FRP INTERNATIONAL

The Official Newsletter of the International Institute for FRP in Construction

Volume 3, Issue 1 (Special BBFS 2005 Issue) ***Spring 2006***

Welcome to the special BBFS 2005 Issue of the IIFC Newsletter. This issue is dedicated to reports from the International Symposium on Bond Behavior of FRP in Structures held in Hong Kong, China, and includes a report from the IIFC President, Professor Jin-Guang Teng providing a summary of IIFC's activities in 2005.

This year we anticipate publishing three further issues of the newsletter. As we move forward I'd like to invite our readers to submit material to the Newsletter on new applications of FRP in Construction, forthcoming conferences and workshops, or general items that may be of interest to the worldwide community. I'd also like to encourage our readers to consider opinion pieces that would serve to initiate discussion on topics of interest and importance. This is your Newsletter, and I hope it will serve as a forum for discussion across the globe, bringing together personnel from the research, construction, materials and product supply, and owner and user communities.

Material can be submitted directly to me at vkarbhari@ucsd.edu or to any of the members on the advisory or editorial boards. Please also feel free to write to me or to the President of IIFC, Prof. J.G. Teng (cejgteng@polyu.edu.hk), with any ideas you may have for the newsletter and for IIFC, itself

Vistasp M. Karbhari, Editor-in-Chief
Email: vkarbhari@ucsd.edu

In this issue

FRP INTERNATIONAL

The Official Newsletter of the International Institute for FRP in Construction

Volume 3, Issue 1 (Special BBFS 2005 Issue) **Spring 2006**

President's Report

IIFC has now been in existence for three years, but it only officially started accepting members two years ago. In this issue President Jin-Guang Teng provides a review of IIFC's activities in 2005.

Review of IIFC Activities in 2005
By
Jin-Guang Teng, President, IIFC

The year of 2005 was a fruitful year for IIFC. I am pleased to provide a summary of the more significant events and developments of IIFC in 2005 in this article.

The IIFC published 4 issues of the newsletter "*FRP International*". Professor Vistasp Karbhari, the Editor-in-Chief of the newsletter, is to be commended for his excellent leadership and effort in ensuring the timely publication of each issue.

The Working Group on Bond between FRP and Concrete successfully organized the International Symposium on Bond Behavior of FRP in Structures (BBFS 2005) on 7-9 December 2005 in Hong Kong, China. The BBFS Symposium was followed by a post-symposium International Workshop on FRP Composites in Construction: State of the Art. More details of these events are given elsewhere in this issue of the newsletter.

The IIFC also organized a very successful competition of FRP photographs, the IIFC Photo Competition, under the leadership of Professor Larry C. Bank. Altogether, 156 photos were submitted to the competition. A panel of judges was formed and selected 1 winner and 5 runners-up in each of the two categories of Research and Application. The results were announced in the December 2005 issue of *FRP International*. Certificates were issued to all winners and runners-up and each winner also received a cheque of US$200 from IIFC. The winning and the runner-up photographs were made into large–size posters and exhibited at FRPRCS-7 held in Kansas City and BBFS 2005 in Hong Kong, and attracted a great deal of interest. A FRPRCS-7, an IIFC meeting was convened by Professor L.C. Bank and was well attended by IIFC members and non-IIFC members. A booklet containing all 156 photographs will be published and distributed to IIFC members in 2006.

The organization work for the next IIFC official conference, The Third International Conference on FRP Composites in Civil Engineering (CICE 2006), was started in 2005. CICE 2006 will be held on 13-15 December 2006 in Miami, USA. The Conference Organizing Committee chaired by Professor Amir Mirmiran of Florida International University has been working hard to ensure a very successful conference. CICE 2006 will be a major event for IIFC in 2006. At this IIFC official conference, there will be various IIFC meetings including the election of new members into the Council and the election of a new Executive Committee. All IIFC members are strongly encouraged to attend CICE 2006.

The IIFC's current vision for conferences in the FRP for construction area is that in addition to an IIFC official conference in even-numbered years (i.e. the CICE series), there should be a regional conference in each of the three regions of Asia, Europe and North America in odd-numbered years. The first regional conference for Asia, the Inaugural Asia-Pacific Conference on FRP in Structures (APFIS 2007), to be held in Sydney, Australia in December 2007 has been announced. AFPFIS 2007 will be chaired by Dr. S.T. Smith of The University of Technology, Sydney, Australia. The Third International Conference on Durability & Field Applications of Fiber Reinforced Polymer (FRP) Composites for Construction has recently become IIFC's regional conference for North America. This conference will be held on 23-25 May 2007 in Quebec City, Canada and will be chaired by Dr. Brahim Benmokrane of the University of Sherbrooke. To complete the conference structure, a regional conference series for Europe needs to be established soon. All IIFC members, but particularly those in the respective regions, are strongly encouraged to support these conferences.

In addition to IIFC's own conference, IIFC also co-sponsors other conferences. In 2005, IIFC was a co-sponsor of the International Symposium on Innovation and Sustainability of Structures in Civil Engineering, which was successfully held on 20-22 November in Nanjing, China. IIFC has recently become a co-sponsor of a number of other conferences, including FRPRCS-8 and ACUN-5. Further details of these conferences are available under the section "IIFC Sponsored Conferences" in this issue of the newsletter. IIFC members are encouraged to take part at these conferences.

The IIFC became an official sponsor of the ASCE Journal of Composites for Construction (JCC) in 2005. Dr Rudi Seracino, Chairman of CICE 2004, has been working with ASCE on the development of a special issue of JCC, containing extended/revised versions of selected papers presented at CICE 2004 held in Adelaide in December 2004. The issue is expected to appear in 2006. A special issue of Construction and Building Materials containing extended/revised versions of selected papers presented at CICE 2004, is also being finalized.

The membership size increased substantially during 2005. The number of individual members went from about around 110 to around 160. IIFC also welcomed two Patron Members in 2005: ISIS Canada and Association for Advanced Composite Technology on Construction Field from Japan. In addition, IIFC has two Collective members: Aslan Pacific and COBRAE. Professors A.A. Mufti, K.W. Neale, T. Ueda, U. Meier, and Mr D. Gremel were instrumental in attracting these Patron/Collective Members to IIFC.

In reporting the 2005 activities, I may have inadvertently omitted events or names, and I apologize in advance for any such omissions. I would also like to extend my gratitude to all those who have given support to this young organization. I look forward to working with you towards even greater success in 2006 and wish you all a happy and successful 2006.

Report on BBFS 2005

The International Symposium on Bond Behaviour of FRP in Structures (BBFS2005) was held on 7-9 December 2005 in Hong Kong, China. In this issue, the Co-chairmen of the Symposium, Prof. Jin-Guang Teng and Dr. Jin-Fei Chen report on this very successful symposium.

Conference Co-Chairmen's Report on BBFS 2005

By
Dr Jian-Fei Chen, Edinburgh University
and
Professor Jin-Guang Teng,
The Hong Kong Polytechnic University

OVERVIEW

The IIFC Working Group on Bond between FRP and Concrete was established in November 2004 with the objectives of:

- promoting research collaboration on FRP-to-concrete bond behaviour
- providing a forum for exchange, discussion and consolidation of ideas and results
- establishing design models and
- developing a state-of-the art report on the behaviour and modelling of bond behaviour between FRP and concrete.

The International Symposium on Bond Behaviour of FRP in Structures (BBFS2005) was organised as part of the Bond WG's activities to provide an international forum for all concerned with the bond behaviour of FRP in all forms of structural applications and a state-of-the-art survey of existing research in this important area. The scope of the symposium covered all aspects of bond performance of FRP in structures, including bond behaviour between (external, near surface mounted and internal) FRP and other structural materials such as concrete, masonry, metal and timber as well as between two FRP elements.

The planning of the symposium began at the end of 2004. A proposal of the symposium was submitted to and approved by the IIFC Executive Committee in March 2005. The symposium received 128 abstract submissions, most of which were accepted after initial reviews. All full papers underwent a rigorous review process by two expert reviewers selected from the International Scientific Committee and the International Organising Committee of BBFS 2005. A total of 6 keynote papers and 69 contributed papers were finally selected for publication in the proceedings and for oral presentation. The papers cover a wide range of bond behaviour issues including fundamental bond mechanisms, debonding failures, dynamic and cyclic loadings, fatigue, durability, and the effects of elevated temperature and fire. They report the current state-of-the-art and point to future directions of research in this exciting area.

The symposium began with a welcome reception on Tuesday 6 December, providing the opportunity to renew old friendship and make new friends. Seventy-two delegates, representing 19 countries, attended the symposium. The 3-day technical program, which commenced on Wednesday 7 December, consisted of 6 keynote lectures given by eminent researchers and two parallel sessions for the presentation of contributed papers. Many delegates had difficulties in deciding which session to attend as most of the presentations were of interest to them. Heated but friendly debates also occurred on many occasions. Several delegates commented that the symposium was unique because almost all the papers were of relevance and interest to them. The success of the symposium is of course attributed to the many people who offered help, not least the authors and presenters for the outstanding quality of their papers and presentations.

The symposium dinner was held on the evening of Thursday 8 December which was attended by 85 delegates and guests. Among the honourable guests were Mr and Mrs Cagley. Mr Cagley, who is the president of ACI and was on a business trip in Hong Kong for a different reason, made an enlightening speech at the dinner. Souvenirs were presented to the keynote speakers as a gesture of appreciation of their support. A Best Paper Award was also presented. Further details of the Best Paper Award is given later in this report.

Delegates of BBFS 2005

A meeting of the members of the Bond WG was held on Friday 9 December to discuss the future work of the WG as well as general IIFC issues. At the general plenary session of the meeting, it was agreed that the title of the WG should be changed from "Bond between FRP and concrete" to "Bond behaviour of FRP in structures" to widen the scope of the WG. Approval of this change from the IIFC Executive Committee is being sought. The WG meeting was then divided into the following 5 sub-groups to discuss relevant work within the appropriate areas:

- FRP strengthened metallic structures, chaired by Professor Len Hollaway
- Externally bonded FRP, NSM FRP and fatigue, chaired by Dr Laura De Lorenzis
- FRP-strengthened timber and masonry structures, chaired by Mr Kay-Uwe Schober
- Test methods and standardisation, chaired by Professor Marco Savoia
- Fire behaviour of FRP or FRP-strengthened structures, chaired by Professor Ali Nadjai

Each sub-group discussed past and current research as well as possible future research within the particular area of concern. The key conclusions from these discussions were presented to all delegates at the lunch on 9 December. A separate report is being prepared to summarise the outcomes of these discussions which will be circulated to the WG members.

Work started immediately after the symposium to publish a special issue of the international journal "Advances in Structural Engineering". Selected authors were invited to contribute revised/extended versions of their papers presented at BBFS 2005 to this special issue. These revised/extended papers are being received with a deadline of 31 March 2006. This special issue is expected to appear by the end of 2006.

All IIFC members shall have by now received a copy of the BBFS2005 proceedings free of charge as part of their membership benefits. We hope that members find the proceedings a useful source of up-to-date information. Additional copies of the proceedings are available at $US60 from the IIFC secretariat. The order form can be found on the inside back cover of this newsletter. This form can also be downloaded from the IIFC website http://www.iifc-hq.org/bbfs2005/.

We would like to thank the Executive Committee of IIFC for its support to the organisation of this symposium. We would also like to thank the Department of Civil and Structural Engineering, The Hong Kong Polytechnic University, which provided support in many ways as a co-organiser of the symposium. Special thanks are due to all authors for their careful preparation of manuscripts, all keynote speakers for sharing their work at the symposium, and the International Scientific Committee and the International Organising Committee who not only reviewed the papers to ensure a quality symposium but also mobilised widespread support for the symposium. We are indebted to all of them for their important contributions to the symposium.

At the symposium banquet

BBFS BEST PAPER AWARD

Initially, two best awards were to be given to two of the papers accepted by the conference: one to the best research paper and one to the best review paper. Since the number of papers in the latter category was small, the Best Paper Award Committee decided to give out only one best paper award to a paper in the former category. All papers co-authored by members of the Award Committee were excluded from consideration. The Award Committee comprised Prof. J.G. Teng, Dr. J.F. Chen, Dr. Laura De Lorenzis and Dr. Rudi Seracino. After a great deal of hard work and discussions, the paper entitled "Durability and Mechanical Properties of Polymer-Layered Silicate Nanocomposites" co-authored by I. Hackman and L. Hollaway was selected to receive the best paper award. The full text of the paper is available elsewhere in this issue of the newsletter. The best paper award was presented at the Symposium Banquet.

BBFS 2005 KEYNOTE LECTURES

The following keynote lectures were presented at BBFS 2005 by leading authorities on the topic:

L.C. Hollaway Surrey University UK	*Advances in Adhesive Joining of Dissimilar Materials with Special Reference to Steels and FRP Composites*
Kenneth W. Neale Universite de Sherbrooke, Canada	*Modelling of Debonding Phenomena in FRP-Strengthened Beams and Slabs*
D.J. Oehlers Adelaide University Australia	*Generic Debonding Mechanisms in FRP Plated Beams and Slabs*
B. Taljsten Technical University of Denmark Denmark	*The Importance of Bonding – An Historic Overview and Future Possibilities*
T. Ueda Hokkaido University Japan	*Interfaces of Fiber Reinforced Polymer Laminates Externally Bonded to Concrete Substrate: Overview on Test Methods and Bond Modeling*
L.P. Ye* Tsinghua University China	*Design against Debonding in the Chinese Code for Strengthening RC Structure with Externally Bonded FRP Sheets*

* presented by a co-author, Dr X.Z. Lu, because Prof Ye was unable to attend the symposium due to unexpected circumstances.

Members of the International Organizing Committee at the Symposium Banquet

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X.Z. Lu	Tsinghua University	China
H.D. Niu	University of California at San Diego	USA
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P. Hamelin	University of Lyon I	France
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M. Motavalli	University of Tehran	Iran
A. Mufti	University of Manitoba	Canada
A. Nanni	University of Missouri-Rolla	USA
K.W. Neale	University of Sherbrooke	Canada
D.J. Oehlers	University of Adelaide	Australia
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T. Ueda	Hokkaido University	Japan
G. Van Erp	University of Southern Queensland	Australia
P. Waldron	University of Sheffield	UK
C.Y. Wang	National Central University	Taiwan, China
Z.S. Wu	Ibaraki University	Japan
J.Q. Ye	University of Leeds	UK
L.P. Ye	Tsinghua Univerrsity	China
Q.R. Yue	National Diagnosis and Rehabilitation of Industrial Building Research Centre	China
J.W. Zhang	Southeast University	China
X.L. Zhao	Monash University	Australia

POST-SYMPOSIUM INTERNATIONAL WORKSHOP

The one-day International Workshop on FRP Composites in Construction: the State-of-the-Art, was organized by the International Institute for FRP in Construction (IIFC) in conjunction with the Department of Civil and Structural Engineering, The Hong Kong Polytechnic University as a post-symposium event. It was financially sponsored by Aslan Pacific Ltd, which is a joint venture of Hughes Brothers, Inc. and Dextra Pacific Ltd.

A number of speakers at the BBFS 2005 symposium were invited to also give lectures at the workshop to an audience of around 200 delegates, who are mainly engineers in Hong Kong. A significant number of participants of the BBFS 2005 symposium also attended the Workshop. The workshop provided a very useful channel for the transfer of the latest international knowledge and experience in the FRP in construction area to the local construction industry in Hong Kong. The speakers and their topics are as follows:

Introductory comments and PolyU research
by Prof. J.G. Teng, The Hong Kong Polytechnic University

Applications of FRP in construction: Overview
by Mr. D. Gremel, Hughes Brothers, Inc., USA

FRPs and FOSs leads to innovation in civil structural engineering in Canada
by Prof. A.A. Mufti, University of Manitoba, Canada

FRP-reinforced concrete structures
by Mr. R. Parretti, Co-Force America, Inc., USA

Strengthening of concrete structures with FRP and steel plates-Australian guideline
by Prof. D.J. Oehlers, University of Adelaide, Australia

Strengthening of prestressed concrete bridge girders with FRP
by Prof. S.H. Rizkalla, North Carolina State University, USA

Strengthening of concrete structures with NSM FRP
by Dr. L. De Lorenzis, University of Lecce, Italy

Strengthening of steel structures with CFRP
by Prof. L.C. Hollaway, University of Surrey, UK

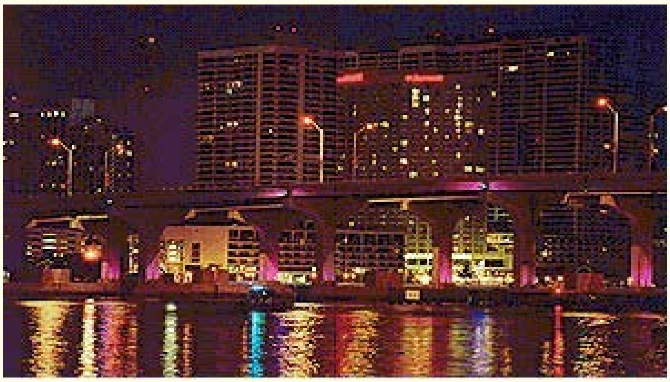
Dr Jian-Fei Chen and Workshop Speakers at the end of the Workshop

CICE 2006 - Miami

Third International Conference on FRP Composites in Civil Engineering
13-15 December, 2006, Miami, Florida, USA.

The next CICE conference will be held in Miami, Florida in 2006 and will be chaired by Prof. Amir Mirmiran. Plans are already underway for what promises to be a very well run and stimulating conference.

The Third International Conference on FRP Composites in Civil Engineering is planned for December 2006 in Miami, FL, USA. The Florida International University and the City of Miami will be hosting this bi-annual event. The conference provides an international forum for researchers and practitioners to exchange ideas and communicate recent advances on the application of FRP composites in civil engineering. Theme of the conference will be FRP Composites in Civil Engineering: From Research To Practice, and it will cover strengthening and repair, new construction, hybrid systems, durability, design codes and guidelines, smart structures, among others. Florida Department of Transportation will showcase its series of bridges in South Florida that have been repaired and retrofitted with FRP. South Florida is filled with cultural and tourist attractions, and for the adventurists, Disney World and the Keywest are within driving distance. A pre-conference workshop on repair of concrete bridges using FRP is being arranged. Also, a one-day post-conference cruise to the Bahamas is being planned. For additional information, please contact Conference Chairman, Dr. Amir Mirmiran, Professor and Chair, Department of Civil and Environmental Engineering, Florida International University, Miami, FL 33174, Tel: (305) 348-2314, fax (305) 348-2802, email: mirmiran@fiu.edu.



CDCC 2007 - Quebec City

Third International Conference on
Durability of Fiber Reinforced Polymer (FRP) Composites for Construction
May 2007, Quebec City, Quebec, Canada

Introduction

The conference will focus on durability of structures newly constructed, repaired and strengthened with FRP composites. Undoubtedly, durability is the key element for successful application of FRP's in construction where life cycle cost has by and large proven to be the most important issue for new construction materials. The current conference is the third in the series. The first one was held in Sherbrooke in 1998 and the second one was held in Montreal in 2002. The conference is intended to provide a unique opportunity for researchers, engineers, consultants, structure owners, and FRP manufacturers to exchange the latest knowledge on durability of FRP composites in construction. This exchange will help determine the needs and directions for future research required to predict the durability of structures constructed with FRP's.

Topics

- Effect of materials and manufacturing process on the durability of FRP products and systems
- Effect of environment on the durability of FRP reinforcements, repair patches, and structural shapes
- Durability of FRP composites and systems under cyclic and sustained loading
- Alkali resistance of glass fibre composites
- Influence of resin and load on bond between concrete and FRP reinforcement
- Special durability enhancement techniques and processes
- Material resistance factors and design criteria
- Fire and thermal cycling
- Durability test methods and facilities
- Accelerated testing
- Monitoring durability performance in field applications
- Design approaches for durable FRP composite structures
- Service life prediction

Web Page

Full details on the conference are published on the web at:
http:www.usherbrooke.ca/cdcc2007

Submission of abstracts	*May 1, 2006*
Notification of acceptance	*July 1, 2006*
Submission of manuscripts	*October 1, 2006*
Notification of acceptance of manuscripts	*January 1, 2007*

Enquiries and correspondence:

Brahim Benmokrane, P.Eng., Ph.D
NSERC Research Chair Professor in Innovative FRP Composite Materials for Infrastructures
ISIS Sherbrooke/Department of Civil Engineering
University of Sherbrooke Tel: (819)821-7758
Sherbrooke, Québec Fax: (819)821-7974
Canada J1K 2R1
E-mail: Brahim.Benmokrane@USherbrooke.ca

IIFC Sponsored Conferences

International Composites Conference-Developments in Composites: Advanced, Infrastructural, Natural, and Nano-composites (ACUN-5), 11-14 July 2006, Sydney, Australia.
http://www.simpas.unsw.edu.au/pmp/acun-5/home.htm

Third International Conference on FRP Composites in Civil Engineering, 13-15 December, 2006, Miami, Florida, USA.
http://www.iifc-hq.org/cice2006/

Third International Conference on Advanced Composites in Construction, 2-4 April 2007, University of Bath, UK.
www.bath.ac.uk/ace/acic07

Third International Conference on Durability and Field Applications of Fiber Reinforced Polymer Composites for Construction, Quebec City, Quebec, Canada, 23-25 May 2007.
Email: Benmokrane@USherbrooke.ca

Eighth International Symposium on Fibre-Reinforced Polymer Reinforcement for Concrete Structures (FRPRCS-8), 16-18 July 2007, Patras, Greece.
http://www.frprcs8.upatras.gr

Inaugural Asia-Pacific Conference on FRP in Structures APFIS 2007, 12-14 December 2007, Sydney, Australia
Email Address: apfis2007@eng.uts.edu.au

Best Paper of BBFS 2005

The following paper won the Best Paper Award at BBFS 2005 and is reprinted herein for wide dissemination to the international community of the FRP for construction area.

Durability and Mechanical Properties of Polymer-Layered Silicate Nanocomposites

I. Hackman and L. Hollaway
School of Engineering, University of Surrey, UK
Email: L.Hollaway@Surrey.ac.uk

ABSTRACT

Chemically treated layered silicates (clays) can be mixed with polymer materials to form a nanocomposite in which clay layers are evenly distributed throughout the material. These high aspect ratio clays have been reported to alter the properties of the polymer by a number of mechanisms; increasing the strength and fire resistance and reducing permeability. The objective of this paper is to present an introduction to nanocomposites and investigate the potential for nanocomposites to be used in adhesives. Tensile, compressive and permeability tests are reported and show that the possible advantages of nanocomposites depend on the properties of the base resin or adhesive. Mechanical property advantages may be achieved with more elastomeric polymers while little improvement is generated in highly glassy materials. The durability of some adhesives may be improved by reducing the permeability of the polymer; however, the type of adhesive and ingressing agent have a large influence on the attainable reductions.

KEYWORDS

Adhesives, durability, nanocomposites, mechanical testing.

INTRODUCTION

Nanocomposites are a new and developing area that has a wide range of potential application. Their use was first demonstrated during the early 1990's when they were incorporated into thermoplastic resins. The technology has progressed through to thermosets, fibre composites and adhesives. There has been a wide range of claims made about the property improvements that these materials can generate, focussing on the mechanical, permeability and fire resistance properties. Many of these claims have been contradictory and property advantages are far from constant between different types of polymer. This paper presents an introduction to nanocomposites and investigates the application of nanocomposite technology into adhesive polymers.

Clay Types and Structure

The clay used in nanocomposites are:

- of high strength and stiffness along their length, reported to be higher than glass fibres (Luo & Daniel 2003).
- of high aspect ratio enabling large surface areas ($700m^2/g$) to be in contact and bond with the polymer.
- modified more easily than most other types of clay; this high level of intercalation chemistry enables the clays to be chemically altered to aid their bonding and dispersion in the polymer.
- naturally occurring and can be purified at a relatively low cost.

These sheets are 0.96nm thick and typically about 250nm in length and width. The large surface area makes them exceptional at altering the properties of a polymer. Between the layers is a gap known as the "gallery layer"; unmodified clays have a small gallery layer. The spacing can be modified when used in nanocomposites, the way in which this gap changes and the final size of the gallery layer will influence the properties of the resulting nanocomposite.

Chemical Modification

Clays are naturally hydrophilic and are immiscible in organic liquids; therefore, the clay must be altered to become organophilic, this modification is known as compatibilisation. The most common compatibilisation process is onium-ion modification; a small hydrocarbon chain (surfactant) is bonded to the surface of the clay layer that enables it to be wetted by and mix with organic liquids.

TYPES OF POLYMER-LAYERED SILICATE NANOCOMPOSITES (PLSN)

The way in which the clay layers are dispersed in the polymer will influence their level of interaction with the polymer, affecting the material properties. There are three distinct types of clay dispersion that can be formed by the introduction of these clay layers.

Conventional Composites: If the clay layers and polymer are not compatible, the surface energies are incompatible for wetting, and consequently no polymer will penetrate the gallery layer. There will be no, or very little, bonding between the clay and the polymer; therefore, the clay will provide little mechanical reinforcement.

Intercalated Nanocomposites: An intercalated nanocomposite is formed when the clay layers are separated by a fixed amount. The clay layers will reinforce the polymer, although the fixed layer separation is unable to provide the optimum level of reinforcement.

Exfoliated Nanocomposites*:* An exfoliated nanocomposite is formed when the clay layers are dispersed in the polymer with random separation and orientation. The clay layers will be sufficiently separated and randomly orientated to allow full interfacial bonding and to contribute all their strength to improve the properties of the nanocomposite.

PROPERTY IMPROVEMENTS

The property improvements generated by the inclusion of nanoparticles in polymers have been well researched since the first nanocomposites were produced by Toyota researchers (Okada *et al.* 1993) using polyamide-6 in the late 1980s and early 1990s. The majority of polymers have been used to construct nanocomposites and all have shown improvements in mechanical properties to varying degrees. Recent research has focussed on the use of thermoplastic resins, as these types of nanocomposites are commercially viable for small-scale products such as food packaging. However, many thermosets have also been used; epoxy resin systems typically used are amine cured Bisphenol A and F resins.

The increase in mechanical properties can be attributed to the high strength and stiffness clay layers acting as short randomly dispersed fibres, transmitting stress through the specimen. The mechanism responsible for the improved barrier resistance is due to the increased path length through the nanocomposite that must be taken to negotiate around the clay layers (Neilson 1967). The tortuous path that an ingressing agent must take can be made longer or shorter depending upon the clay loading applied to a nanocomposite.

NANOCOMPOSITE RESEARCH

The majority of research work undertaken to date relating to nanocomposites has been mainly associated with pure polymers, but investigations are now being extended to fibre-matrix composites and adhesives. Some work has been carried out into glass fibre/epoxy nanocomposites (Haque *et al*. 2003, Subramaniyan *et al*. 2003). Most research conducted in the early evolution and assessment of polymer-clay nanocomposites was carried out by chemists and material scientists. This led to production, characterisation and property evaluation of the nanocomposites, with little application of the technology.

NANOCOMPOSITE ADHESIVES

Previous researchers have shown that most nanocomposites can improve the mechanical and barrier properties of the polymer in which they are applied, whether thermoplastic or thermosetting polymer. The transfer of this technology to adhesives would represent an efficient way of improving the durability of adhesively bonded joints while potentially improving their mechanical performance. However, the high viscosity of adhesives presents a challenge with respect to the processing of these materials. In order to attain a high level of property improvement an exfoliated or partly exfoliated/intercalated structure must be formed. This can be achieved relatively easily in liquid epoxy resins where the processing can be performed on a basic resin with few additives. However, commercially available adhesives are highly viscous and contain many additives to improve in-service properties. The use of solvents or high temperature processing would be required to apply the organoclay to the base part of an adhesive polymer. The adhesive could then be applied as normal with the organoclay within the adhesive. However, the formation of an adequate clay morphology may not be created due to the high viscosity of the adhesive during cure, investigation into this aspect would be required.

EXPERIMENTAL INVESTIGATION

Provided the organoclay could be introduced into the adhesive and an adequate clay structure obtained the improvements in the properties would be similar to those in a non-adhesive type polymer. The basic mechanical and barrier properties of two different epoxy systems were investigated to discover the way in which organoclays can modify the properties of polymers. Due to the difficulties in the processing of adhesives a basic epoxy resin and two different curing agents, representing each extreme in the glassy-elastomeric state to cover all types of adhesives were used to produce nanocomposites to test the mechanical and permeability properties.

Materials

The resin component of the nanocomposite was a low molecular weight DGEBA with no diluents or additives. Two curing agents were used to attain results from two different systems, a high performance glassy system (Ethacure 100, diethyltoluenediamine) and the other a more elastomeric lower performing system (Polypox H205, poly (oxypropylene) diamine). The organoclay used was Nanomer I.30E from Nanocor, a leading distributor in organoclays. This nanoclay was selected after a trial with a number of different organoclays to select the one that would form the best clay structure.

Nanocomposite Preparation

The morphology of a nanocomposite is dependent upon temperature, time and shearing rate of the mixing. Direct mixing methods alone will not break down the primary clay particles to form a uniform material. The nanocomposites formed still retains a micro-aggregated structure, similar to all direct mixing methods. Uniform nanocomposites can only be achieved through high-shear mixing techniques such as high-speed dissolvers, extensive ultra-sonics, grinding or high pressure mixing (Liu *et al*. 2005).

Nanocomposites were processed as follows;

- resin and organoclay were mixed together by hand in the required quantities until the clay was roughly mixed.
- resin and organoclay were stirred at 750rpm for 4 hours at 80-90°C.
- resin and organoclay were mixed in a vertically stirred grinding media mill with 2mm glass beads for 3 hours at 2000rpm until all large clay particles had been removed.
- the resin was fully degassed, the curing agent was added and cured.

TENSILE PROPERTIES

Tensile tests were conducted using 125x12x6mm specimens reduced to 10mm in the central 50mm of the specimen; specimens were tested at 1mm/min until failure. Polypox and Ethacure specimens of 0, 5 and 10wt% I.30E nanoparticles were manufactured by the method described above.

The results from the tensile tests are summarised in Figures 1 and 2, showing the relative ultimate stress and modulus of the nanocomposites compared to the pristine polymer. The Polypox nanocomposites achieved a 14.2 and 28.6% increase in tensile modulus at 5 and 10wt% organoclay loading respectively. However, the increase in ultimate stress was smaller and did not increase proportionally with increasing clay content. The increase in ultimate stress was 12.2 and 4.4% at 5 and 10wt% clay loading respectively. The high clay loading at 10wt% leads to a slightly premature failure that is not experienced at 5wt%.

The Ethacure system performed less well with the organoclay providing a modest improvement in tensile modulus but reducing the ultimate tensile stress. The Polypox system is more easily reinforced than the Ethacure due to the low density of cross-linking creating a more elastomeric material. The Ethacure material is a highly glassy densely cross-linked system in which any small impurity will generate high stress concentrations and lead to premature rupture of the material.

COMPRESSIVE PROPERTIES

Compression tests were carried out on 14mm diameter cylinders 28mm long, loaded at 0.5mm/min. Polypox specimens of 0, 2, 5 and 10wt% and Ethacure specimens of 0 and 5wt% I.30E nanoparticles were manufactured by the method described above. The relative properties of the Polypox nanocomposites are shown in Figure 3. The Polypox nanocomposites achieved an increase of 5.3 and 25.9% in compressive ultimate stress and compressive modulus respectively. While the compressive modulus increased with direct proportionality to the clay loading the ultimate compressive stress appears to reach a critical loading between 2.5 and 5wt%. After this critical value, little increase in ultimate compressive stress can be achieved with increasing clay loading.

These increases were much higher than those of the more glassy Ethacure nanocomposites in which increases of 3.9 and 4.5% were found for the ultimate compressive stress and compressive modulus respectively. In a similar way to the tensile properties the level of reinforcement that can be obtained depends on the relative degree of glassy-elastomeric characteristic of the resin system.

The mechanical properties that may be achieved with any form of polymer or adhesive nanocomposites will depend on the physical nature of the base material. If the polymer or adhesive is highly glassy there will be little improvement in the physical properties of any nanocomposite produced. However, if the polymer or adhesive is of a slightly more elastomeric type system some reasonable improvements in the physical properties may be achieved.

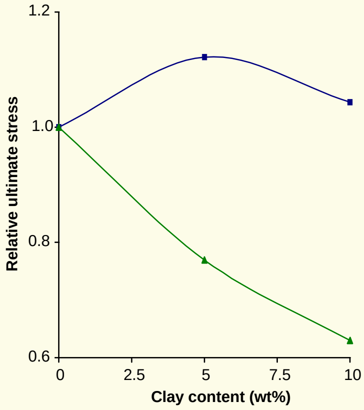


Figure 1. Relative ultimate tensile stress of (■) Polypox and (▲) Ethacure nanocomposites.

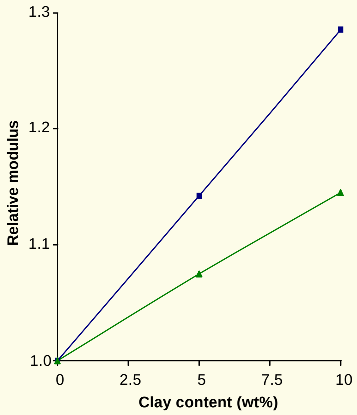


Figure 2. Relative tensile modulus of (■) Polypox and (▲) Ethacure nanocomposites.

PERMEABILITY

Permeability tests were undertaken to gain an understanding of the way that organoclays can alter the permeability of polymers. Gravimetric tests were used to monitor the uptake of agents into different types of polymer system. Specimens of 125x12x6.4mm were prepared; although not standard, this specimen geometry was chosen so that flexural tests could be performed on the specimens after saturation. Specimens of Polypox and Ethacure containing 0, 5 and 10wt% I.30E organoclay were produced, three specimens of each type being tested. Unmodified clay of the same type that is used in the organoclay was used to prepare 5wt% clay filled composites using the Polypox system. Two different ingressing agents, water and one solvent were used to assess the specimen permeability. Distilled water and acetone were selected and placed with the specimens in test tubes for the duration of the tests. The specimens in water were maintained at 50°C and the acetone at room temperature. Specimens were removed for their test tube, surface dried and weighed on a 0.1mg precision analytical balance periodically.

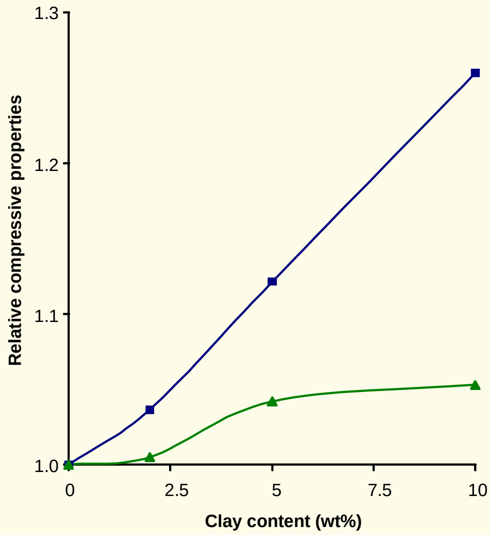


Figure 3. Relative compressive properties of Polypox nanocomposites. (■) Compressive modulus and (▲) ultimate compressive stress.

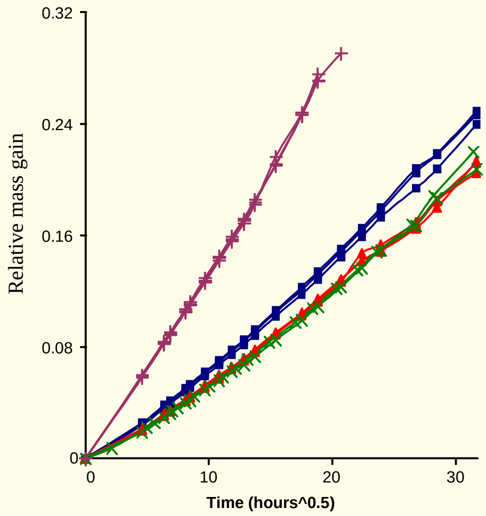


Figure 4. Uptake of acetone into Polypox specimens. (■) 0wt%, (▲) 5wt%, (×) 10wt% and (+) 5wt% unmodified clay.

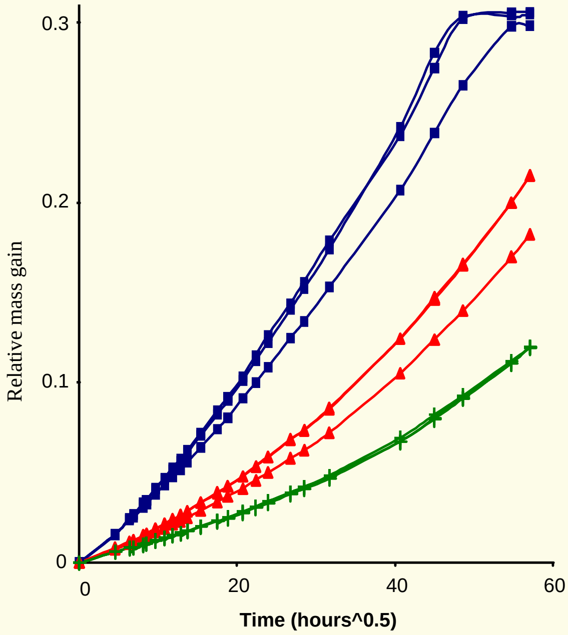


Figure 5. Uptake of acetone into Ethacure specimens.
(■) 0wt%, (▲)

The uptake of acetone into Polypox specimens can be seen in Figure 4. There appears to be only a small reduction in the acetone uptake in the Polypox specimens and little difference between the 5 and 10wt% specimens. The average overall acetone uptake of both 5 and 10wt% nanocomposites is about 0.85 times that of the pristine polymer. The specimens produced from the unmodified clay absorbed the solvent much faster and broke up long before the pristine and nanocomposite specimens. The clay layers in the unmodified specimen are not separated and have no polymer between the clay layers. These spaces between the clay layers can be taken up by the solvent, increasing the amount of acetone absorbed by the specimens.

The uptake of acetone into Ethacure specimens can be seen in Figure 5. The rate of acetone uptake of the nanocomposites is vastly reduced compared to the pristine polymer. The pristine polymer has reached equilibrium uptake after 2700 hours, while the nanocomposite specimens, assuming the rate of uptake remains constant, should reach equilibrium at around 5000 and 8800 hours for 5 and 10wt% respectively. The average overall rate of acetone uptake (before reaching equilibrium) for the 5 and 10wt% specimens is 0.47 and 0.28 times that of the pristine material. These values are close to the theoretical values predicted by Neilson's tortuous path model, 0.34 and 0.2 times for 5 and 10wt% nanocomposites respectively for a perfectly exfoliated nanocomposite with a clay aspect ratio of 200.

The uptake of water into Polypox specimens can be seen in Figure 6. The nanocomposites do not appear to have altered the amount of water absorbed. The 5wt% unmodified specimens have again absorbed almost twice the amount of water as the other specimens for the same reasons as those highlighted above. The uptake of water into Ethacure specimens (Figure 7) was also not improved by the organoclay. Although the clay morphology is the same in all Ethacure specimens in both water and acetone the affect of the organoclay is very different. The permeability reductions attainable in layered silicate nanocomposites are often stated to be dependant solely upon clay morphology due to creation of a tortuous path. However, the clay morphology in all the Ethacure specimens was the same but the permeability reductions obtained for water and acetone are dissimilar. The permeability of the nanocomposites must be affected by more than just the clay morphology. The reductions in permeability that can be achieved are heavily dependant upon the interaction between the ingressing agent and the polymer. Therefore, potential permeability reductions will depend on the specific polymer and ingressing agent, with some polymers achieving a permeability decrease while others would be unaffected. However, the presence of a solvent is not a common occurrence and the majority of ingressing agents occurring during the service life of a component are water based. This will require further research with different polymers to establish the types of polymer in which permeability reduction in water could be achieved.

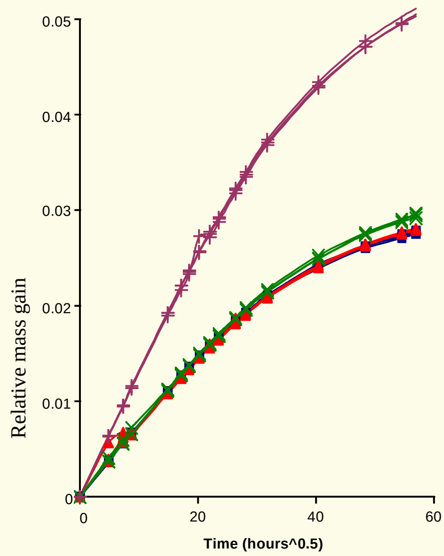


Figure 6. Uptake of water into Polypox specimens.
(■) 0wt%, (▲) 5wt%, (×) 10wt% and (+) 5wt%

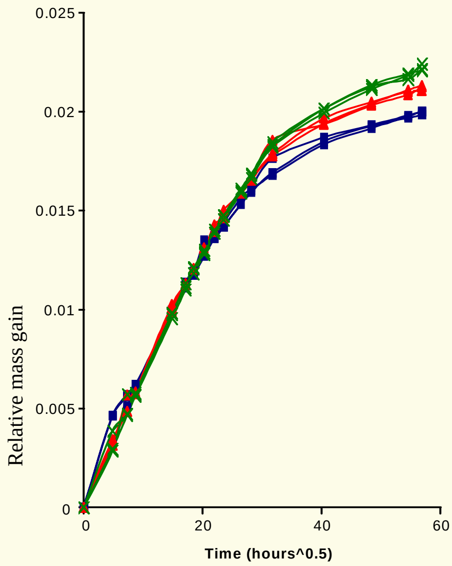


Figure 7. Uptake of water into Ethacure specimens. (■) 0wt%, (▲) 5wt% and (×) 10wt%.

CONCLUSIONS

The properties of any nanocomposite are dependant upon the base properties of the resin or adhesive system used. The mechanical properties will depend on the position of the material within the glassy-elastomeric property range. The barrier properties will also depend on the base material; the affinity the material has with the ingressing agent appears to affect whether any reduction in permeability can be achieved. This may result in permeability reductions being achievable in some and not other polymer or adhesives depending upon the specific types of chemicals found within the system. This would mean that any new material used to form a nanocomposite would have to be tested to determine whether barrier improvements could be achieved for the specific agent that the component will be exposed to during service. This series of tests, although not carried out using a standard adhesive, displays the general types of properties that can be developed with any form of epoxy amine cured polymer. Research will continue into commercially available adhesives to discover if exfoliated nanocomposites can be achieved and explore the resulting properties of any adhesive nanocomposite generated.

REFERENCES

Haque, A. and Shamsuzzoha, M. (2003), "S2-Glass/Epoxy Polymer Nanocomposites: Manufacturing, Structures, Thermal and Mechanical Properties", *Journal of Composite materials*, 37(20), 1821-1837. IMTCR 2004 Lecce 7-9 June 2004 Italy.

Liu, W., Hoa, S. and Pugh, H. (2005), "Epoxy-clay nanocomposites: dispersion, morphology and performance", *Composites Science and Technology*, 65, 307-316.

Luo, J. and Daniel, I. (2003), "Characterization and Modelling of Mechanical Behaviour of Polymer/Clay Nanocomposites", *Composites Science and Technology*, 63, 1607-1616.

Neilson, L.E. (1967), *Journal of Macromolecular Science*, A1(5), 929-942.

Okada, A., Kojima, Y., Usuki, A., Kawasumi, M., Fukushima, Y., Kurauchi, T. and Kamigaito, O. (1993), "Mechanical Properties of Nylon 6-Clay Hybrid", *Journal of Materials Research*, 8, 1185.

Subramaniyan, A. K., Bing, Q., Nakaima, D., and Sun, C. T. (2003), "Effect of Nanoclay on Compressive Strength of Glass Fibre Composites", *Proceedings of the 18th Technical Conference, American Society for Composites*, Gainesville, FL, Oct. 20-22.

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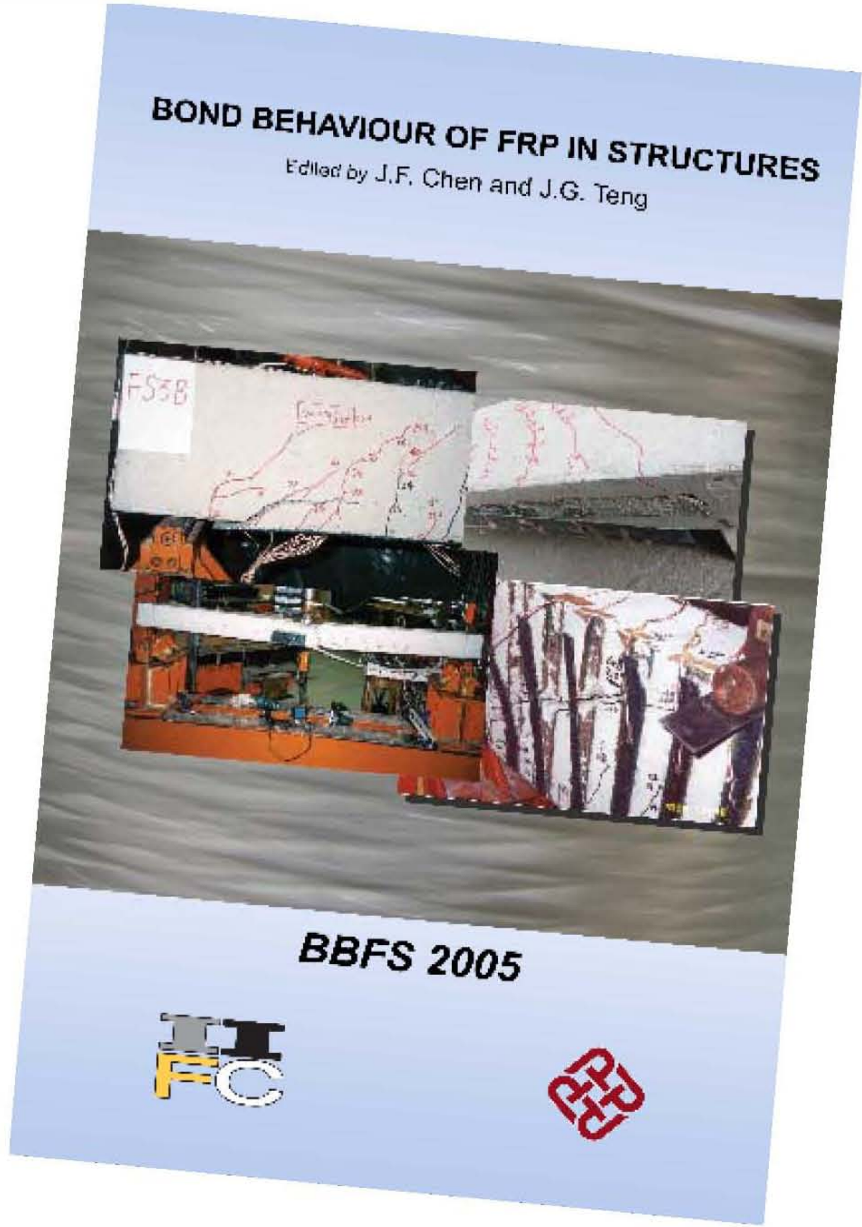

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