to migrate across adjacent plies. The effect of fatigue loading on delamination growth in practical composite structures has also received relatively little attention. The main aim of the proposed research is to develop an accurate predictive algorithm for delamination migration. Once this has been completed the research will focus on adding a fatigue loading capability to the delamination growth model.

**An investigation of the mechanical performance of z-pin reinforced composite laminates**

P Robinson and D Hitchings

A fundamental weakness of polymer matrix composite laminates is their susceptibility to delamination. Reinforcement in the through-thickness direction by inserting pins into the laminate, after the prepreg assembly stage, is one strategy which is currently being proposed to overcome this weakness. In this project the various failure processes associated with the pins, (including pull-out, shear-out, pin fracture and laminate damage) will be investigated experimentally and computationally. Finite element models will be developed for the failure processes in a form suitable for use in the design of z-pin reinforced components.

**Dynamic delamination modelling using FEM and damage mechanics**

L Iannucci and P Robinson

The advanced numerical modelling of composite materials, subject to a range of loadings some of which may be severe or dynamic, requires a detailed understanding of the damage initiation and growth within the composite material. Damage in the composite is usually in the form of matrix cracking crushing and fibre cracking and crushing. However, potentially the most debilitating damage mode is the debonding between laminae within the composite laminate. This can cause a dramatic reduction in compressive strength of the composite. The current project aims at developing advanced state-of-the-art Finite Element (FE) modelling techniques based on a damage mechanics approach to accurately model the initiation and propagation of the delamination due to impact/crush or other severe static/dynamic loadings. It expected that some modifications to the material models within LS-DYNA3D code will be required to improve the correlation between simulation and observed results.

**ELRIPS: Modelling the failure progression of resin infused composite structures for high performance applications**

D Hitchings and P Robinson
Composite structures produced by resin infusion techniques will inevitably suffer from variability in resin distribution due to either imprecise placement of the fibre preform layer(s) or distortion of the preform either during mould closure or during the infusion process. Whilst it will be possible to assess the impact of such variations in small coupons by physical testing it will be prohibitively expensive to investigate by test the significance of all possible cases of such defects for large structural components. Accurate predictive modelling will therefore be key to full exploitation of the potential of resin infused structures for high performance applications. In addition to aiding the design of large resin infused structures, such modelling will help firstly to establish general guidance on limits for acceptable defects, which will be important in the development of the manufacturing process, secondly to provide an accept / reject tool for components which have fallen outside these limits and thirdly to assess in-service damage and its interaction with the pre-existing defects. This research project will focus on the development of a finite element based strategy for the prediction of failure progression in resin infused structures.

**Investigation of the FE- modelling of fatigue driven delamination**

P Robinson and U Galvanneto

This project is investigating methods of representing fatigue degradation of an interface element. The aim is to develop a physically accurate and computationally efficient modelling technique for fatigue-driven delamination failure of laminated composite structures. Existing degradation methods already proposed in the literature and new methods will be investigated. A key aspect of the project is to develop a technique which can be applied to a variety of interface element laws.

**Lifetime prediction of adhesive joints**

A.C. Taylor, A.J. Kinloch

This project investigates the initiation and propagation of fatigue cracks in a typical adhesive joint geometry, the single lap joint. The project evaluates various methods to detect the initiation of fatigue cracks, including strain-gauge, compliance, microscopy and dye-penetrant techniques. The proportion of the total lifetime spent prior to crack initiation and during crack propagation will be calculated, and used to improve life predictions using fracture mechanics data.

**Fatigue performance of structural adhesives and nanocomposites**

A.C. Taylor, A.J. Kinloch

The performance of structural adhesives and novel nanocomposite materials under fatigue loading is being investigated using a fracture mechanics methodology.

**The effect of morphology on fracture toughness of thermoplastic-toughened epoxy resins incorporating carbon nanotubes**

B.R.K. Blackman, A.J. Kinloch, A.C. Taylor

**Quantification and modelling of the fracture & fatigue performance of nanoparticle-modified epoxies**

A.C. Taylor

This project will quantify and model the effect of the addition of nanoparticles on the performance of rubber-toughened epoxy. A range of microstructures will be manufactured. The fracture and fatigue performance will be measured, and the results will be compared with the performance of current composite materials.

**Mechanisms and modeling of stringer debonding in post-buckled carbon-fibre composite stiffened panels**

E S Greenhalgh & B G Falzon

The aims of this research are to characterise and model the mechanisms associated with skin/stringer debonding during post-buckling of composite stiffened panels under monotonic loading. The subsequent aim will be to develop simplified models, based on the critical physical mechanisms which control stringer debonding using a commercial finite element code (HKS ABAQUS). The research will focus on both pristine and partly debonded/damaged skin/stringer configurations, and will consider
primarily secondary-bonded structures. Through identifying the controlling factors that influence skin/stringer debonding, a further aim will be to develop optimised structural configurations that inhibit stringer detachment and thus improve post-buckling performance.

**Runway Stone Lofting Mechanisms & Impact on Aircraft Structures**

E S Greenhalgh, R Olsson & L Iannucci

Lofting of debris on runways and roads can lead to considerable damage to aircraft structures or car windscreens. It is vital for vehicle designers to be able to predict the probability of an impact on the structure exceeding a critical magnitude (either energy or momentum). However, there is a dearth of literature on the mechanisms which cause stone lofting. This project investigates the development of models to predict the stone lofting processes and the subsequent trajectories, and provides experimental validation of the studies through drop-weight impacts.

**Physically-based Mixed-Mode Failure Criteria for Delamination Growth in Composite Materials**

E S Greenhalgh, P Robinson

Although delamination has long been recognised as the ‘Achilles Heel’ of composites, reliable prediction of delamination growth is proving problematic, leading to the use of large safety factors & reticence in using composites in safety-critical applications. The recognised approach to studying delamination has been to characterise fracture toughness ($G$). The change in strain energy for an increment of crack growth. $G$ is split into mode I (peel) and mode II (shear) components because $G_c$ is dependent upon the mode mixity. By conducting experimental tests under controlled mixed-mode combinations, a delamination failure locus is produced, a graph of $G_I$ against $G_{II}$. Such a locus can be described by a mathematical expression (failure criterion) which can be implemented within a finite element model of a damaged composite structure. However, in practice, this approach has proved to be problematic & can be unreliable. Although a range of failure criteria have been developed, most of them are purely empirical. The aims of this proposal are to develop failure criteria which are based on the physics of delamination fracture in composites. These criteria will include parameters that relate to the influence of loading, material and environmental factors. These aims will be achieved through both experimental investigation (fracture toughness testing) and predictive (analytical and numerical) models, linking these approaches through detailed fractographic analysis. This approach will provide an insight into the dominant failure mechanisms that control delamination toughness, model their contributions, leading to formulation of a physically based failure criterion.

**Inverse method to determine stiffness variations in composites**

R. Olsson

Development of an inverse method to determine local stiffness in laminates by a combined optical/numerical method. The aim is to measure the local constitutive behaviour of impact damage zones.


PUBLICATIONS


**Lifetime prediction of adhesive joints**

A C Taylor, A J Kinloch

This project investigates the initiation and propagation of fatigue cracks in a typical adhesive joint geometry, the single lap joint. The project evaluates various methods to detect the initiation of fatigue cracks, including strain-gauge, compliance, microscopy and dye-penetrant techniques. The proportion of the total lifetime spent prior to crack initiation and during crack propagation will be calculated, and used to improve life predictions using fracture mechanics data.

**ELRIPS: Composite bonded repairs: strength and fatigue performance**

B G Falzon, J M Hodgkinson and U Galvanetto

Design methods for adhesively bonded composites require theoretical models to predict both strength and durability. Although analytical and experimental work has been reported on the static strength of bonded composites, little information is available on their fatigue behaviour. This work will address some of the basic engineering issues involved with the characterisation of fatigue life of patch repairs bonded with low-temperature cure adhesives. Repair integrity will be assessed using NDT and improved numerical techniques developed to predict strength and fatigue life.

**The application of fracture mechanics to engineering adhesive joints: an investigation into mode II and high rate loading**

B R K Blackman

This project will investigate (i) methods to determine mode II fracture in adhesive joints and (ii) methodology to determine mode I and mode II fracture in adhesive joints at high loading rates. A combination of experimental, FE and theoretical studies will be undertaken. It is intended that these studies will enable the development of new test protocols which will be validated via ESIS TC4 round robins.
**PUBLICATIONS**


Mould for the introduction of fibre waviness into a thick composite laminate.

**Process induced variability in resin infused composite structures**  
JM Hodgkinson, PT Curtis

This project builds on experience from a previous PhD project that investigated the effects of processing variables on output quality and mechanical properties of flat CFRP panels manufactured by the Resin Infused under Flexible Tooling (RIFT) process. The intention is to extend the work to investigate real structures and other resin infusion techniques. The work will feed into the development of probabilistic techniques for rapid certification of composite structures.

**Ultra-inert hierarchical fibre-reinforced nanocomposites**  
A. Bismarck, M. Shaffer & E. S. Greenhalgh

By combining conventional reinforcing fibres and nanomaterials within thermoplastic fluoropolymers we hope to create a new class of materials with superior mechanical, environmental and chemical performance, as well as significantly reduced through-life costs. The benefits of such materials will include reduced costs due to inspection and repair, increased durability of components and opportunities to introduce composite materials to new applications and platforms. This project will tackle the key fundamental questions required for the successful creation of such materials. Specifically, the interactions between both conventional carbon fibres and nanomaterials/nanotubes will be understood and adjusted in order to allow the development of methods to fabricate effective hierarchical composites. In addition, a detailed study of the deformation and fracture mechanisms of these new architectures will provide the knowledge base to tailor the proportions and distribution of the composite constituents.
High speed video footage of a compression test failure of a 10mm thick waisted unidirectional carbon fibre specimen. B.R.K. Blackman, A. J. Kinloch

Compression testing of thick composites

J M Hodgkinson, P Robinson

It has been recognised for some time that compression strength data obtained for thin (2mm) UD laminates is not realised for thicker specimens. This project intends to investigate specimen and jig design using experimental and modelling techniques in order to determine whether this is a true size effect, influenced by manufacturing difficulties associated with thick laminates. Or whether hitherto poor experimental techniques have been the problem.

MYMOSA, MotorcYcle and MOtorcyclist SAFety

U. Galvanetto, L. Iannucci, R. Olsson, P. Robinson

Fracture toughness measurement for in-plane failure modes of laminated composites

Silvestre T Pinho, Paul Robinson, Lorenzo Iannucci

This project aims at developing procedures for measuring the energy-absorbing capabilities of laminate composites during failure. Test methods for measuring the fracture toughness for the fibre-dominated and matrix-dominated failure modes will be developed.

The fracture behaviour of adhesively bonded carbon-fibre composite

B R K Blackman, J G Williams

This project is investigating several important issues relating to the use of adhesively bonded carbon fibre composites in the automotive industry, including the effects of pre-bond moisture and the effects of impact and high rate deformation. Both fracture mechanics test coupons and bonded composite structures are to be evaluated.

The machining of polymers for automotive applications

B R K Blackman, J G Williams

This project will investigate the parameters which affect the surface quality and precision of machined polymer components including the effects of fracture toughness, yield stress and ductility of the materials on the surface roughness of machined parts. It is well known that rate is a major factor since machining is usually performed at high rates and the materials used are visco-elastic. The rates are sufficiently high to generate adiabatic heating which can greatly affect the product quality.

Development of a Compression Strength Test for Thick CFRP Composites

P Robinson and J M Hodgkinson

Confidence in the capability of composites for primary structural components of aircraft has lead to the increasing use of composites for thick sections. Current test standards (eg ASTM and
ISO) for compression strength of unidirectional laminates are focussed on relatively thin (ie 2mm thick) laminates for design purposes, but manufacturers need to be confident of the basic material properties of thick laminates for use in design. Research programmes carried out thus far, at IC and elsewhere, suggest that when the only variable is the coupon thickness, 10mm thick coupons produce “apparent” strengths about 50% lower than those from 2mm thick laminates. The strength of a thick laminate may not be the same as that of a thinner laminate due to differences in, for example, fibre waviness, residual stresses and defect distribution that can arise during manufacture, all of which could be exacerbated as the laminate thickness increases. But it is also the case that the failure mode rarely occurs in the gauge section when current test methods are applied to thick laminates and so the low ‘apparent’ compression strength may not be representative of the actual strength.

This project is for the design, development and evaluation of a test method suitable for compression strength measurement of thick composite laminates. The strategy will be to use finite element analysis in the design of the test method (specimen and jig) prior to manufacture and evaluation trials.

The fatigue behaviour of nano-modified adhesives

**BRK Blackman, AJ Kinloch, AC Taylor**

To characterise the fatigue and fracture behaviour of nano-modified adhesive systems and relate to microstructure.

The blast survival of window constructions

**BRK Blackman, JP Dear**

Many buildings in cities and towns and other locations have not been designed to withstand explosive blast and energetic flying debris. A vulnerability of many buildings is their windows and when these are subjected to blast damage often fragmented glass is showered onto the occupants in the building. This project will characterise and model blast loading of window constructions.

Nanotube Wettability: the key to hierarchical composites

**M Shaffer, Alexander Bismarck, Emile Greenhalgh**

This project will focus on introducing carbon nanotubes into matrices for conventional fibre composites. To achieve this goal, as detailed a control of the nanotube surface, as has been developed for the interfaces of conventional fibre composites, will be needed. Although much of the understanding developed for conventional carbon fibre systems may be applied to the nanomaterials, the change in scale is expected to bring new phenomena to light.

Physically-based Mixed-Mode Failure Criteria for Delamination Growth in Composite Materials

**E S Greenhalgh, P Robinson**

Although delamination has long been recognised as the ‘Achilles Heel’ of composites, reliable prediction of delamination growth is proving problematic, leading to the use of large safety factors & reticence in using composites in safety-critical applications. The recognised approach to studying delamination has been to characterise fracture toughness (G). The change in strain energy for an increment of crack growth, G is split into mode I (peel) and mode II (shear) components because Gc is dependant upon the mode mixity. By conducting experimental tests under controlled mixed-mode combinations, a delamination failure locus is produced, a graph of GI against GII. Such a locus can be described by a mathematical expression (failure criterion) which can be implemented within a finite element model of a damaged composite structure. However, in practice, this approach has proved to be problematic & can be unreliable. Although a range of failure criteria have been developed, most of them are purely empirical. The aims of this proposal are to develop failure criteria which are based on the physics of delamination fracture in composites. These criteria will include parameters that relate to the influence of loading, material and environmental factors. These aims will be achieved through both experimental investigation (fracture toughness testing) and predictive (analytical and numerical) models, linking these approaches through detailed fractographic analysis. This approach will provide an insight into the dominant failure mechanisms that control delamination toughness, model their contributions, leading to formulation of a physically based failure criterion.

Modelling of impact damage in composite laminates

**R. Olsson**

Development of analytical and FE structural models of impact damage in laminates. The aim is to gain basic understanding of key parameters affecting membrane and bending stiffness of impact damage zones.
Inverse method to determine stiffness variations in composites

R. Olsson

Development of an inverse method to determine local stiffness in laminates by a combined optical/numerical method. The aim is to measure the local constitutive behaviour of impact damage zones.

Full field strain measurements of panels loaded after impact

R. Olsson

Full field optical strain measurement of specimens with impact damage loaded in tension and compression. The data was used in related PhD project to determine stiffness reduction in impact damage zone by an inverse method.

PUBLICATIONS


Adrian F Gill, Paul Robinson, Dennis Hitchings, Measurement of damage progression in open hole tension tests, 16th International Conference on Composite Materials, Japan, (July, 2007), .

Paul Robinson, Steven Message, Interface effects in mode II interlaminar toughness testing of unidirectional composites, 16th International Conference on Composite Materials, Japan, (July, 2007), .


Carbon nanotube/glass composites
A R Boccaccini (+Collaborators at University of Padova, Italy)

The suitability of carbon nanotubes to be used as reinforcement in silicate glass matrix is being investigated. Model composite systems are fabricated by hot-pressing and the mechanical properties, hardness, fracture strength, fracture toughness, are measured and discussed.

The fatigue behaviour of nano-modified adhesives
BRK Blackman, AJ Kinloch, AC Taylor

To characterise the fatigue and fracture behaviour of nano-modified adhesive systems and relate to microstructure

The influence of nano-particles on the ductility of styrene based plastics
BRK Blackman, DR Moore, JG Williams

Strategies for the incorporation of nano-particles into thermoplastic polymers, and the effects on toughness and ductility is being investigated in this project.

Toughness of Polymer Nanomaterials
A J Kinloch, A C Taylor

The research uses a novel approach in an attempt to increase the toughness of structural adhesives and composites, whilst maintaining the required elevated-temperature and fire-resistance properties. This new non-polymeric toughening approach is based upon the concept of developing nanocomposites, using nano-ceramic and nano-tube materials.

Fatigue performance of structural adhesives and nanocomposites
A.C. Taylor, A.J. Kinloch

The performance of structural adhesives and novel nanocomposite materials under fatigue loading is being investigated using a fracture mechanics methodology.

Nanoclay-modified epoxy for electrical applications
A.C. Taylor

This project investigates the structure, mechanical and electrical properties of epoxy polymers modified with nanoclay.
Nanoparticle-modified coatings
A.C. Taylor

The microstructure and properties of polyester resins modified with nanoparticles will be investigated. Thermal degradation during processing is also considered.

Quantification and modelling of the fracture & fatigue performance of nanoparticle-modified epoxies
A.C. Taylor

This project will quantify and model the effect of the addition of nanoparticles on the performance of rubber-toughened epoxy. A range of microstructures will be manufactured. The fracture and fatigue performance will be measured, and the results will be compared with the performance of current composite materials.

Fracture of Nano silica and rubber toughened epoxies at high rate
A.C. Taylor

Ultra-inert hierarchical fibre-reinforced nanocomposites
A. Bismarck, M. Shaffer & E. S. Greenhalgh

By combining conventional reinforcing fibres and nanomaterials within thermoplastic fluoropolymers we hope to create a new class of materials with superior mechanical, environmental and chemical performance, as well as significantly reduced through-life costs. The benefits of such materials will include reduced costs due to inspection and repair, increased durability of components and opportunities to introduce composite materials to new applications and platforms. This project will tackle the key fundamental questions required for the successful creation of such materials. Specifically, the interactions between both conventional carbon fibres and nanomaterials/nanotubes will be understood and adjusted in order to allow the development of methods to fabricate effective hierarchical composites. In addition, a detailed study of the deformation and fracture mechanisms of these new architectures will provide the knowledge base to tailor the proportions and distribution of the composite constituents.

Nanotube Wettability: the key to hierarchical composites
M Shaffer, Alexander Bismarck, Emile Greenhalgh

This project will focus on introducing carbon nanotubes into matrices for conventional fibre composites. To achieve this goal, as detailed a control of the nanotube surface, as has been developed for the interfaces of conventional fibre composites, will be needed. Although much of the understanding developed for conventional carbon fibre systems may be applied to the nanomaterials, the change in scale is expected to bring new phenomena to light.

Morphing wing technologies
L Iannucci and D Dye

The development of novel morphing wing technologies using Nanotubes, SMA, Piezo-ceramics, EAP, etc. A scoping study to investigate the 'best' option to replace control surfaces.

Smart wing development
L Iannucci

This project involves the fabrication and testing of novel morphing concepts to replace conventional control surfaces for flight control. One concept will examine the use of aligned nanotubes as an actuator. The novel approach will also be tested in a wind tunnel to investigate aeroelasticity effects.
**PUBLICATIONS**


Damage detection based on proper orthogonal decomposition

U. Galvanetto

The Proper Orthogonal Decomposition (POD) is emerging as a powerful numerical tool to examine experimental data in dynamics and vibrations. The method has been used to quantify spatial coherence in turbulence problems in fluid dynamics and oscillating structures monitored by several sensors and to determine the number of active state variables in a dynamic structural system. POD theory will be applied to the simulation of damage detection in solid structures.

A cellular system for wireless structural integrity monitoring (EPSRC)

P Cawley

This is a joint project with Professor Gordon Hayward and Dr Alistair McNab of the Centre for Ultrasonic Engineering at Strathclyde University. It is investigating the application of wireless communications to interconnect a network of permanently mounted ultrasonic sensors for the structural monitoring of off-shore structures, power and process plant, nuclear power stations and aircraft, where practical monitoring will often necessitate the deployment of a large number of sensors and their associated wiring. The connections and wiring are expensive to install, they are susceptible to damage and can compromise the performance of the sensor network; a wireless system is therefore potentially highly advantageous. The project is investigating three types of transducer, each having its own area of application with different level of complexity. These can be summarised as follows: (1) a self contained ‘matchbox’ sensor for the in-situ measurement of material thickness and the monitoring of crack propagation; (2) An embedded piezoelectric sensor for the passive monitoring of carbon fibre reinforced composite plates using acoustic emission; (3) an array transducer producing imaged data using Lamb waves for shell and plate inspection. Although these transducers are substantially different, the challenge is to design a modular electronic system which will enable them to be integrated within a common
communications network and to allow relevant sensor information to be passed back to a central host computer. This involves the implementation of a hierarchy of data acquisition, signal processing and communication functions. The Imperial College part of the project is primarily the design of the array transducer for shell and plate inspection.

**Improved understanding of attenuating ultrasonic waves**

*M Lowe*

This is a joint project with Dr Marc Deschamps at the University of Bordeaux. The theory of guided wave propagation in plates is well understood for structures in which there is no significant energy loss, such as Lamb waves in a free metal plate. However, there are circumstances when the energy of the waves may decay rather rapidly. These include leaky waves, when a plate is immersed in a fluid or embedded in another solid, and damped waves, when materials such as plastics have strong energy-absorbing characteristics. Theoretical models have been developed for these cases and are mostly satisfactory, but there are some aspects which are poorly understood. This project aims to improve the understanding of the decay phenomena. This understanding will be very valuable for the development of inspection techniques for such structures.

**The propagation of energy in ultrasonic waves in anisotropic or curved plates**

*M Lowe*

This is a joint project with Dr Marc Deschamps at the University of Bordeaux. A thorough understanding of the nature of the propagation of guided waves in plates is fundamental to the exploitation of long-range testing techniques, but some aspects are still only moderately well understood. So far the techniques which are emerging are addressing the simplest cases of waves which propagate in flat isotropic plates or along the principal axes of anisotropic plates (carbon fibre composites for example) or along the axes of pipe structures. A scientific understanding of the nature of the energy propagation in arbitrary directions in plates, which may in general be anisotropic, absorbing, and curved, will support the further development of such techniques. The project aims to improve understanding in general in this area with initial emphasis on flat anisotropic plates.

**Large area inspection by guided waves (RCNDE - core project)**

*P Cawley*

This project will investigate the fundamental principles of using guided ultrasonic waves to create a map of defects in a complex shell structure. This technique is well established for pipe applications - essentially one-dimensional with low feature density (bends, stiffeners, joints, branches etc). Recent research has extended the concept to the scanning of simple plates, again with low feature density, e.g. the detection of corrosion in petrochemical storage tanks. A major step forward, which will be the topic of this new research project, would be to develop such a scanning technique for structures with higher feature density. This is very ambitious, but it would open up this idea to a vastly wider range of applications, such as aircraft structures, ship structures and containments with stiffeners. The difficulty is that the waves will both reflect and mode-convert at the structural features as well as at the defects, creating complex reflection signals which will have to be interpreted. This will necessitate the use of higher frequencies and higher modes than have been considered to date, and will require work in wave mechanics, transduction, and signal processing.

**Development of the thermosonic method of NDT**

*P Cawley*

The thermosonic technique uses a pulse of high power ultrasound in the 20-100 kHz frequency range to excite the test structure; the resulting vibration field causes crack surfaces to rub, so generating heat which causes a transient temperature rise that is detected by a thermal imaging camera. The technique was recently developed in USA, but its sensitivity in different circumstances has not been defined and the method has not been engineered to allow reliable, reproducible testing. This project aims to clarify the mechanism of heat generation at a crack and to identify the amplitude and distribution of the vibration field required to obtain reliable defect detection at different locations in the structure. An excitation system
will then be designed that is easy to apply in a reproducible way and the system will be tested on a variety of components. The sensitivity obtained with the thermosonic technique will also be compared with that achieved using the same excitation but by measuring the vibration at harmonics of the drive frequency, rather than the heat generation.

**PUBLICATIONS**


Virtual testing of motorbike helmets

U. Galvanetto and L. Iannucci

This project will be the continuation of the one on 'Numerical crash analysis of motorbike helmets'.

Buckling analysis of composite struts

U. Galvanetto and B. G. Falzon

The project aims at investigating numerically the idea that a small inclination in the direction of the fibres of composite struts could increase their buckling load. The project investigates the behaviour of struts similar to the ones used in the suspensions systems of formula one cars.

Computer aided design of horse-riding helmets

U. Galvanetto and L. Iannucci

This project aims at improving the designing process of horse riding helmets by investigating the possibility of defining a numerical procedure, which should be able to simulate the impact tests. The numerical procedure should be able to reproduce the results obtained in real tests and should also have a certain predictive capability.

Residual Strength and Stiffness of Blast Damaged Composite Panels

Dr L A Louca

Additional funding to the above project has been obtained to investigate joint panel interaction and failure.

Residual strength and stiffness of blast damaged composites

L. A. Louca

A primary design consideration for naval vessels is the effects of an impulsive load due to an underwater explosion or an air blast. Key to the design process is to establish the damage tolerance of the structure involved which entails determining the residual strength and stiffness characteristics after the structure has been subjected to the impulsive load. The main objective of is to investigate the residual strength and stiffness characteristics of a typical composite panel under various levels of impulsive loading. This will be achieved by a combination of both experimental and numerical simulations in order to gain an understanding of the type of failure modes and the development of the damage process mechanisms that can occur. In particular the modelling of delamination, which has been observed in previous shock loading tests will be investigated for large panels using a volumetric energy dissipation function. The residual capacity will
then be characterised as a function of damage level. This can then be used to assess the vulnerability of the vessel depending on the level of impulsive load and the location of the damaged panel.

**Delamination testing of stitched and asymmetric glass-fibre laminates**

_B R K Blackman, J G Williams_

This project is designed to develop methods for the evaluation of the delamination toughness of various forms of glass fibre-polymer matrix composite laminates. Of particular interest in this project are the effects of using asymmetric laminates and the effects of mode II loading.

**Mechanisms and modeling of stringer debonding in post-buckled carbon-fibre composite stiffened panels**

_E S Greenhalgh & B G Falzon_

The aims of this research are to characterise and model the mechanisms associated with skin/stringer debonding during post-buckling of composite stiffened panels under monotonic loading. The subsequent aim will be to develop simplified models, based on the critical physical mechanisms which control stringer debonding using a commercial finite element code (HKS ABAQUS). The research will focus on both pristine and partly debonded/damaged skin/stringer configurations, and will consider primarily secondary-bonded structures. Through identifying the controlling factors that influence skin/stringer debonding, a further aim will be to develop optimised structural configurations that inhibit stringer detachment and thus improve post-buckling performance.

**Full field strain measurements of panels loaded after impact**

_R. Olsson_

Full field optical strain measurement of specimens with impact damage loaded in tension and compression. The data was used in related PhD project to determine stiffness reduction in impact damage zone by an inverse method.

**Impact performance and shock from advanced composites technology (IPSOFACTO)**

_L Iannucci, P Robinson_

Achieving adequate impact worthiness is the largest obstacle to extending the use of composite components in aerospace, marine propulsion, or defence systems, especially for safety critical components. While composites offer weight benefits, performance under severe impact or shock loading is difficult to assess. In particular non-linear dynamic finite element analyses must be validated against the large range of failure mechanisms exhibited by composite materials. The validation at a component level can be very expensive and time consuming. Improved simulation of the impact event and the degradation of composite properties will enable “right first time” design and reduce testing requirements. The key to meeting such improvements is the development of novel failure models which can be implemented into commercial Finite Element systems. These objectives can be met by the unique resources of the consortium partners, which include world-leading academic centres and industrial sectors. Research will be focussed on end-user needs, and enable the commercial growth of the aerospace composites manufacturing industry. Benefits will target the 2010 - 2013 time frame.

**Development of a wing joint and anti-icing system**

_P Robinson and B Falzon_

This research is funded by the DTI and industry for one year, as part of a consortium studying a variety of aspects in the development of a new composite small aircraft. Imperial’s part of the project includes two main themes: the development of a structural wing joint and an investigation of anti-icing techniques. The wing joint development will include design, analysis and validation testing. An experimental test programme will be performed to assess possible anti-icing strategies for a composite wing structure.


METAL MATRIX COMPOSITES

FEGSEM images showing TiB2 platelets visible after dissolution of Aluminium alloy matrix.

Processing and characterisation of Al-Alloy -
titanium diboride particulate metal matrix
composites

Peter Lee, Richard Dashwood

Titanium diboride (TiB2) particles are commonly used in aluminium master alloys as a grain refining agent. London and Scandinavian Metallurgical Company Ltd. (LSM) produce master alloys via a patented in-situ salt reaction process with a typical TiB2 concentration of 0.2 wt. %. To further take advantage of the physical and mechanical properties of the TiB2 particles, LSM have adapted their process to introduce higher concentrations of TiB2, up to a limit of ~ 8 wt. %. Beyond this concentration the increased viscosity of the melt results in inadequate casting behaviour. A centrifugal casting technique has been used to concentrate the TiB2 particulate beyond the level achievable by in-situ reaction alone, to produce a particulate reinforced metal matrix composite. In this project settling experiments were carried out in order to ensure that excessive clustering of the TiB2 particles within the AA2618 did not occur. Centrifugal accelerations ranging from 10g to 68g were employed to cast composites with a range of TiB2 concentrations, with a maximum of 30 wt. % (22 vol. %) achieved whilst casting at 68g. Preliminary investigations have shown that X-Ray Computed Tomography (XRCT) has the potential to be a very effective tool for characterising the distribution of TiB2 particles.

PUBLICATIONS


Scanning electron microscopy (SEM) image showing the fracture surfaces of borosilicate glass matrix composites containing a high volume fraction of carbon nanotubes (10 vol%) fabricated by hot-pressing in a dedicated facility in the Department of Materials.

**Optomechanical glass matrix composites**

**A R Boccaccini**

The objective of the present project is to develop processing procedures for the fabrication of novel transparent glass fibre (and glass microsphere) reinforced silicate glass matrix composites with improved mechanical and optical properties for technical applications. The project includes also the characterisation of the mechanical properties of the new products, including fracture strength, toughness and thermal shock resistance, and the measurement of optical properties, including composite effective refractive index and light transmittance. Existing models for predicting the thermomechanical behaviour of composite systems are being adapted and applied to the composites developed in this work. Moreover, modelling of the optical properties of selected composite systems will be carried out. The successful completion of the project will lead to novel, transparent and strong glass-glass composites exhibiting fracture toughness values at least three times higher than those of monolithic glass. These new totally inorganic materials will be attractive for various optical applications where currently standard monolithic glasses cannot be used due to poor mechanical properties. More conventional applications of wide commercial interest, e.g. as architectural and building materials, will be also possible, including applications where high fire and thermal shock resistance are required and where standard laminated glass are not suitable due to their organic components.

**Shape distortion during sintering of glass-containing graded composite materials**

**A R Boccaccini (+Collaborators at Technical University of Aachen, Germany)**

Powder technology is the simplest, most cost-effective and therefore the preferred method to fabricate functionally graded composite materials with glass or ceramic matrices. In general, however, due to their varying composition, different areas of a graded material will shrink at different rates during sintering. This difference in shrinkage rate often induces shape distortion, warping or crack formation. Thus, the powder compact preparation parameters and the sintering process itself must be optimised to avoid such defects. The aim of the present...
Ceramic Matrix Composites: Glass Ceramic Composites

Project is to develop methods for predicting distortion and cracking during sintering of graded composites. The experimental investigation concentrates on glass/metal and glass/ceramic composites with different graded and layered microstructures. Shrinkage and shape distortion of powder compacts during sintering is assessed by the heating microscopy technique. Available theoretical models for the sintering of composite materials are to be adapted for the particular problem of glass and ceramic matrix composites with graded composition and the results compared with the experimental data.

Novel biodegradable composite foams based on PDLLA/Bioglass and PDLLA/nanoceramic particles for tissue engineering

A R Boccaccini

In order to enhance the bioactivity and the osteoconductivity of scaffolds for bone tissue engineering, bioactive glass microparticles and TiO2 nanoparticles are used as fillers and coatings of porous biodegradable polymeric substrates. In this project poly(DL-lactide) (PDLLA) composite foams containing different volume fractions of TiO2 nanoparticles and coated by bioactive glass layers are produced and characterized in terms of their mechanical and biological response. The degree of bioactivity will be tested “in-vitro” by immersion of samples in simulated body fluid (SBF). Scanning electron microscopy (SEM) will be used for the analysis of the pore size and morphology in foams both in the as-received conditions and after immersion in SBF.

Bioactive composite scaffolds for bone tissue engineering with functionalised properties

A R Boccaccini

Bioglass?-based foams are being produced and characterized for tissue engineering scaffolds. The foams are coated with a thin poly(D,L-lactic acid) (PDLLA) layer. The Bioglass?-based foams, fabricated by the (patented) replication process are sintered under controlled conditions determined in experimental investigations. As-sintered foams are coated by dipping in a PDLLA dimethanol carbonate (DMC) solution. The bioactivity of foams is maintained in the PDLLA-coated foams, but the kinetics of the transformation of the crystalline phase (Na2Ca2Si3O9) in the foam struts to an amorphous phase was slower in the PDLLA-coated foams, compared with as-sintered foams. Another focus of the project is on assessing the improvement of mechanical strength and fracture resistance of the brittle foams, achieved by the polymer coating. The compressive and three-point bending strengths of the Bioglass?-based foams are being measured. The study is completed with in-vitro and in-vivo studies to assess the suitability of the scaffolds for bone regeneration.

Functionalisation strategies for composite tissue engineering scaffolds

A R Boccaccini

The aim of this project is the functionalization of Bioglass?-based scaffold surfaces in order to bind biomolecules (proteins or growth factors) with the purpose to promote cell adhesion and proliferation. The scaffold is a composite based on PDLLA coated Bioglass?-foams. The scaffold surface can be functionalized by adapting an immobilization technique as used in previous studies by the investigator. The sol – gel precursor for the surface modification is 3-Aminopropyl-triethoxysilane (APTS). After the surface treatment, the surface amine groups can dock to the carboxyl groups of a biomolecule. The advantage is that proteins are firmly bound to the scaffold surface while maintaining almost 100 % activity.

Bioactive coatings on biomedical metallic devices by electrophoretic deposition

A R Boccaccini, J. A. Roether (partially funded by EU Network of Excellence (EU Commission)

Ni-Ti shape memory alloys have recently been introduced to medicine and dentistry where the shape memory effect and superelastic behaviour are fully exploited. They have applications as teeth root prosthesis, bone plates and marrow needles for fixing broken bones and in prosthetic joints. Surface coating of the NiTi substrate is desirable to improve the corrosion resistance and the biocompatibility. It is of particular interest to prevent Ni release and to improve the adhesion of cells to the surface of the implants. Moreover the coating of the NiTi substrate with a
biocompatible ceramic may lead to the design of novel composites for surgical implants.

Development of new materials from wastes by means of sintering or vitrification and crystallisation

A R Boccaccini, R D Rawlings, R Sweeney C. Cheeseman

Many industrial processes produce solid waste in fine powder form, e.g. fly ashes from domiciliary incinerators and from coal fired power stations. Most solid wastes are buried in land-fills, which is a costly and environmentally unsatisfactory process. It is essential to search for new options for reuse of these wastes. The current research focuses on the development of glasses and glass-ceramics, and their composites, from wastes.
PUBLICATIONS


TiO$_2$ nanoparticles incorporated in biodegradable polymer composite foams for tissue engineering scaffolds. The surface topography of foam walls leads to better cell attachment

**New ceramic coatings for carbon bonded carbon fibre (CBCF) materials**

A. R Boccaccini, R. D. Rawlings

This project is focussed on the development of novel ceramic coatings for carbon-carbon composite materials. Coating microstructure as well as mechanical and impact properties will be evaluated.

**Coal-biomass ash deposition during deeply staged combustion**

J Williamson

The co-firing of biomass with coal is now widely practised by all UK power stations to take advantage of the UK Renewable Obligation Credits (ROC's). However, the interaction of the alkali rich residues from biomasses are known to modify the ash properties and deposition behaviour of an aluminosilicate coal ash. The performance of low NOx burners, fitted to all power stations to meet the NOx emissions legislation, is known to be sensitive to burner aerodynamic changes with ash deposition. This project will investigate the changes in ash behaviour as the the combustion conditions are made even more reducing to meet the planned introduction of lower emission levels to be introduced by the EU. The ashes and deposits produced from co-firing current imported biomass and future energy crops will feature as part of the experimental programme.

**Reducing slagging and fouling constraints in high levels of biomass co-firing**

J Williamson

The power generators have responded to the need to reduce carbon dioxide emissions by
replacing some of the coal with biofuels. Nevertheless, powerstation operators remain cautious in the levels of replacement, fearing that the interaction of a highly alkaline biomass residue with an aluminosilicate coal ash could cause serious boiler slagging. This project will use pilot plant facilities to investigate the nature of the deposits (crystalline and amorphous materials) formed with successively increasing amounts of biomass. The effectiveness of selective fuel additives aimed at retaining volatile alkaline species will be investigated.

Development of low cost systems of co-utilisation of biomass in large power plant

J Williamson

The need to reduce carbon dioxide emissions from large UK power plant has seen the introduction of co-firing technology with imported biomass and coal. The Imperial College activity was to assess the impact of the introduction of a highly alkaline ash on the properties of the coal ash. The microstructure and properties of ashes and deposits from combustion test facilities were characterised.

**PUBLICATIONS**


MODELLING, DESIGN AND FINITE ELEMENT ANALYSIS

Helmet FE model

ELRIPS: Composite bonded repairs: strength and fatigue performance
B G Falzon, J M Hodgkinson and U Galvanetto

Design methods for adhesively bonded composites require theoretical models to predict both strength and durability. Although analytical and experimental work has been reported on the static strength of bonded composites, little information is available on their fatigue behaviour. This work will address some of the basic engineering issues involved with the characterisation of fatigue life of patch repairs bonded with low-temperature cure adhesives. Repair integrity will be assessed using NDT and improved numerical techniques developed to predict strength and fatigue life.

Compression testing of thick composites
JM Hodgkinson, P Robinson

It has been recognised for some time that compression strength data obtained for thin (2mm) UD laminates is not realised for thicker specimens. This project intends to investigate specimen and jig design using experimental and modelling techniques in order to determine whether this is a true size effect, influenced by manufacturing difficulties associated with thick laminates. Or whether hitherto poor experimental techniques have been the problem.

MYMOSA, MotorcYcle and MOtorcyclist SAgety
U. Galvanetto, L.Iannucci, R.Olsson, P.Robinson

Computer aided design of horse-riding helmets
U. Galvanetto and L.Iannucci

This project aims at improving the designing process of horse riding helmets by investigating the possibility of defining a numerical procedure, which should be able to simulate the impact tests. The numerical procedure should be able
to reproduce the results obtained in real tests and should also have a certain predictive capability.

**Residual Strength and Stiffness of Blast Damaged Composite Panels**

**Dr L A Louca**

Additional funding to the above project has been obtained to investigate joint panel interaction and failure.

**PUBLICATIONS**


Falzon, B.G. and Hitchings, D., Capturing mode switching in postbuckling composite panels using a modified explicit procedure, Composite Structures 60, (2003), pp447-453.


Falzon, B.G., Buckling and postbuckling of stiffened composite structures, Chapter 9 in 'Stability of Plated Structures', (March 2006).


Other Publications: Books and Contribution to Books

OTHER PUBLICATIONS

BOOKS AND CONTRIBUTIONS TO BOOKS


### TECHNICAL REPORTS and TECHNICAL MEMORANDA

All non-confidential Composites Centre Technical Reports (TR) and Technical Memoranda (TM) are listed below. TRs give a comprehensive coverage of the subject, whilst TMs give a briefer survey of the topic. The reports are taken from MSc Composite Materials Project Reports, except those that are indicated by *, which have been taken from PhD thesis/progress reports and **, which are taken from Research Assistants’ reports.

#### TECHNICAL REPORTS

**2006**

<table>
<thead>
<tr>
<th>Title and authors</th>
<th>TR Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investigation into resin infused composites for marine applications</td>
<td>TR06/02</td>
</tr>
<tr>
<td>Adeline, B. and Hodgkinson, J.M.</td>
<td></td>
</tr>
<tr>
<td>Low cost manufacturing of composite structure via resin infusion under flexible</td>
<td>TR06/03</td>
</tr>
<tr>
<td>tooling</td>
<td></td>
</tr>
<tr>
<td>Awang Ngah, S. and Hodgkinson, J.M.</td>
<td></td>
</tr>
<tr>
<td>The fracture mechanics and micromechanisms of resin rich composites</td>
<td>TR06/04</td>
</tr>
<tr>
<td>Bertenshaw, T. and Hodgkinson, J.M.</td>
<td></td>
</tr>
<tr>
<td>A new composite rig for a new composite boat</td>
<td>TR06/05</td>
</tr>
<tr>
<td>Bonfigli, F. and Hodgkinson, J.M.</td>
<td></td>
</tr>
<tr>
<td>Investigation in energy absorption capability of composite tubes</td>
<td>TR06/06</td>
</tr>
<tr>
<td>Cho, J. and Iannucci, L.</td>
<td></td>
</tr>
<tr>
<td>Resin infusion of composite sandwich structures for skis and snowboards</td>
<td>TR06/07</td>
</tr>
<tr>
<td>Fergusson, A. and Dear, J.</td>
<td></td>
</tr>
<tr>
<td>Low cost manufacturing for non-crimp fabrics composites</td>
<td>TR06/08</td>
</tr>
<tr>
<td>Kasbon, S. and Hodgkinson, J.M.</td>
<td></td>
</tr>
<tr>
<td>Characterisation of autoclave cured carbon-epoxy RIFT laminates</td>
<td>TR06/09</td>
</tr>
<tr>
<td>Lees, M. and Hodgkinson, J.M.</td>
<td></td>
</tr>
<tr>
<td>The virtual fields method</td>
<td>TR06/10</td>
</tr>
<tr>
<td>Moreno, J. and Robinson, P.</td>
<td></td>
</tr>
</tbody>
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**2005**

<table>
<thead>
<tr>
<th>Title and authors</th>
<th>TR Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>FE simulation of dent growth in compressed sandwich panels</td>
<td>TR05/01</td>
</tr>
<tr>
<td>Ahmed, A., and Olsson, R.</td>
<td></td>
</tr>
<tr>
<td>Interlaminar fracture mechanics – some unresolved issues</td>
<td>TR05/02</td>
</tr>
<tr>
<td>Batho, T. and Hodgkinson, J.M.</td>
<td></td>
</tr>
<tr>
<td>Fine structure carbon nanotube reinforced polyamide nanocomposites</td>
<td>TR05/03</td>
</tr>
<tr>
<td>Chu, T., Bismarck, A., and Shaffer, M.</td>
<td></td>
</tr>
</tbody>
</table>
### Other Publications: Technical Reports and Technical Memoranda

<table>
<thead>
<tr>
<th>Title and authors</th>
<th>TR Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance of polymer-nanocomposites</td>
<td>TR05/09</td>
</tr>
<tr>
<td>Damage detection in beam structures</td>
<td>TR05/10</td>
</tr>
<tr>
<td>Violaris, G. and Galvanetto, U.</td>
<td></td>
</tr>
<tr>
<td>* Investigation of the micromechanics of delamination in fibre reinforced composites</td>
<td>TR05/12</td>
</tr>
<tr>
<td>Datta, S.</td>
<td></td>
</tr>
<tr>
<td>* Physically-based failure models and criteria for laminated fibre-reinforced composites. Development and FE implementaion</td>
<td>TR05/13</td>
</tr>
<tr>
<td>Pinho, S., Iannucci, L. and Robinson, P.</td>
<td></td>
</tr>
<tr>
<td>* Impact optimisation of composites using genetic and probabilistic algorithms</td>
<td>TR05/14</td>
</tr>
<tr>
<td>Yong, M., Iannucci, L. and Falzon, B</td>
<td></td>
</tr>
<tr>
<td>Compression behaviour of thick composite materials: novel test methods</td>
<td>TR05/15</td>
</tr>
<tr>
<td>Wolfenden, S.</td>
<td></td>
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#### 2004

<table>
<thead>
<tr>
<th>Title and authors</th>
<th>TR Number</th>
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<tbody>
<tr>
<td>Surface modification of carbon nanotubes as a route to nanocomposites</td>
<td>TR04/01</td>
</tr>
<tr>
<td>Lamorinière, S., Bismarck, A. and Shaffer, M.</td>
<td></td>
</tr>
<tr>
<td>Polymer fibre actuator</td>
<td>TR04/02</td>
</tr>
<tr>
<td>Leung, A. and Hodgkinson, J.M.</td>
<td></td>
</tr>
<tr>
<td>Bioglass / polymer composite foams and ligaments for tissue engineering applications</td>
<td>TR04/03</td>
</tr>
<tr>
<td>Lim, J. and Boccaccini, A.R.</td>
<td></td>
</tr>
<tr>
<td>Electric ceramic coatings and composites by Electrophoretic Deposition (EPD)</td>
<td>TR04/04</td>
</tr>
<tr>
<td>Ng, A and Boccaccini, A.R.</td>
<td></td>
</tr>
<tr>
<td>Processing of TiO2 matrix composites by electrophorectic deposition and slurry dipping</td>
<td>TR04/05</td>
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<tr>
<td>Sun, B., and Boccaccini, A.R.</td>
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#### 2003

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<tr>
<th>Title and authors</th>
<th>TR Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preparation and characterization of novel composite materials based on biore sorbable polymer substrates and bioactive glasses for tissue engineering applications</td>
<td>TR03/01</td>
</tr>
<tr>
<td>Blaker, J. and Boccaccini, A.R.</td>
<td></td>
</tr>
<tr>
<td>Development of a test method for the measurement of intralaminar fracture toughness of undirectional laminated composites</td>
<td>TR03/02</td>
</tr>
<tr>
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<td>Pitch-based composites</td>
<td>TR03/04</td>
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<td>Compressive analysis of unnotched and open-hole sandwich composite structures</td>
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### 2002

<table>
<thead>
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<th>Title and authors</th>
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<tr>
<td>Impact and interlaminar fracture behaviour of interleaved carbon/epoxy laminates</td>
<td>TR02/03</td>
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<td>Investigation of mechanical properties of perforated composite plates used for</td>
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<td>acoustic attenuation panels</td>
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<td>Godage, I.</td>
<td></td>
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<td>* Introduction to resin transfer moulding</td>
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<td>Introduction of half thickness joints in woven fabric reinforced GFRP</td>
<td>TR02/07</td>
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<td>Oh, S-T.</td>
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<tr>
<td>Novel processing of titanium diboride reinforced steel metal matrix composite</td>
<td>TR02/08</td>
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<td>Lieberman, S.</td>
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<td>An investigation into the use of edge delaminations for interlaminar fracture</td>
<td>TR02/09</td>
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<td>Development of bioactive resorbable polymer-bioglass composite</td>
<td>TR02/10</td>
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<td>Roether, J.</td>
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<td>Fatigue testing of woven laminates</td>
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<td></td>
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<td>Modelling of SCRIMP</td>
<td>TR02/12</td>
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<td></td>
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<td>Repair of concrete structures with bonded composite plates</td>
<td>TR02/13</td>
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### 2001

<table>
<thead>
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<th>Title and authors</th>
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<td>TR01/02</td>
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<tr>
<td>Matthews, F.L., Kinloch, A.J. and Charalambides, M</td>
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<td>TR01/05</td>
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<td>Arroupé, P. and Selerland, T.</td>
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<tr>
<td>Interfaces in flax fibre/epoxy composite systems</td>
<td>TR01/06</td>
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<td>Yau, M. and Oakeshott, J.</td>
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<tr>
<td>Screwed joints for composite structures</td>
<td>TR01/07</td>
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<td></td>
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<td>TR Number</td>
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<td>TR00/02</td>
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<td>Bayldon, J. and Matthews, F.L.</td>
<td></td>
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<tr>
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<td>TR00/03</td>
</tr>
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<td>Cohn, P. and Matthews, F.L.</td>
<td></td>
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<tr>
<td>An investigation into core crushing in Honeycomb panels during cure</td>
<td>TR00/04</td>
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<tr>
<td>Dymond, M. and Godwin, E.W.</td>
<td></td>
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<td>The effect of composition on mechanical behaviour of two titanium metal matrix</td>
<td>TR00/05</td>
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<td>composites</td>
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<td></td>
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<td>** Prediction of spring forward in carbon-epoxy channel sections</td>
<td>TR00/07</td>
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<tr>
<td>Oakeshott, J.</td>
<td></td>
</tr>
<tr>
<td>Fracture mechanics testing of composite materials used in military bridges</td>
<td>TR00/08</td>
</tr>
<tr>
<td>Kahn, M.</td>
<td></td>
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<tr>
<td>Mechanical properties of knitted and woven fabric reinforced composite materials</td>
<td>TR00/09</td>
</tr>
<tr>
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<td></td>
</tr>
<tr>
<td>Failure modes of composite flanges</td>
<td>TR00/10</td>
</tr>
<tr>
<td>Paraschi, M. and Oakeshott, J.</td>
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</tr>
</tbody>
</table>

**TECHNICAL MEMORANDA**

**2007**

<table>
<thead>
<tr>
<th>Title and authors</th>
<th>TM Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ageing of carbon epoxy composites</td>
<td>TM07/01</td>
</tr>
<tr>
<td>Arvanitelis, C. and Robinson, P.</td>
<td></td>
</tr>
<tr>
<td>Allistic performance of CFRP composites</td>
<td>TM07/01</td>
</tr>
<tr>
<td>Baker, N. and Groves, A.</td>
<td></td>
</tr>
<tr>
<td>Smart Nanocomposite</td>
<td>TM07/01</td>
</tr>
<tr>
<td>Wan-Ching Chen, N. and Iannucci, L.</td>
<td></td>
</tr>
<tr>
<td>Buckling of composite rods</td>
<td>TM07/01</td>
</tr>
<tr>
<td>Ding, S. and Robinson, P.</td>
<td></td>
</tr>
<tr>
<td>The effects of hygrothermal environment on composite laminate mechanical properties</td>
<td>TM07/01</td>
</tr>
<tr>
<td>Gavrilakis, N. and Hodgkinson, J.M.</td>
<td></td>
</tr>
<tr>
<td>Impact damage and damage tolerance of sandwich panels</td>
<td>TM07/01</td>
</tr>
</tbody>
</table>
Ghasemi, A. and Kirby, B.
*Enhancing the structural properties of composites through nanotechnology - factor fiction?*  
TM07/01

Gould, N. and Falzon, B.

Delamination: a survey of the remaining problems
Kyriakides, M. and Robinson, P.

Structural applications of composites in aero engines
Masania, K. and Hodgkinson, J.M.

Elastic 3D properties of composite materials
Yu, J and Olsson, R.

2006

<table>
<thead>
<tr>
<th>Title and authors</th>
<th>TM Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resin film infusion</td>
<td>TM06/01</td>
</tr>
<tr>
<td>Adeline, B. and Hodgkinson, J.M.</td>
<td></td>
</tr>
<tr>
<td>Aerospace industry: fabrication processes for polymer composite structures</td>
<td>TM06/02</td>
</tr>
<tr>
<td>Bonfigli, F. and Robinson, P.</td>
<td></td>
</tr>
<tr>
<td>Carbon nanotubes as reinforcement to inorganic matrices</td>
<td>TM06/03</td>
</tr>
<tr>
<td>Cho, J. and Boccaccini, A.R.</td>
<td></td>
</tr>
<tr>
<td>The use of composites in orthopaedic components</td>
<td>TM06/04</td>
</tr>
<tr>
<td>Kasbon, S. and Greenhalgh, E.S.</td>
<td></td>
</tr>
<tr>
<td>Piezoelectric composite materials</td>
<td>TM06/05</td>
</tr>
<tr>
<td>Lees, M. and Hodgkinson, J.M.</td>
<td></td>
</tr>
<tr>
<td>Shear properties of composite laminates</td>
<td>TM06/06</td>
</tr>
<tr>
<td>Moreno, J. and Olsson, R.</td>
<td></td>
</tr>
<tr>
<td>How can composite materials be used for a better environmental management</td>
<td>TM06/07</td>
</tr>
<tr>
<td>Signor, C. and Oakeshott, J.</td>
<td></td>
</tr>
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2005

<table>
<thead>
<tr>
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<th>TM Number</th>
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</thead>
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<tr>
<td>Reinforced thermoplastics - composition, processing and applications</td>
<td>TM05/01</td>
</tr>
<tr>
<td>Ahmed, A. and Hodgkinson, J.M.</td>
<td></td>
</tr>
<tr>
<td>An investigation into the views regarding the national and international standards relating to motorcycle crash helmets</td>
<td>TM05/02</td>
</tr>
<tr>
<td>Batho, T. and Galvanetto, U.</td>
<td></td>
</tr>
<tr>
<td>Composite materials in sports equipment</td>
<td>TM05/03</td>
</tr>
<tr>
<td>Dhillon, H. and Hodgkinson, J.M.</td>
<td></td>
</tr>
<tr>
<td>A review of the current knowledge of compression strength testing of thick CFRP composites</td>
<td>TM05/04</td>
</tr>
<tr>
<td>Lander, J. and Robinson, P.</td>
<td></td>
</tr>
<tr>
<td>Fatigue phenomena in composites</td>
<td>TM05/05</td>
</tr>
</tbody>
</table>
### Other Publications: Technical Reports and Technical Memoranda

**Mouton, J-B. and Galvanetto, U.**

**Vibration based structural damage identification**  
*Sanat, M. and Galvanetto, U.*  
TM05/06

**Composite materials in building and construction**  
*Violaris, G. and Hodgkinson, J.M.*  
TM05/07

---

#### 2004

<table>
<thead>
<tr>
<th>Title and authors</th>
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</thead>
<tbody>
<tr>
<td>The potential of carbon nanotubes for structural composites</td>
<td>TM04/01</td>
</tr>
<tr>
<td><em>Lamorinière, S. and Robinson, P.</em></td>
<td></td>
</tr>
<tr>
<td>Smart fabrics - a review of conductive material technologies</td>
<td>TM04/02</td>
</tr>
<tr>
<td><em>Leung, T.K., and Hodgkinson, J.M.</em></td>
<td></td>
</tr>
<tr>
<td>The uses of shape memory alloys within composite materials</td>
<td>TM04/03</td>
</tr>
<tr>
<td><em>Lim, J. and Iannucci, L.</em></td>
<td></td>
</tr>
<tr>
<td>Composite materials for Electromagnetic Interference (EMI) Shielding</td>
<td>TM04/04</td>
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#### 2003

<table>
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<td>Health monitoring of composite structures</td>
<td>TM03/01</td>
</tr>
<tr>
<td><em>Fensome, C.</em></td>
<td></td>
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<tr>
<td>Factors affecting the compression stability of sandwich panels</td>
<td>TM03/02</td>
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<tr>
<td><em>Fournier-Le Ray, R.</em></td>
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<tr>
<td>Manufacturing distortion in high performance composites</td>
<td>TM03/03</td>
</tr>
<tr>
<td><em>Havez, D.</em></td>
<td></td>
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<td>Composite structures in unmanned aerial vehicles</td>
<td>TM03/04</td>
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<tr>
<td><em>Mokkas, E.</em></td>
<td></td>
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<tr>
<td>Review of metal matrix composites in aerospace applications</td>
<td>TM03/05</td>
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<tr>
<td><em>Quiroz-Taborda, N.</em></td>
<td></td>
</tr>
<tr>
<td>Design and manufacture of modern composite bicycle frames: a literature review</td>
<td>TM03/06</td>
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#### 2002

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<td>Fibre-matrix interfacial strength</td>
<td>TM02/01</td>
</tr>
<tr>
<td><em>Godage, I.</em></td>
<td></td>
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<tr>
<td>Survey of composite bridges worldwide</td>
<td>TM02/02</td>
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<tr>
<td><em>Liberman, S.</em></td>
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<tr>
<td>Manufacture and uses of filament wound composites</td>
<td>TM02/03</td>
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<td><em>Malmy, F.</em></td>
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<tr>
<td>Biomedical/prosthetic applications of composites</td>
<td>TM02/04</td>
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<tr>
<td><em>Oh, S-T.</em></td>
<td></td>
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<tr>
<td>The performance and future prospects of natural fibre composites</td>
<td>TM02/05</td>
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<td><em>Roether, J.</em></td>
<td></td>
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56
<table>
<thead>
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<th>Title and authors</th>
<th>TM Number</th>
</tr>
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<tr>
<td>Low cost manufacture of high performance composite - the materials, manufacturing processes and relative performance</td>
<td>TM02/06</td>
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<td>Su, J.</td>
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<td>Automotive applications of composite materials</td>
<td>TM02/07</td>
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<td>Vernon, M.</td>
<td></td>
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<tr>
<td>Current use of composites in road cars</td>
<td>TM02/08</td>
</tr>
<tr>
<td>Virelizier, F.</td>
<td></td>
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<tr>
<td>The role of the interface in determining the properties of composites</td>
<td>TM02/09</td>
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<td>Taib, K.</td>
<td></td>
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<tr>
<td>A review of the effects of 'interleaving' on the fracture behaviour of laminates</td>
<td>TM02/10</td>
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### 2001

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<tr>
<td>Rheology of modern polymer matrices, viscoelastic properties &amp; viscosity models</td>
<td>TM01/01</td>
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<td>Selerland, T. and /Papandreou, G-D.</td>
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<tr>
<td>Use of composites in the marine industry</td>
<td>TM01/02</td>
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<td>Oakeshott, J. and Artelluci, N.</td>
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<td>Non-linear stress/strain behaviour in CFRP</td>
<td>TM01/03</td>
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<td>Oakeshott, J. and Yau, M.</td>
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<tr>
<td>Applications of composites for medical implants &amp; prostheses: requirements &amp; performance</td>
<td>TM01/04</td>
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<td>Matthews, F.L and Bruce, J.</td>
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<td>Impact-induced degradation of polymer matrix composites in service</td>
<td>TM01/05</td>
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<td>Matthews, F.L. and Kingston, J.</td>
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<td>ARALLTM and GLARETM</td>
<td>TM01/06</td>
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<td>Selerland, T. and Abdul-Latif, M.</td>
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<td>Use of composites in the offshore oil industry</td>
<td>TM01/07</td>
</tr>
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<td>Godwin, E.W. and Mary, G.</td>
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<tr>
<td>Current research and development in composites machining</td>
<td>TM01/08</td>
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### 2000

<table>
<thead>
<tr>
<th>Title and authors</th>
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<tr>
<td>* Predicting the notched tensile strength of FRP laminates</td>
<td>TM00/01</td>
</tr>
<tr>
<td>Matthews, F.L. and Herd, R.</td>
<td></td>
</tr>
<tr>
<td>Potentials of 3D preforms for structural composites</td>
<td>TM00/02</td>
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<tr>
<td>Selerland, T. and Davis, S.</td>
<td></td>
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<tr>
<td>Factors affecting injection moulding of composites</td>
<td>TM00/03</td>
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<tr>
<td>Oakeshott, J. and Paloumbi, V.</td>
<td></td>
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<tr>
<td>Recycling of fibre-reinforced plastics</td>
<td>TM00/04</td>
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<tr>
<td>Matthews, F.L. and Bunce, C.</td>
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<tr>
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<td>Authors</td>
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<tr>
<td>----------------------------------------------------------------------</td>
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<tr>
<td>Composites in the High Volume Automobile Industry</td>
<td>Hodgkinson, J.M. and Iverson, B.</td>
</tr>
<tr>
<td>Environmental resistance and long-term loading of composites</td>
<td>Hodgkinson, J.M. and Kamalski, N.</td>
</tr>
<tr>
<td>Composites in civil engineering</td>
<td>Oakeshott, J. and Neves, R.</td>
</tr>
<tr>
<td>* Low cost composite materials</td>
<td>Oakeshott, J. and Ngah, F.</td>
</tr>
<tr>
<td>Composite suspension springs for road vehicles</td>
<td>Godwin, E.W. and Clifford, S.</td>
</tr>
<tr>
<td>The effects of fire on composite materials</td>
<td>Godwin, E.W. and Bocquillon, V.</td>
</tr>
</tbody>
</table>
COMPOSITES CENTRE MSC PROJECT REPORTS

2006

Abbas, H. Hot-forming of both thermoplastics and Thermosetting prepregs
Chen, J. Modelling failure of Formula 1 car components using FE
Chen, F. Infusion of 3D woven carbon materials
Feng, Z. Bioactive polymer composite foams containing ceramic nanoparticles for tissue engineering
Geng, X. Morphing wing design
Gimat, M. Manufacture, test and evaluation of a composite wing joint for a new light aircraft
Kourkoutsaki, T. Conductive Pre-Preg
Kwak, M. Investigating failure of carbon-fibre reinforced composites
Liu, L. Glass and ceramic matrix composites containing carbon nanotubes
Li, X. Comparative study on the failure behaviour of several advanced carbon-epoxy composites used in Formula 1
Martinez, C. New flexible, disposable and formable tooling materials for use in composite processing
Mohammadi, F. Sensing and Actuation of composite laminates
Pang, B. Fabrication of optically transparent fibre reinforced glass matrix composites
Rostami, S. Computer simulation of composite structures’ crashworthiness
Sreeraman, S. Repair of composite materials
Sun, L. Effect of curvature on impact response and damage tolerance
Tsalikis, D. Investigation of “back-out factors” to determine UD tensile properties from 0/90 data
Zhang, X. Modelling and experiments on open-hole tension and compact tension using DSP

2005

<table>
<thead>
<tr>
<th>Author</th>
<th>Title</th>
</tr>
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<tbody>
<tr>
<td>Abbott, A.</td>
<td>Processing and characterisation of all-cellulose composites</td>
</tr>
<tr>
<td>Arvanitellis, C.</td>
<td>Inorganic matrix composites with carbon nanotube reinforcement</td>
</tr>
<tr>
<td>Baker, N.</td>
<td>Novel highly porous Bioglass®/PDLLA coated composite scaffolds by the</td>
</tr>
<tr>
<td>Name</td>
<td>Title</td>
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<td>Chen, W-C.</td>
<td>Structure/property relationships of nanocomposite coatings</td>
</tr>
<tr>
<td>Dowdell, D.</td>
<td>Production &amp; evaluation of high performance thermoplastic/carbon fibre prepps</td>
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<td>Garcia de la Fuente, C</td>
<td>Determination of fibre volume fraction in composite laminates by optical microscopy/software and acid digestion of the matrix.</td>
</tr>
<tr>
<td>Gavrilakis, N.</td>
<td>Experimental study of dent growth in sandwich panels.</td>
</tr>
<tr>
<td>Gould, N.</td>
<td>FE investigation of the double-edge notched tension specimen for evaluation of the essential work of fracture of polymer films.</td>
</tr>
<tr>
<td>Gulati, S.</td>
<td>Investigation of the Composite Centre’s NDE capability</td>
</tr>
<tr>
<td>Hong, Y-J.</td>
<td>Investigating the applicability of polyhydroxyalkanoate (PHA)/Bioglass® composites for tissue engineering</td>
</tr>
<tr>
<td>Ioannou, F.</td>
<td>Simple structural models for impact on curved panels</td>
</tr>
<tr>
<td>Kim, J.</td>
<td>Mode II delamination using an effective crack length approach</td>
</tr>
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<td>Kristien, J.</td>
<td>Delamination in composite materials</td>
</tr>
<tr>
<td>Kyriakides, M.</td>
<td>The effects of testing machine stiffness on apparent laminate properties.</td>
</tr>
<tr>
<td>Masania, K.</td>
<td>High performance thermoplastic / carbon fibre / carbon nanotube composites</td>
</tr>
<tr>
<td>Robinson, R.</td>
<td>Flexural behaviour of composite sandwich panels with and without defects</td>
</tr>
<tr>
<td>Sinniah, S.</td>
<td>Development and characterisation of intermetallic composites by powder technology and electrophoretic deposition</td>
</tr>
<tr>
<td>Suttle, H.</td>
<td>An optimised route to transparent oxide fibre reinforced glasses</td>
</tr>
<tr>
<td>Takun, Z.</td>
<td>Biodegradable polymer matrix composites containing ceramic nanoparticles and bioactive components for tissue engineering applications</td>
</tr>
<tr>
<td>Yu, J.</td>
<td>Tailored aeroelasticity of a composite swept wing</td>
</tr>
</tbody>
</table>

**2004**

<table>
<thead>
<tr>
<th>Name</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ahmed, A.</td>
<td>FE simulation of dent growth in impacted sandwich panels loaded in compression</td>
</tr>
<tr>
<td>Batho, T.</td>
<td>Interlaminar fracture mechanics – some unresolved issues</td>
</tr>
<tr>
<td>Chu, T.</td>
<td>Fine structured carbon nanotube polyamide nanocomposite</td>
</tr>
<tr>
<td>Chu, K.</td>
<td>Investigation of delamination migration in composite laminates</td>
</tr>
<tr>
<td>Dhillon, H.</td>
<td>Investigation into welding of thermoplastic composites</td>
</tr>
<tr>
<td>Harun, L.</td>
<td>Orthotropic rescaling for plates</td>
</tr>
<tr>
<td>Lander, J.</td>
<td>Investigation into CFRP, UD, NCF and hybrid stack mechanical behaviour</td>
</tr>
<tr>
<td>Mouton, J-B.</td>
<td>An investigation into the effects of bi-directional stacking sequence and damage progression in fatigue</td>
</tr>
<tr>
<td>Sanat, M.</td>
<td>Performance of polymer-nanocomposites</td>
</tr>
</tbody>
</table>
Other Publications: Composites Centre MSc Project Reports

Unerman, T. Investigation of the failure of conventional compression tests for thick CFRP composites
Violaris, G. Damage detection in beam structures using proper orthogonal decomposition

2003
Lamorinière, S. Surface modification of carbon nanotubes as a route to nanocomposites
Leung, A. Polymer fibre actuator
Lim, J. Bioglass®/polymer composite foams and ligaments for tissue engineering applications
Ng, A. Piezoelectric ceramic coatings and composites by Electrophoretic Deposition (EPD)
Pandya, S. Effects of z-pins under open hole compression
Sun, B. Processing of TiO2 matrix composites by electrophoretic deposition and slurry dipping

2002
Blaker, J. Preparation and characterization of novel composite materials based on bioresorbable polymer substrates and bioactive glasses for tissue engineering applications
Fensome, C. Development of a test method for the measurement of intralaminar fracture toughness of unidirectional laminated composites
Fournier-Le Ray, R. Adhesive systems for thermal ageing resistance
Havez, D. Development of draping and performing technologies for carbon fibre fabrics
Hoo, Y-K. The effect of humidity on the performance of engineering polymers
Karapappas, P. Processing of ceramic matrix composites by using electrophoretic deposition (EPD)
Longland, S.  Friction and starter film effects in the measurement of Mode II interlaminar toughness
Mokkas, E.  Pitch-based composites
Quiroz-Taborda, N.  Compressive analysis of unnotched and open-hole sandwich composite structures
Riddell, T.  Pressed metal end fittings to composite tubes

2001

Godage, I.  Mechanical characterisation of perforated acoustic panels
Lieberman, S.  Steel based composite materials
Malmy, F.  Growth of delaminations in fatigue
Oh, S-T.  Novel ply joints in GFRP laminates
Roether, J.  Development of bioactive resorbable polymer-bioglass composite
Su, J.  Requirements for modelling RTM and RFI processes
Vernon, M.  Use of side delaminations in fracture toughness testing
Virelizier, F.  Trimming of BMC and SMC automotive parts

2000

Abdul-Latif, M.  Micromechanical modelling of woven CFRP using FEM
Ali, U.  A feasibility study to strengthen brick bridge parapets using advanced composite materials.
Artelluci, N.  Design of access holes in a composite wing box
Bruce, J.  Composite metal hybrid joints
Bunce, C.  Smart actuation of bi-stable composite laminates
Idrees, H.  Effect of temperature on the mechanical properties of polyester and vinyl ester composite materials
Jogia, M.  Damage detection using smart sensing
Kingston, J.  Optimisation of radome panel joints
Latif, M.  Investigation of residual stresses in laminates.
Lazarus, S.  Optimal design using genetic algorithms
Lee, H.  Study of pre-treatments for bonding thermoplastic composites.
Mary, G.  Detection of first-ply failure
Pinard, F.  Study of composite wing box stringer run-out
Wallois, Y.  Characterisation of failure in composites by a non-Euclidian metric
Syed, A.  Finite element analysis of a notched tension specimen.
Yau, M.  Interfaces in flax fibre/epoxy composite systems.
PHD THESES

2005

Das, S  The interlaminar response of z-fibre reinforced composites
Datta, S.  Investigation of the micromechanics of delamination in fibre reinforced composites
Diamanti, K  Active-sensor health monitoring of composite structure using low-frequency lamb waves
Donadon, M.  The structural behaviour of composite laminates manufactured using resin Infusion under flexible tooling
Ngah, F.  Statistical process optimisation and probabilistic performance assessment of resin infused carbon-epoxy composite laminates
Pinho, S  Modelling failure of laminated composites using physically-based failure models

2003

Ko, A.  An investigation in the use of a stationary mesh approach to simulate delamination growth in composite laminates
Lee, J.  Compressive behaviour of composite laminates before and after low velocity impact
McCallum, S.  Experimental, analytical and computational studies in resin transfer moulding
Ng, D.  The design and durability of adhesively-bonded joints
Kiuna, N.  Investigation of flow parameters in resin transfer moulding

2002

Barber, A.H.  Fibre-matrix interactions in model glass fibre-thermoplastic composites
Beard, M.D.  Guided wave inspection of embedded cylindrical structures
Davies, A.  Crashworthiness of composite sandwich structures
Korenberg, C.  The durability of adhesive joints
Vogt, T.K.  Determination of material properties using guided waves
2001

Mahdi, S. The performance of bonded repairs to composite structures
Morrey, E.L. Potential hazards associated with combustion of polymer composite materials, and strategies for their mitigation
Paraschi, M. A fracture mechanics approach to the failure of adhesive joints
Zafeiropoulos, N. Engineering and characterization of the interface in flax/polypropylene composite materials

2000

Diaz Valdes, S.H. Structural integrity monitoring of CFRP laminates using piezoelectric devices
Jackson, C.B. Liquid metal infiltration of fibrous ceramic performs
Thompson, I.D. Development of a mouldable bioactive composite
Syahril Processing and properties of Fe-11%Al based alloys
Wells, J.J. Thick film processing of Yba2Cu3O7-x
Within the departments associated with the Centre there is a wide range of standard, multi-purpose and specialised equipment. These facilities are summarised below; full details may be obtained on request.

**PROCESSING**

Autoclave, RIFT, Heated presses, Prepreg and laminate cutting, High shear mixers, Extruders, Roll mill, Instrumented MMC casting, Metallurgical rolling mills, Furnaces, High power CO2 lasers.

**ANALYSIS AND STRUCTURAL CHARACTERISATION**

Optical and electron microscopes, Image analysis, Atomic force microscopy, UV and IR spectroscopy, FTIR spectroscopy, FT Raman spectroscopy, X-ray diffraction, ESCA, Secondary ion mass spectrometry, chromatography, thermogravimetry, dilatometry, mercury porosimetry. Dynamic mechanical analysis, DSC, DTA, DMTA, NMR.

**NON-DESTRUCTIVE TESTING**

Laser surface profilometry, X-radiography, Acoustic emission, Vibrational methods, Frequency response analysers, Ultrasonic inspection, Generation and detection of Lamb waves in plates and pipes. Extensive modelling software is also available for the prediction of Lamb wave dispersion curves, finite element modelling of wave propagation and the prediction of the interaction of ultrasonic waves with multi-layered media.

**ENVIRONMENTAL**

Thermal chambers, Environmental chambers, Humidity ovens.

**MECHANICAL CHARACTERISATION**

An extensive range of universal static and fatigue testing machines: special testing machines with capacities of up to 400 tonnes, Microtensometer, Instrumented pendulum, drop-weight, and ballistic impact, Hardness testing, Digital Speckle Photogrammetry.

**COMPUTING**

A comprehensive internal College computing network has access to the national and international internet. On-site networked workstations run under UNIX. A large number of PC compatible and Macintosh computers are present throughout the college, many of which are directly connected to the on-site network. Software includes several finite element codes and composites analysis programs.
# ACADEMIC STAFF DIRECTORY and KEY WORDS INDEX

## ACADEMIC STAFF DIRECTORY

<table>
<thead>
<tr>
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<th>AREA OF EXPERTISE</th>
<th>CONTACT DETAILS</th>
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</thead>
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<table>
<thead>
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<th>AREA OF EXPERTISE</th>
<th>CONTACT DETAILS</th>
</tr>
</thead>
</table>
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<table>
<thead>
<tr>
<th>STAFF MEMBER</th>
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<th>CONTACT DETAILS</th>
</tr>
</thead>
<tbody>
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</tr>
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</tr>
<tr>
<td>STAFF MEMBER</td>
<td>AREA OF EXPERTISE</td>
<td>CONTACT DETAILS</td>
</tr>
<tr>
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<td>-------------------------------------------------------</td>
<td>-------------------------------------------------------</td>
</tr>
</tbody>
</table>
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Keywords Index

KEYWORDS INDEX

Abrasion and wear
Professor Brian Briscoe

Adhesives
Dr Bamber Blackman, Professor Anthony Kinloch, Dr Ambrose Taylor

Aerospace Structures
Professor Glyn Davies, Dr Brian Falzon, Emile Greenhalgh, Mr Dennis Hitchings, Dr John Hodgkinson, Dr Lorenzo Iannucci, Dr Robin Olsson, Dr Silvestre Pinho, Dr Paul Robinson

Biocomposites
Dr Alexander Bismarck, Dr Aldo R Boccaccini

Boundary element methods
Professor Ferri Aliabadi

Carbon-Carbon Composites
Professor Rees Rawlings

Ceramic and Glass Matrix Composites
Dr Aldo R Boccaccini, Professor Rees Rawlings.

Civil and Structures
Dr Ahmed Elghazouli, Dr Luke Louca

Damage Modelling and Tolerance
Professor Ferri Aliabadi, Professor Glyn Davies, Dr Brian Falzon, Dr Ugo Galvanetto, Dr Emile Greenhalgh, Mr Dennis Hitchings, Dr Lorenzo Iannucci, Dr Luke Louca, Dr Robin Olsson, Dr Silvestre Pinho, Dr Paul Robinson

Delamination Fracture Mechanics
Dr Bamber Blackman, Dr Maria Charalambides, Dr Ugo Galvanetto, Dr Emile Greenhalgh, Mr Dennis Hitchings, Dr John Hodgkinson, Dr Lorenzo Iannucci, Professor Anthony Kinloch, Dr Silvestre Pinho, Dr Paul Robinson, Professor Gordon Williams

Design
Dr Lorenzo Iannucci

Durability
Dr Alexander Bismarck, Dr Bamber Blackman, Dr Emile Greenhalgh, Professor Anthony Kinloch, Dr Ambrose Taylor

Dynamics
Dr Ugo Galvanetto, Mr Dennis Hitchings
Fatigue
Professor Ferri Aliabadi, Dr Ugo Galvanetto, Dr Emile Greenhalgh, Professor Anthony Kinloch,
Mr Hugh MacGillivray, Dr Paul Robinson, Dr Ambrose Taylor

FE Modelling
Professor Glyn Davies, Dr Brian Falzon, Dr Ugo Galvanetto, Mr Dennis Hitchings, Dr Lorenzo Iannucci,
Dr Luke Louca, Dr Silvestre Pinho, Dr Paul Robinson

Fire Design
Dr Ahmed Elghazouli

Fracture Toughness Testing
Dr Bamber Blackman, Dr Maria Charalambides, Dr Emile Greenhalgh, Dr John Hodgkinson,
Dr Patrick Leevers, Dr Robin Olsson, Dr Silvestre Pinho, Dr Ambrose Taylor, Dr Paul Robinson,
Professor Gordon Williams

Functional Composites
Dr Alexander Bismarck, Dr Aldo R Boccaccini, Professor Rees Rawlings

High Rate Testing
Dr Bamber Blackman, Dr Lorenzo Iannucci, Mr Hugh MacGillivray

Image Analysis
Dr Rodney Coleman

Impact
Dr Bamber Blackman, Professor Glyn Davies, Dr Emile Greenhalgh, Mr Dennis Hitchings,
Dr John Hodgkinson, Dr Lorenzo Iannucci, Dr Patrick Leevers, Dr Robin Olsson, Dr Paul Robinson

Impulsive Loading
Professor Brian Briscoe, Dr Luke Louca

Interfaces
Dr Alexander Bismarck, Dr Bamber Blackman, Professor Brian Briscoe, Professor Anthony Kinloch,
Dr Daryl Williams

Joining
Dr Bamber Blackman, Dr John Hodgkinson

Low Cost Materials
Dr Brian Falzon, Dr Ugo Galvanetto, Dr Emile Greenhalgh, Dr John Hodgkinson, Dr Lorenzo Iannucci,
Dr Paul Robinson

Manufacturing
Dr Aldo R Boccaccini, Dr Richard Dashwood, Dr Emile Greenhalgh, Dr John Hodgkinson

Marine Structures
Dr Ahmed Elghalzouli, Dr Luke Louca

Metal Matrix Composites
Dr Richard Dashwood, Dr Peter Lee, Dr Mary Ryan

Nanocomposites
Dr Alexander Bismarck, Dr Bamber Blackman, Dr Emile Greenhalgh, Dr Milo Shaffer,
Dr Ambrose Taylor, Dr Sophia Yaliraki
Polymer Matrix Composites: Failure Analysis and Fracture Mechanics

**NDT**
Professor Peter Cawley, Dr Ugo Galvanetto, Dr John Hodgkinson, Dr Michael Lowe

**Non Linear Modelling**
Professor Ferri Aliabadi, Dr Brian Falzon, Dr Ugo Galvanetto, Mr Dennis Hitchings, Dr Lorenzo Iannucci, Dr Silvestre Pinho

**Numerical Modelling**
Professor Ferri Aliabadi, Professor Glyn Davies, Dr Brian Falzon, Dr Ugo Galvanetto, Mr Dennis Hitchings, Dr Lorenzo Iannucci, Dr Silvestre Pinho

**Processing**
Dr Alexander Bismarck, Dr Aldo R Boccaccini, Professor Brian Briscoe, Dr John Hodgkinson, Professor Chris Lawrence, Dr Patrick Leevers

**Process Modelling**
Dr Aldo R Boccaccini, Dr Chris Lawrence, Dr Peter Lee, Dr Joaquim Peiró, Professor Spencer Sherwin

**Repair**
Dr Brian Falzon, Dr Emile Greenhalgh, Dr John Hodgkinson, Professor Anthony Kinloch

**Residual Stress Measurement**
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**Smart Structures**
Professor Peter Cawley, Dr John Hodgkinson

**Stochastic Processes**
Dr Rodney Coleman

**Structures**
Professor Ferri Aliabadi, Professor Glyn Davies, Dr Ahmed Elghazouli, Dr Brian Falzon, Dr Emile Greenhalgh

**Thermoplastics**
Dr Alexander Bismarck, Professor Anthony Kinloch, Dr Patrick Leevers, Professor Gordon Williams

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Professor Brian Briscoe, Dr Daryl Williams

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